Project Title
Evaluating temporal and spatial spawning patterns of Channel Catfish *Ictalurus punctatus* to provide alternatives for nonnative fish control in the San Juan River

Bureau of Reclamation Agreement Number:

Reclamation Agreement Term:

Note: Recovery Program FY23 scopes of work are drafted in May 2022. They often are revised before final Program approval and may subsequently be revised again in response to changing Program needs. Program participants also recognize the need and allow for some flexibility in scopes of work to accommodate new information and changing hydrological conditions.

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U.S. Fish and Wildlife Service New Mexico Fish and Wildlife Conservation Office (NMFWCO), American Southwest Ichthyological Researchers (ASIR), and Kansas State University (KSU)

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__ Ongoing-revised project
X Requested new project
__ Unsolicited proposal

Expected Funding Source:
X Annual funds
__ Capital funds
__ Other *[explain]*

Relationship to LRP

This project's actions relates to task 3.1.1.7 (Evaluate and implement effective alternative nonnative fish reduction methods) in the Long-Range Plan (USFWS 2016).

Study Background/Rationale

Channel Catfish *Ictalurus punctatus* are an economically important species in the United States, and as such have been both extensively studied and widely introduced outside of its native range (Gisbert et al. 2021; Haubrock et al. 2021). Channel Catfish are opportunistic feeders known to consume fish (Hedden et al. 2020, Hedden et al. 2022), and this invasive predatory threat is considered a leading factor contributing to the decline of native fishes in the Colorado River Basin (Mueller and Marsh 2002; Olden and Poff 2005). Within the San Juan River, Channel Catfish prey on multiple size classes of native fishes including the endangered Colorado Pikeminnow *Ptychocheilus lucius* (Hedden et al. 2020). Larger Channel Catfish (>500 mm total length [TL]) consumed more fish prey compared to smaller (< 300 mm TL) Channel Catfish (Hedden et al. 2020) however, small Channel Catfish may also predate on younger life stages of native fishes, potentially impacting early life-stage recruitment. For example, in a laboratory study, Channel Catfish that were 74 mm TL were able to consume Razorback Sucker *Xyrauchen texanus* larvae of about 14.4 mm TL (Carpenter and Mueller 2008). Consequently, the suppression of Channel Catfish in the San Juan River has been a long-term management action undertaken to improve the recovery of Colorado Pikeminnow and Razorback Sucker.

In the San Juan River and Upper Colorado River Basin, management to remove Channel Catfish has typically targeted large-bodied individuals due to size selectivity of capture methods. Within the San Juan River, mechanical removal of Channel Catfish using raft-mounted electrofishing has occurred in multiple phases: intensive (Franssen et al. 2014); experimental (Duran et al. 2018) and winter removal (Davenport and Furr 2021). While intensive mechanical removal resulted in a shift in size classes, exploitation rates have ultimately been insufficient to cause population level declines (Pennock et al. 2018). Winter removal was proposed as an alternative approach to increasing exploitation rates because turbidity was expected to be lower; however, exploitation rates were found to be similar to intensive removal years (Davenport and Furr 2021), suggesting that seasonal change in sampling did not improve capture rates. Previous methods of nonnative management have proven ineffective in reducing the abundance of the San Juan River population of Channel Catfish, so novel management approaches should be considered to improve this management action.

We propose conducting three tasks to evaluate temporal and spatial patterns of Channel Catfish spawning in the San Juan River with the goal of disrupting spawning or displacing larvae. Each of these tasks, while conducted separately, will be used in combination to better understand when and where Channel Catfish spawn and to assist with identifying methods for improving nonnative fish management. Task 1 will be a retrospective analysis of the age (in days) of young-of-year Channel Catfish collected during San Juan River Basin Recovery Implementation Program (SJRBRIP) sponsored larval sampling between 2009-2021. Estimates of when Channel Catfish spawn over several years and flow conditions will allow us to determine approximately when spawning occurs, its variablity among years and to investigate environmental factors that influence Channel Catfish spawning. Task 2 will evaluate Channel Catfish seasonal movement patterns prior to and during its spawning and attempt to identify spawning sites and seasonal movement patterns. This information will be incorporated with that obtained from Task 1 to infer how movement patterns are associated with estimates of seasonal spawning during environmentally similar years. In addition, we propose using activity loggers in Task 2 to monitor daily activity patterns in adult Channel Catfish. Because these loggers can record activity as the percentage of time the sensor was in motion each minute, we hypothesize that the use of the tags will reveal behavioral patterns, such as nest building, which could be linked to spawning activity. Task 3 will target age-0 Channel Catfish to determine relative abundance of young-of-year in the sampling area relative to adult movement patterns. These age-0 fish will be aged to determine when adult Channel Catfish spawned and these dates will be compared with adult movement patterns (Task 2 via activity tags) to assess putative spawning dates generated by the two efforts. If correlated, back calculated age estimates will be used to assess the level to which adult Channel Catfish activity patterns can predict nest building behaviors.

Task 1 (Clark Barkalow, Grey, and Diver)

Background and Justification

The study of larval fishes can provide key information about the life history traits of a species. For example, aging of larval fishes reveals the spawning periodicity of species and factors that contribute to reproductive success. These data have been crucial in our understanding of factors that promote spawning success of Razorback Sucker and Colorado Pikeminnow in the San Juan River, which have improved management actions such as timing and duration of reservoir releases. Similarly, understanding both when Channel Catfish spawn and what factors contribute to reproductive success may elucidate novel management strategies that could be used to target early life stages, reducing recruitment rates to the adult population, and/or through the direct removal of spawning adults. This type of management action has been implemented for invasive Smallmouth Bass *Micropterus dolomieu* in the Green River. This multi-faceted nonnative removal approach targets both early-life stages through flow spikes and temperature depression (release from Flaming Gorge Dam) and through the mechanical removal of spawning individuals (Bestgen 2018). The timing of these management actions was refined using back calculated spawning dates obtained from larval Smallmouth Bass larval otoliths, and in 2021, a 3-day flow release occurred for the purpose of disrupting Smallmouth Bass spawning (Bestgen et al. 2022). Preliminary results of this flow spike experiment showed a reduced abundance of age-0 Smallmouth Bass and reduced reproduction by adults, suggesting that this could be a viable management strategy for the control of Smallmouth Bass in the Green River.

Disruption of Channel Catfish spawning may be a valuable nonnative fish control method; however, refinement of this management action is precluded by a lack of information on the spawning ecology of this species in the San Juan River. Larval fish data collected during American Southwest Ichthyological Researchers' (ASIR) monitoring provides information about when age-0 Channel Catfish are present in the San Juan River, but because of the larger size and more advanced ontogenetic stage of Channel Catfish in these collections, they are not necessarily representative of the spawning period. Consequently, back calculation of spawning dates using aged otoliths is required to determine when Channel Catfish are spawning in the San Juan River. A pilot study was performed on a small subset of age-0 Channel Catfish by ASIR and the New Mexico Fish and Wildlife Conservation Office (NMFWCO), at zero cost to the San Juan Program, to investigate the utility of Channel Catfish otoliths for early-life history and reproductive ecology studies (i.e., back-calculated spawning dates). Specimens were selected from collections of larval fishes from the University of New Mexico Museum of Southwestern Biology Division of Fishes. Channel Catfish from collections made in 2017 (MSB ACC2017-IV:16) were selected for the pilot study due to the relatively high number and spatial distribution of larvae collected that year. Age-0 Channel Catfish were not collected in Reach 5 or 6, so only Channel Catfish from Reach 1 to Reach 4 were used in the study (Table 1).

Table 1. Channel Catfish number and length range selected for the pilot study in Reach 1 to Reach 4.

Reach	**n**	**Standard length (mm)**
1	3	15.5–20.1
2	25	11.4–21.0
3	17	11.5–19.6
4	21	11.4–15.9

Daily age has been evaluated in age-0 Channel Catfish and otoliths have been validated as a reliable aging structure (Sakaris and Irwin 2008). The lapillus otolith (Long and Stewart 2010) was removed from 66 Channel Catfish from 2017, mounted on 25 x 75 mm microscope slides, and polished with lapping film to expose daily annuli. Otoliths were aged by two experienced readers using an Olympus BX53 microscope under magnification of 100–400X. Any discrepancies in age between readers were reevaluated concurrently to obtain consensus. Hatch dates were calculated by subtracting otolith age (in days) from the collection date. Spawning dates were then calculated by subtracting incubation time, which was determined using a temperature dependent equation (Small and Bates 2001) from hatch date.

In the pilot study of 2017 specimens, ages of Channel Catfish were 9–20 d and growth rates were 0.4–1.4 mm/d. Channel Catfish spawned from 30 June to 12 July 2017 (12 d; Figure 1) and initiated spawning when water temperature was 18.9°C (USGS #09379500 San Juan River Near Bluff, UT). In 2017, Channel Catfish spawning initiated at lower water temperature, relative to hatcheries and other rivers (Tin 1982; Pawiroredjo 2001). Hatch dates occurred from 7 July to 18 July. We did not attempt to examine the influence of abiotic variables on spawning period or early life history of Channel Catfish because this pilot study only included a one year (i.e., a single flow and temperature regime).

Although this initial pilot study is informative about aspects of early-life history of Channel Catfish and its spawning periodicity, much is still unknown. Flow dynamics may be important for timing of Channel Catfish hatch dates (Erickson et al. 2021), so spawning and hatch dates from the pilot study are likely not representative of years with disparate conditions. Additional investigation would allow specimens to be selected from a greater range of sizes and environmental conditions and would be better able to clarify ages, growth rates, spawning periodicity, and spawning cues of Channel Catfish.

Innovative nonnative control options will likely depend on accurate information on reproductive timing and early-life history to adequately control Channel Catfish. For example, if spawning periodicity is found to be consistent across years, then removal efforts could target this period that adults are spawning. In addition, incorporating estimates of spawning dates for Channel Catfish relative to known estimates for Razorback Sucker and Colorado Pikeminnow will be important for ensuring removal methods avoid harming native fish species. Progressing the understanding of Channel Catfish reproductive ecology and early life history in the San Juan River supports nonnative fish control in the river by informing utility of environmental disruption as a means of Channel Catfish control. Additionally, detailed knowledge of when Channel Catfish spawn may enable detection of spawning areas (Task 2), thus facilitating alternative mechanisms for removal of spawning adults.

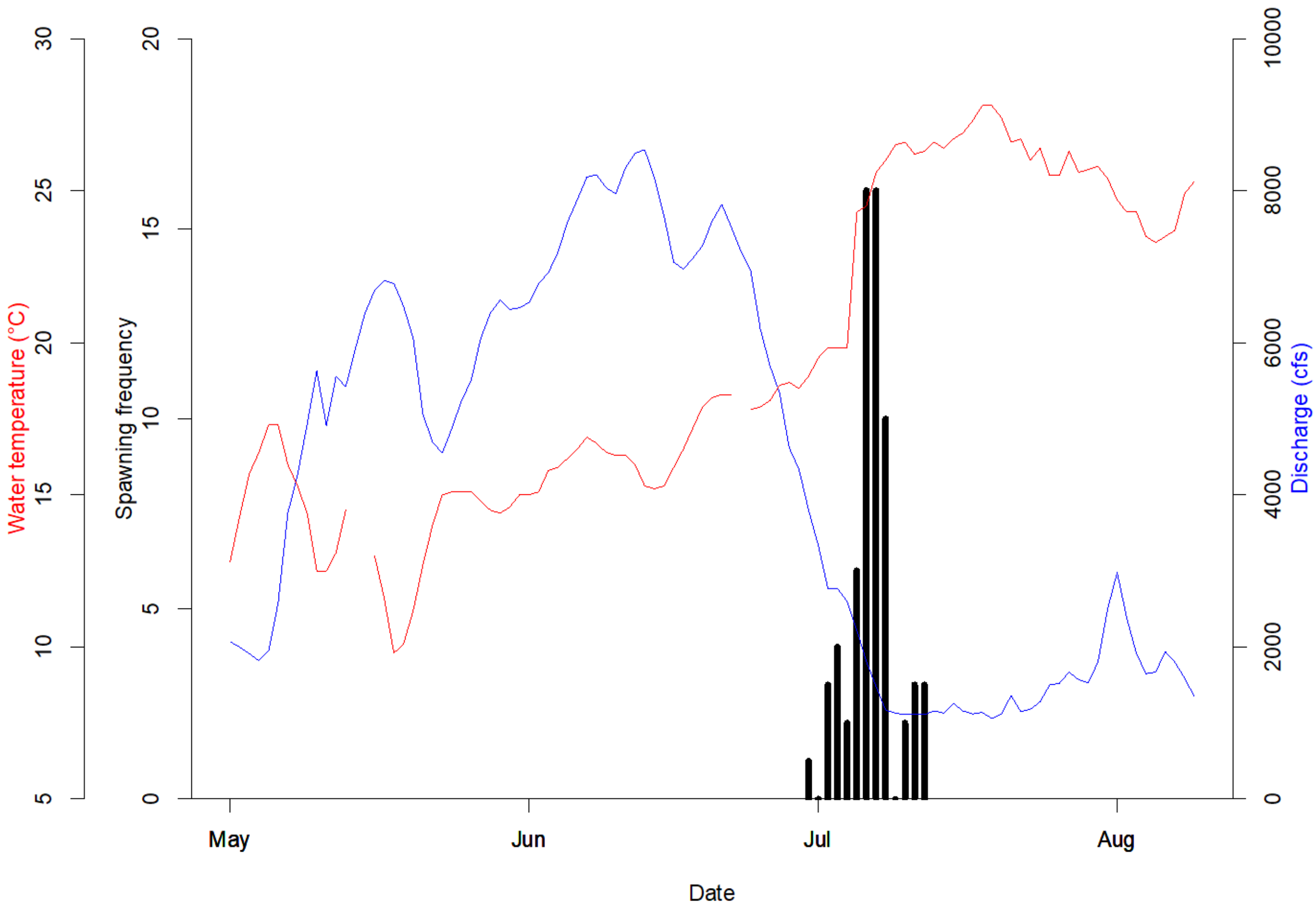

Figure 1. Channel Catfish spawning (black bars) initiated on 30 June on the descending limb of the hydrograph (blue line) when temperature was 18.9°C (red line).

Objectives:
The objective of this study is to provide information on spawning periodicity, age, and growth of Channel Catfish to refine current nonnative fish control procedures or develop alternatives.

Our specific objectives are to:

1. To provide information on early life history including timing of hatching, and growth rates of age-0 Channel Catfish.
2. Evaluate abiotic variables influencing growth rates.
3. Evaluate abiotic variables influencing spawning periodicity.
4. Develop age-length equation.
5. Back-calculate spawning dates for Chanel Catfish in ASIR's larval fish long-term monitoring dataset.

Study Area:
Specimens proposed for this study were collected during San Juan River larval fish monitoring from 2009–2021 between river miles 139.7 and 3.2.

Study Methods/Approach:

Specimens proposed for this study were collected as part of the long-term San Juan River larval monitoring project and are curated at the University of New Mexico Museum of Southwestern Biology Division of Fishes (Table 2). Prior to 2009, larval fish were fixed in 10% solution of formalin and therefore cannot be used for otolith examination; specimens from 2009-2021 (fixed in 95% ethanol; EtOH) will be used for back-calculated estimates. A minimum of 60 Channel Catfish will be aged, when possible, from each year from 2009 to 2021 (Table 2). Because low numbers of Channel Catfish were preserved in 2015, 2019, and 2020, every available Channel Catfish would be aged from those years. Specimen selection will be distributed across the spatial (geomorphic reach) and temporal sampling of larval collections. When possible, larvae will be selected so the sample is representative of all sampled mesohabitats with the exception of fish captured in isolated pools. These individuals will be excluded as elevated water temperatures often associated with isolated pools may skew larval growth rates and are unlikely to represent growth rates from riverine habitats.

Table 2. Channel Catfish specimens in 95% EtOH held at the University of New Mexico Museum of Southwestern Biology.

Year	Available specimens	Proposed sample size
2009	242	60
2010	404	60
2011	309	60
2012	283	60
2013	330	60
2014	856	60
2015	30	30
2016	89	60
2017	171	66 (Completed)
2018	317	60
2019	22	22
2020	24	24
2021	Being processed	60
TOTAL	**> 4,277**	**683 (includes completed)**

Standard length (SL) and total length will be measured for each fish selected for inclusion in this study. Most Channel Catfish preserved during San Juan River larval fish monitoring are age-0 juvenile fish. Ontogenetic stage will be determined for all specimens. The lapillus otolith will be removed from the right side of 683 Channel Catfish from 2009 to 2021. Otoliths will be mounted on 25 x 75mm microscope slides and polished with lapping film to expose annuli. Otoliths will be read with an Olympus BX53 microscope under magnification of 100–400X and age determined by two experienced readers. Any disagreements in otolith age count will be reconciled in a joint reading. The total annuli (age of fish) will be counted on each otolith and the total age (d) and the age at swim-up, indicated by a growth check (Sakaris and Irwin 2008), will be recorded. Otoliths will be measure (μm) across the longest axis and at swim-up check to obtain a relationship between otolith size and body size (mm SL). If a clear relationship between body length and otolith size exists, it will be used to estimate the body length and growth rate of the fish at swim up.

Analyses

Daily somatic growth rates will be calculated by subtracting mean size-at-hatch (Tin 1982; Téletchéa and Téletchéa 2020) and dividing by otolith age in days. Differences in growth rate will be evaluated using the appropriate parametric or nonparametric test (e.g., ANOVA or Kruskal-Wallis test). Growth rates and spawning dates will be compared among reaches to determine if specific reaches support greater growth. Spawning dates will be back-calculated by subtracting otolith age and incubation time from the collection date.

A multiple linear regression will be used to evaluate influence of abiotic, spatial, and temporal variables on both spawning periodicity and growth rates. Temperature, discharge, and turbidity will be obtained from the USGS Near Bluff Gage (USGS #09379500). Cumulative growing-degree days ($\sum$GDD), a measure of the metabolically relevant temperature, will be calculated using the equation $\sum GDD = T_{avg} - T_{base}$ (Cesaraccio et al. 2001; Neuheimer and Taggart 2007; Pawiroredjo et al. 2008), where T_{avg} is mean daily temperature and T_{base} is the minimum temperature required for spawning to occur. For Channel Catfish, T_{base} is 21°C. Although temperature and GDD are both thermal metrics, GDD will be included as a covariate to address the overall warmth a larva experiences during the growing period rather than instantaneous temperature on the last day of growth (i.e., temperature on collection date). The seven-day and fourteen-day change in temperature ($7\Delta T$, $14\Delta T$) and discharge ($7\Delta Q$, $14\Delta Q$) will be calculated for each date as metrics of hydrologic and thermal variation. Spatial variables will include geomorphic reach and river mile and temporal variables will include photoperiod and year. Variables will be evaluated for multicollinearity using variance inflation factors (Daoud 2017) and VIF>5 will be removed from potential models. Variable selection will be performed with simultaneous forward and backward variable selection. Model selection will be performed with Akaike information criterion (AIC_C) with models with $AIC_C < 2$ having the highest support.

Length-age relationship will be determined using a growth curve analysis. Logistic, von Bertalanffy (1983), and linear growth models that incorporate environmental parameters will be fitted to the datasets to investigate the relationship between age and length (SL). Model selection will be performed using AIC_C. The best-fit equation will be used to back-calculate spawning dates of all Channel Catfish collected over all years of larval fish monitoring.

Finally, Channel Catfish spawning dates will be compared with those of Colorado Pikeminnow and Razorback Sucker using published equations (Clark Barkalow et al. 2021). In the San Juan River, timing of Channel Catfish and Colorado Pikeminnow spawning is assumed to overlap, thus attempts to use flow to disrupt Channel Catfish spawning may also impact that of Colorado Pikeminnow. Elucidating spawning overlap between the two species will be necessary.

Deliverables and Schedule:

Initial determination of spawning dates of museum curated Channel Catfish will be completed by February 2023 and used to inform Task 2. Results will be presented during the February 2024 Biology Committee meeting. A draft report will be provided to the San Juan River Basin Biology Committee for review by 31 March 2024. Upon receipt and incorporation of written comments, a final report will be completed by 30 June 2024 and submitted to the Program Office with electronic copies of the data. Finally, this work will result in the likely development of a peer-reviewed manuscript and an article for Swimming Upstream in 2024.

Task 2 (Bogaard and Gido)

Background and Justification:

Understanding the reproductive ecology of fishes is integral for effectively managing populations. Quantification of spawning periodicity, site selection, and habitat type can be particularly useful for understanding factors that contribute to successful reproduction of fishes(Dammerman et al. 2019). For species of conservation concern, this information can allow mangers to improve or increase suitable spawning habitat to promote reproduction. Conversely, for nonnative fishes, identifying where individuals spawn could allow for a more targeted removal approach for spawning adults and an opportunity to reduce access to suitable spawning habitat (Coulter et al. 2016; Hedden et al. 2016). Previous and extensive removal efforts in the San Juan River determined river-wide electrofishing was unlikely to cause declines in the population size of Channel Catfish (Pennock et al. 2018). However, targeted efforts for nonnative fish during their spawning season at high density spawning sites has the potential to increase the efficiency of control or removal efforts.

Spawning sites of fishes have historically been identified through visual surveys (e.g., snorkeling) or through the identification of aggregates of spawning-capable adults. Advances in biotelemetry have allowed researchers to track fish movement during the spawning season to infer spawning reaches and preferred habitat types. In addition to the use of radio tags that pinpoint an individual's location, the use of tags with activity and temperature sensors can reveal patterns in daily and seasonal activity of a fish as it relates to abiotic conditions (Hedden and Gido 2016). Activity sensors record activity as the percentage of time the sensor was in motion each minute. For nest building species, a spike in daily activity may indicate approximately when that animal initiated spawning activities (Hedden and Gido 2016). Thus, for nest building Channel Catfish, the combination of activity and locality data could inform both when and where individuals spawn.

Movement patterns of Channel Catfish in the San Juan River has not been extensively investigated, but limited tag data suggest that in some years fish can show extensive migrations during the summer (Duran et al. 2018). In other systems, Channel Catfish are known to make relatively large migrations in rivers with individuals generally making upstream migrations in the spring, localized movements in the summer, and downstream movements in the fall (Dames et al. 1989; Newcomb 1989; Pellett et al. 1998; Wendle and Kelsch 1999). However, the temporal scale of Channel Catfish tagging and recapture in the San Juan River may be too coarse to infer spawning movements and areas. A more temporally intensive investigation into individual movements outside of, and during, the spawning season is needed to identify when and where spawning occurs. Clearly defining the spatial and temporal scale of Channel Catfish reproduction will be imperative to gauging the potential for targeted management actions to reduce their abundances in the San Juan River.

Objectives:

The objective of this task is to examine Channel Catfish movement and spawning behavior over two years to identify spawning sites or reaches with high spawning activity in the San Juan River.

Our specific objectives are to:

1. Assess seasonal distribution and movement patterns among both sexes and across two size classes of adult Channel Catfish.
2. Identify spawning site selection and aggregations of Channel Catfish before and during the spawning season.
3. Test for seasonal differences in hourly activity and temperature for both sexes and size classes of Channel Catfish.

Data collection and analysis will be completed by winter 2024 and will be included in the draft final report (31 March 2025) and final report (30 June 2025).

Study Area:

Channel Catfish size and density tends to decrease from upstream to downstream (Franssen et al. 2014). Thus, tagging and release locations will be distributed in reaches that are suspected to have the highest densities of spawning adults between river miles 124-76.4 (Powerline to Sand Island boat launch; Davenport and Furr 2021). Radio transmitters will be implanted in Channel Catfish captured in October 2022 and 2023. Following implantation, we will conduct raft mounted telemetry trips monthly outside of the expected spawning season, and weekly during the expected spawning season, which will be informed from the results obtained in Task 1. The extent of active telemetry efforts may be extended if fish emigrate beyond the study area.

Figure 2. Map of the San Juan River and its tributaries. Channel Catfish will be tagged between the Powerline access (near river mile 124) and Sand Island boat launch (river mile 76.4). Remote radio receivers will detect individuals as they emigrate beyond the tagging reach, and Passive Integrated Transponder (PIT) antennas may detect broad scale movement patterns.

Study Methods/Approach:

Tagging

One hundred adult Channel Catfish will be captured and implanted with a coded radio transmitter with an estimated battery life of 300 days (Advanced Telemetry Systems, Isanti, Minnesota, n = 60 F1800C, and n = 40 ARC400ARC400 archival transmitters). Because larger fish may exhibit different movement patterns than smaller adults, and males and females may exhibit different behaviors, we will divide transmitters between size classes (n = 50, 300-450 mm, n = 50 >450 mm), and aim to achieve an even sex ratio (n = 50 male and n = 50 female; Pellet et al. 1998; Butler and Wahl 2011). Sex will be determined by physical characteristics and confirmed during surgical transmitter implantation.

We will capture and tag fish using raft electrofishing in October of 2022 and 2023 to monitor any pre-spawn movements. To implant each transmitter, we will make an incision of about 10 mm into the peritoneal cavity, adjacent to the left pelvic fin (Hart and Summerfelt 1975). Incisions will be closed with 2 to 3 external interrupted absorbable synthetic sutures (3-0, PDS 2; Ethicon, Inc., Sommerville, NJ). Additionally, we will implant PIT tags into all individuals. PIT tags will serve as a secondary mark and may provide additional encounters at antennas deployed throughout the San Juan River (Figure 2). We will hold individuals for less than one hour, releasing them within one river mile of capture location, to minimize bias from long term post-operative care (Ovidio and Philippart 2002).

Data Collection

We will use a combination of passive and active telemetry techniques to quantify seasonal movements and identify spawning reaches. Passive tracking of fish will occur at two existing remote radio telemetry stations, located at river miles 124 (Powerline access; Figure 2) and 76.4 (Sand Island boat launch). Because remote telemetry stations are equipped with two-directional four element Yagi antennas, the time of detection and signal strength may be used to determine the direction of movement and if individuals emigrate from the tagging reach. Additionally, detections from remote telemetry stations may be used to inform active tracking efforts. For example, if individuals emigrate from the tagging reach, we can expand our active tracking efforts. We will use raft mounted antennas and radio receivers to conduct active telemetry surveys to locate individuals every 3-5 weeks outside of the spawning season We will perform additional surveys beyond the tagging reach as needed. By pairing the maximum signal strength with GPS coordinates, we will determine individual locations during each survey.

Channel Catfish demonstrate interannual fidelity to nesting locations, initiating spawning behavior as water temperature increases from 16-24°C (Appleget and Smith 1951; Pellet et al. 1998). To identify specific nesting sites, we will increase tracking efforts to every two weeks in April, and weekly May through July, when mean water temperatures are historically optimal for Channel Catfish spawning. However, this schedule will be refined using results obtained in Task 1 (estimated completion February 2023). Although Channel Catfish may spawn in monogamous pairs, nesting sites may occur in high use areas and are often visited by other adult conspecifics (Tatarenkov 2006). We will use individual spawning locations to assess patterns in broad scale spawning site selection and the propensity of Channel Catfish to aggregate prior to and during the spawning season.

To identify the exact timing and location of spawning, a subset of 40 individuals (n = 10 male 300-450 mm, n =10 female 300-450 mm, n = 10 male >450 mm, n = 10 female >450 mm) will be implanted with transmitters equipped with temperature and activity sensors. Activity sensors record activity as the percentage of time the sensor was in motion each minute (Hedden and Gido 2016; Figure 3). Because Channel Catfish exhibit a high level of parental care (i.e., nest guarding) and aggressive spawning behavior, we expect periods of high activity to be indicative of spawning behavior (Clemens and Sneed 1957; Becker 1983). Transmitters will be retrieved from individuals, using raft-mounted electrofishing, following the spawning season.

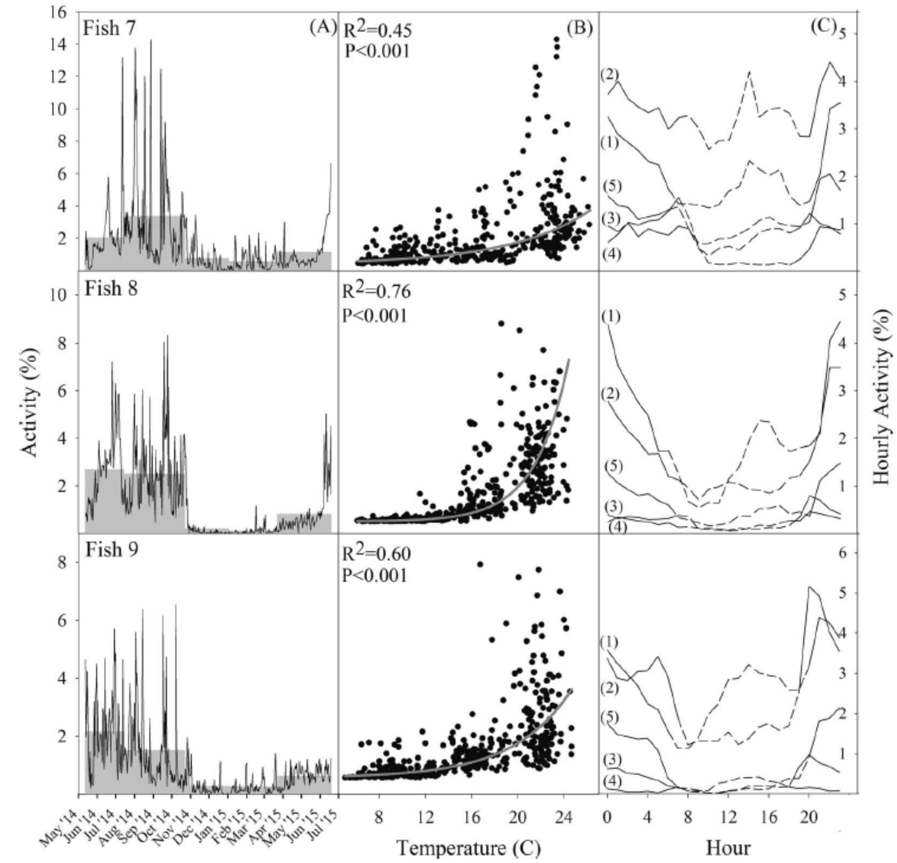

Figure 3. Average daily (line) and seasonal (bars) activity (%), (B) relationship between average daily temperature and activity, and (C) average seasonal hourly activity of three Flathead Catfish (*Pylodictis olivaris*) in the Gila River, New Mexico, using radio transmitter activity and temperature sensors. Activity was recorded from May 2014 to June 2015. Panel (C) dashed lines represent daylight hours and solid lines evening hours during May to July 2014 (1), July to October 2014 (2), October 2014 to January 2015 (3), January to March 2015 (4), and March to June 2015 (5). Adapted from Hedden and Gido (2016).

Data Analysis

Using radio telemetry data, we will quantify and summarize seasonal distributions and movements of Channel Catfish. The FishTracker toolbox in ArcMap will be used to estimate home and seasonal core ranges (Laffan and Talyor 2013) based on digitized maps of the study area. This tool calculates kernel density estimates of occupation times using assumed transit time between known locations, while accounting for hard river boundaries (Figure 4). Seasonal kernel density estimation has been used to detect spawning locations and identify aggregations where the core ranges of multiple individuals overlap (Kirby et al. 2017; Acre et al. 2021). Other movement modelling tools and R packages will be considered as needed (Joo et al. 2020). We will quantify associations to habitat types by mapping physical stream characteristics (i.e., riffle density and channel type) with home and core ranges (Acre et al. 2021). Linear and non-linear models will be used to identify relationships between home ranges and species habitats or longitudinal positions in the river. Differences in home range sizes and movements among different size classes, sexes, and tagging locations will be examined with ANOVA. In conjunction with movement analyses, we will quantify differences in activity among sex and size classes and evaluate relationships between activity and environmental parameters (Hedden and Gido 2016; Figure 3).

Figure 4. Hypothetical kernel density estimation using the FishTracker ARC GIS toolbox. Known fish locations are used to determine occupancy times and calculate home range (90^{th} percentile) and core range (50^{th} percentile), accounting for transit times and hard river boundaries.

Deliverables and Schedule:

Data collection and analysis will be completed by winter 2024 and will be summarized in the draft report (31 March 2025) and final report (30 June 2025) submitted to the Program. Preliminary results will be presented at the February 2024 and 2025 Biology Committee meetings. A draft report will be distributed to the San Juan River Basin Biology Committee for review by 31 March 2025. Upon receipt and incorporation of written comments, a final report will be produced by 30 June 2025 and submitted to the Program Office along with electronic copies of the data. Finally, this work will result in the likely development of a peer-reviewed manuscript.

Task 3 (Clark Barkalow, Grey, and Diver)

Background and Justification:

Though the use of activity sensors in Channel Catfish will hopefully indicate spawning activity (i.e., nest building; Task 2), this assumption should ultimately be confirmed through the collection of eggs, embryos, or larval fish. As the exact location of Channel Catfish spawning sites (nests) is currently unknown and the collection of eggs and/or embryos seems unfeasible, we propose collecting age-0 Channel Catfish for otolith microstructure analysis and subsequent spawning date calculations. Our hypothesis is that the back calculated estimates of when the Channel Catfish spawned within our study reach will align with peaks in activity detected through the use of activity sensors.

Current larval fish monitoring methods are designed to target low velocity habitats which are used by larval Colorado Pikeminnow *Ptychocheilus lucius* and Razorback Sucker *Xyrauchen texanus* (Farrington et al. 2022). These habitats are not necessarily suitable habitats for age-0 Channel Catfish. Larval fish monitoring typically captures low numbers of Channel Catfish, relative to the sub-adult and adult population in the river, suggesting a spatial mismatch during these years (Table 2; e.g., 2015, 2019, 2020). Age-0 Channel Catfish have been collected in large numbers in riffles, sand shoals and cobble shoals, and observed swimming downstream of high-velocity areas like rapids (pers. comm. M.A. Farrington); however larval monitoring does not target these habitats as the objective is to monitor spawning success of Razorback Sucker and Colorado Pikeminnow. Additionally, the results of the pilot study conducted for 2017 (Task 1; Figure 1) indicated a brief spawning period for Channel Catfish which, coupled with rapid transitioning to juvenile stage and associated increase in swimming ability, may suggest that age-0 fish are only susceptible to capture by larval seine for a brief period.

To obtain more accurate estimates of Channel Catfish spawning periodicity within this study period, a directed effort designed to sample habitats utilized by age-0 Channel Catfish is included. In addition to providing more robust estimates of spawning back calculations, more intensive sampling may also provide evidence of spatial spawning densities within the San Juan River. This task is designed to confirm peaks in activity from the activity sensors implanted in adult Channel Catfish and to identify patterns in age-0 Channel Catfish abundances post-spawning. Results of this study will inform management decisions involved in nonnative fish removal in the San Juan River and may allow eggs, embryos, larvae and even nesting adults, to be targeted for removal.

Objectives:
The objective of this task is to perform targeted collection of age-0 Channel Catfish to compare with adult spawning activity data.

Specific objectives are to:

1. Collect age-0 Channel Catfish larvae from habitats in which they are most likely to occur.
2. Remove and age otoliths and back-calculate spawning dates.
3. Compare spawning dates from otolith aging to spawning dates indicated by activity sensors (Task 2).
4. Analyze age-0 Channel Catfish spatial trends within the study area.

Study Area:

Age-0 fish will be sampled between RM 124 (Powerline) and RM 76.4 (Sand Island boat launch). This study area matches that of Task 2 and is designed to facilitate the direct comparison of age-0 Channel Catfish collections with the activity sensors implanted in the adult Channel Catfish. If the study area in Task 2 is expanded due to emigration of adult Channel Catfish from the study area, then the study area in Task 3 will be modified similarly.

Study Methods/Approach:

Channel Catfish transition directly from yolk-sac larvae to juveniles (ontogenetic phase with a full adult complement of fin rays; Tin 1982; Reyes 2010) and actively swim one to two days post-hatch

(Burr et al. 2020). Recently hatched Channel Catfish remain in the nest guarded by the male for about 7 days, at which point they may school for one to two weeks (Burr et al. 2020). The location of Channel Catfish nests in the San Juan River is currently unknown, precluding the collection of larvae directly from nests; thus, sampling will be scheduled to target age-0 Catfish soon after leaving the nest. Using the back-calculated spawning dates obtained in Task 1, sampling will be planned to target age-0 Channel Catfish as they leave the nest, which should be approximately 10–14 days after peak spawning. For example, based on the pilot study, Channel Catfish spawning peaked around 7 July, so sampling of age-0 individuals would occur roughly 21 July. Spawning periodicity likely varies with abiotic factors like flow and temperature, so the actual sampling period will depend on the results of Task 1, Task 2, and the hydrologic conditions in 2023.

One sampling trip will occur approximately 10–14 days after the presumptive spawning period. One inflatable raft will be launched at the upstream extent of the study area (tentatively RM 124; Powerline) and will be equipped with seines for fish sampling, materials for sample preservation, and water quality monitoring equipment. Age-0 Channel Catfish surveys will be performed using a fine-mesh seine (1 x 1 m x 0.8 mm). Seine hauls will be measured (m) and length, mesohabitat designation with average substrate type, GPS coordinates (UTM) and river mile to the nearest tenth of a mile, will be recorded on field data sheets. Water quality will be measured at each site with a Hanna multimeter (temperature ºC), pH, conductivity, total dissolved solids) and turbidity will be measured with a Secchi disk. At least one photograph will be taken at each sampling site. Catch per unit effort (CPUE) will be calculated as fish/m^2 sampled.

Age-0 Channel Catfish prefer relatively shallow (< 1.0 m) low velocity habitat (<0.8 m/s; Brewer and Rabeni 2008). Seining will focus on habitats expected to be inhabited by age-0 Channel Catfish including riffles, shallow low velocity habitat on the periphery of the main channel, habitats with overhanging or inundated vegetation, and secondary channels. Additionally, large numbers of age-0 Channel Catfish have been collected at a shoal at RM 81.6 and other shoals (sand shoals and cobble shoals) in the main channel (pers. comm. M. A. Farrington), so this habitat type will also be sampled when encountered. Seine hauls will be performed in as many suitable habitats as possible or at least every three river miles to ensure samples are spatially distributed within the study area. Additionally, seine hauls will be performed near locations where archive tagged fish have been detected congregating.

Channel Catfish are easily identifiable in the field, so only Channel Catfish will be retained during this effort. All other larvae will be returned to the river. Channel Catfish will be preserved in a 95% solution of ethanol and returned to the laboratory for otolith removal. Only Channel Catfish less than 35 mm TL will be collected for this study because individuals larger than 35 mm TL in July are assumed to be age-1+ fish (based on published growth rates; SJR larval monitoring protocol; Tin 1982).

We propose removing otoliths from up to 200 Channel Catfish collected during this effort. If greater than 200 age-0 Channel Catfish are collected, they will be subsampled based on size and collection locale. Standard length and total length will be recorded for each specimen. Otolith removal and aging will follow the methods outlined in Task 1. Additionally, the age at swim-up, denoted by a growth check on the otolith (Sakaris and Irwin 2008) will be determined and the period in which the fish occupied the nest calculated.

Male Channel Catfish guard and maintain the nest (Tatarenkov et al. 2006), so it is assumed that nest guarding will be detected by radio telemetry during the period between spawning and larval swim-up. The presumed nest guarding period, determined by calculating spawning and swim-up dates from otoliths, will be compared against activity tags and radio tags and telemetry data to confirm spawning.

Spawning activity, from activity trackers will be compared with back-calculated spawning dates to compare adult activity to timing of when larvae were produced. Back-calculated spawning dates will be plotted against discharge and temperature and timing of spawning activity overlayed with it. A linear model will be developed analyze the relationship between spawning dates (from otoliths) and adult activity (from radio telemetry).

Lastly, the spatial distribution of age-0 Channel Catfish will be analyzed within the study area. Because young Channel Catfish school together after leaving the nests, collection of a group of similarly sized individuals may indicate the presence of a nearby nest. However, age-0 Channel Catfish may be susceptible to drift (Brewer and Rabeni 2008) and may drift after becoming entrained in the thalweg during feeding (Brown and Armstrong 1985), so collection of age-0 individuals, particularly in low numbers, does not necessarily indicate a spawning area. A multiple regression analysis will be performed to analyze the relationship between physical habitat characteristics (e.g., mesohabitat, cover, vegetation, river mile), adult activity, and age-0 Channel Catfish CPUE.

Deliverables and Schedule:

A presentation will be prepared to report results of this study at the February 2024 Biology Committee meeting. A draft report will be presented to the San Juan River Basin Biology Committee for review by 31 March 2024. Upon receipt and incorporation of written comments, a final report will be produced by 30 June 2024 and submitted to the Program Office along with electronic copies of the data. Finally, this work will likely result in the development of a peer-reviewed manuscript and Swimming Upstream article in 2024.

Budget Summary: Table 3. Summary of Office Budgets for fiscal year 2022-2026.

Fiscal Year	NMFWCO	ASIR	KSU
2023	$96,559.54	$ 43,986.61	$97,746.63[i]
Total	$96,559.54	$ 43,986.61	$97,746.63[ii]

Reviewers:

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[i] Four Corners Power Plant NFWF will contribute an additional $33,000 for radio and archival tags for this project.
[ii] Four Corners Power Plant NFWF will contribute an additional $33,000 for radio and archival tags for this project.