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ARTICLE

History and ecology of wild-captured crawfish in Louisiana

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Abstract

Objective: The lower Mississippi River floodplain has historically been harvested for wild crawfish since the 1800s. Changes in seasonal hydrology align with the life history of the red swamp crawfish *Procambarus clarkii* and the white river crawfish *P. zonangulus*, making them primary targets for commercial and recreational harvesters. The goal of this study was to use over 20 years of long-term data from Louisiana to evaluate the association of river stage and local precipitation with crawfish harvest.

Methods: Crawfish landings data from 1999 to 2022, in addition to monthly Atchafalaya River stage height and monthly precipitation, were used to evaluate potential (delayed) effects of the environmental variables across a range of months.

Result: Annual wild crawfish landings averaged 5 million kg at a value of US$10 million, with 90% of statewide landings historically from the Atchafalaya River basin. We found two clusters of the effect of river stage on crawfish landings: (1) late-fall (November and December) river stage significantly increased the early crawfish season (February) landings; and (2) winter (January and February) river stage significantly increased the March and April crawfish landings. Precipitation was only found to have an effect in one monthly combination.

Conclusion: The wild crawfish fishery is viewed as an annual crop with little regulation, and this status may continue into the future. However, we have now quantified the effects of environmental variables associated with harvest, providing a deeper understanding of the river–crawfish relationship. These results may assist the future management of crawfish if harvest increases or if the river system experiences extreme (flow) conditions.

KEYWORDS

Atchafalaya River basin, crawfish, *Procambarus clarkii*

INTRODUCTION

Louisiana is well known for its crawfish production (commonly the red swamp crawfish *Procambarus clarkii*, referred to here as "crawfish," the regional name), which is comprised of harvest from both the aquaculture and wild-capture sectors. Crawfish aquaculture constitutes the majority of the market; however, recent work has begun to document the local knowledge and environmental drivers (e.g., floodplain connectivity) that operate in the wild-capture crawfish fishery (Vargas-Lopez et al. 2020). Recreational and commercial fishermen have harvested crawfish from the lower Mississippi River floodplain since at least the late 1800s. Some evidence suggests that commercial trade in crawfish existed during the early 1800s, with the first recorded commercial harvest occurring in 1880 and consisting of 10,614 kg, worth US$2140 (McClain and Romaire 2004). Recordkeeping before the late 1950s is limited; however, commercial harvests between 1988 and 2010 averaged 7,711,070 kg/year, with a high of 22,679,618 kg in 1993 and a low of 177,808 kg in 2000 (Isaacs and Lavergne 2010).

To harvest wild crawfish legally for commercial purposes, an individual must hold two licenses: a commercial fishing license and a commercial crawfish trap license (Louisiana Department of Wildlife and Fisheries 2021). Crawfish are typically caught in baited, wire-mesh traps that are soaked in ponds, swamps, or slow-moving rivers. There are no limits on season, size, or possession for wild crawfish harvests except when specified within wildlife management areas where commercial crawfish harvest may be allowed. The Louisiana Department of Wildlife and Fisheries (LDWF) is responsible for monitoring and managing wild crawfish through gear, licensing, and reporting requirements. Harvest controls are not necessary to protect the crawfish resource, as their populations are (thus far) resilient and influenced by environmental conditions rather than fishing mortality (McClain et al. 2007). Although biologists may conduct occasional studies on wild crawfish, they do not sample, monitor, or survey the populations as with other fishery resources. Currently, only one program collects commercial fishery-dependent data on inland fisheries in Louisiana, and this program includes commercial crawfish harvest. The Trip Ticket Program has officially been collecting commercial landings data in Louisiana since its implementation by the LDWF in January 1999. As landings are sold to wholesale or retail seafood dealers, the dealers must collect specific information about the fisher, vessel, and dealer, as well as the area fished, species landed, quantity, and dockside value. Each month, dealers send the data back to the LDWF, which maintains a database of trip ticket information. Commercial fishermen who sell their catch directly to consumers are also required to complete and submit trip tickets.

Wild crawfish are the most economically important freshwater species in Louisiana (based on trip ticket reporting). In 2016, crawfish landings alone accounted for $12.6 million of the freshwater fisheries landings, representing about 70% of the total value for freshwater fisheries landings for that year (Bonatakis 2019). Although Louisiana is home to over 39 different species of freshwater crawfishes (Walls 2009), the red swamp crawfish and the white river crawfish *P. zonangulus* make up nearly the entire annual commercial crawfish harvest (McClain and Romaire 2004). The red swamp crawfish is native to the southern Mississippi Valley and northern Mexico, although it has been introduced in other areas of North America, Europe, Africa, Asia, and South America and commercial harvests have been recorded from Europe, Asia, and Africa (Oficialdegui et al. 2020). The white river crawfish naturally occurs in the southern United States along the Gulf of Mexico and northward up the Mississippi River drainage, possibly as far as the confluence of the Mississippi and Ohio rivers (McClain and Romaire 2004). Red swamp and white river crawfishes have similar habitat requirements, including riparian zones that experience natural cycles of flooding and drying—conditions that are common to much of Louisiana.

Impact statement

This study documents over 20 years of wild crawfish capture in Louisiana, a fishery dating back to the 1800s. The fishery has an annual value over US$10 million, and 90% of landings are from the Atchafalaya River basin. Monthly river stage has a positive and significant (delayed) effect on crawfish landings.

The majority of the crawfish life cycle depends on the flood pulse and the subsequent magnitude and duration of inundation. In the spring, crawfish mating occurs in open waters. After spring, when water levels decrease and temperatures increase, females retreat to burrows to continue the reproductive process. Crawfish burrows are usually dug by a single individual, with burrow diameter determined by the size of the crawfish and usually containing a single female or sometimes a male and female together (Correia and Ferreira 1995; Longshaw and Stebbing 2016). Successful survival and reproduction within the burrows depend on many factors, such as the severity and length of the dry period, the characteristics of the burrow, and the health of the animal, but it is evident that Louisiana crawfish have evolved over millions of years to reproduce within the protection of their burrows (Duffy and Thiel 2007). When water levels increase in the late fall with the start of the annual flood pulse, crawfish begin to emerge from their burrows and the hatchlings are released from the tails of the females. At this point, the timing of inundation is very important, as it influences the success of newly hatched crawfish (Alford and Walker 2013). Juveniles mature during winter and spring, while water levels are typically high. Wild crawfish abundance and subsequent harvest are driven by varying patterns of seasonal hydrology from river systems—for example, precipitation patterns in the upper and middle Mississippi River Valley watershed—and such patterns thus align with the life history of these crawfish species (McClain and Romaire 2004). However, local precipitation that might not change the river stage can still locally inundate crawfish habitat and exert a positive effect on crawfish populations.

The seasonality of wild crawfish harvest relies on many environmental variables that allow for the spawning and growth of individuals (McClain et al. 2007). Many of Louisiana's coastal basins contain flooded, low-lying areas; areas that flood periodically; drier areas; and upland forests. Crawfish species that are native to these basins have adapted to the cycle of flooding and drying, as have the animals that feed on crawfish. Although crawfish are steadily abundant during some years, crawfish landings notably fluctuate in other years. The variable annual abundance of these crawfish may be influenced by changing water levels and other environmental factors.

Flood regime has been documented as an important factor in fisheries production in Louisiana river basins across multiple species (Alford and Walker 2013). An increase in flood duration and magnitude should benefit populations of organisms that utilize floodplain habitats by enhancing their growth and reproductive output. That is, density-dependent effects caused by increases in the availability of mating and nursery habitat will lead to greater biomass and growth of the organism. Additionally, density-independent effects may lead to greater forage production because of high nutrient loads diverting from the Mississippi River during each flood. Another environmental variable, precipitation, is of interest, as river levels and precipitation totals are not well correlated. The Atchafalaya River flow is largely controlled by the U.S. Army Corps of Engineers, which regulates the flow (at the Old River Control Structure) between the Mississippi and Atchafalaya rivers. Therefore, discharge can be high due to precipitation elsewhere in the state or country, even while local precipitation totals are low. The inverse can also be true: local precipitation accumulation can be high when river discharge levels are low. We analyzed crawfish landings data from the LDWF Trip Ticket Program (1999–2022) to address three questions: (1) What are the long-term characteristics of the wild-capture crawfish fishery in Louisiana?, (2) Does the Atchafalaya River stage predict wild crawfish landings?, and (3) Does local precipitation predict wild crawfish landings?

METHODS

Data sources

Wild crawfish

Data on wild crawfish landings were provided by the LDWF Trip Ticket Program and contained monthly wild crawfish harvest data from 1999 to 2022. Trip ticket information is completely confidential and protected under state and federal law. As such, any information leading to fisher identification is withheld. Additionally, any data manipulation that leads to three or fewer individual sales records being reported could lead to fisher or dealer identification (Wildlife and Fisheries: Records; Confidentiality 2022). Due to these confidentiality regulations, we handled all crawfish landings at the aggregate river basin level. (When delimited to parish, sometimes there were less than three records in that area.) Data recorded on individual trip tickets included the common name of the species (both prominent crawfish species are recorded as "wild crawfish"), month and year of harvest, the quantity of crawfish landed (in pounds, which we converted to kilograms), the value (US$) of total landings, and the river basin of crawfish harvest. Note that we include data from 2000 and 2006 in annual reporting; however, these 2 years were excluded from subsequent modeling. The year 2000 was characterized by problems with trip ticket reporting (LDWF, personal communication); the year 2006 followed Hurricane Katrina, which physically and economically devastated south Louisiana infrastructure and crawfish markets. Data from trip tickets measure the crawfish harvest only. There is no measure of effort available for this fishery; rather, recorded landings served as a proxy for crawfish relative abundance, a practice that is common to shellfish fisheries (e.g., Leslie and Shelmerdine 2012; Welby 2016) and other fisheries (e.g., Ochwada-Doyle et al. 2016). Although we evaluated wild crawfish landings from across the state of Louisiana, the vast majority of landings come from the Atchafalaya River basin, which is why the environmental variables described below pertain only to that basin.

River stage

River stage (height) data were provided by the U.S. Army Corps of Engineers Atchafalaya Basin Stage Data from a search query starting with January 1, 1999, and ending with December 31, 2022, for Atchafalaya River stage height (feet; 1 ft = 0.3048 m) at Simmesport, Louisiana (site 03045; https://rivergages.mvr.usace.army.mil/WaterControl/stationinfo2.cfm?sid=03045). Simmesport is located approximately 8 km from the head of the Atchafalaya River and represents a reference location upstream from nearly all of the wild crawfish harvest locations. A total of 8728 days were included in the data, of which 246 days were missing values (likely due to equipment malfunction). Fortunately, the missing values were not a concern because (1) missing values represented less than 3% of the overall data, (2) missing values were spread out across the data such that periods of missing data usually were not greater than 1–2 days, and (3) the Atchafalaya River is large and not subject to rapid changes in stage height over any given period of a few days. We aggregated the data by month and year to calculate a mean stage height at the same monthly resolution as the wild crawfish harvest data.

It is worth mentioning that we also considered Atchafalaya River discharge as a potential environmental variable for predicting wild crawfish harvest. (Atchafalaya River discharge data were queried in the same manner as described above for stage height.) Ultimately, we used stage height as our environmental river variable because (1) unsurprisingly, stage height and discharge had an extremely strong correlation (>0.95, depending on how the data were summarized); (2) stage height represents a more direct measurement of flooded habitat and water levels (factors known to influence the crawfish life cycle) than discharge; and (3) discharge data were missing from over 50% of the dates within our range, so a concerning amount of interpolation would have been required to use the data.

Precipitation

Precipitation data were provided by the Southern Regional Climate Center (https://www.srcc.tamu.edu/), which hosts a Climate Data Portal from which data are available for public access and download. Using this data portal, we queried monthly (aggregate) precipitation starting with January 1, 1999, and ending with December 31, 2022, for the Lafayette, Louisiana, Regional Airport (station 13976) due to the station's close proximity to the Atchafalaya River basin and the consistency of the available data. The data included a cumulative rainfall value for each month of the query, and no interpolation was necessary.

Analysis

Prior to any statistical analysis, we first wanted to simply describe the wild-capture crawfish fishery in Louisiana because almost no peer-reviewed literature exists for this fishery. For instance, we wanted to document annual landings and value across all basins over time, describe the monthly increase and decrease (i.e., cycle) of wild-captured crawfish every spring, and evaluate which basins contributed the most to statewide landings.

To evaluate our hypotheses about river stage and precipitation influencing crawfish harvest, we ran a series of linear regression models that represented combinations of time intervals over which an environmental relationship could exist. For both river stage and precipitation, we used monthly values from November to March, representing the 5 months leading up to the peak crawfish harvesting season. Monthly crawfish landings were taken from February to May. Using the monthly values of crawfish landings and environmental predictors, we ran 19 models. Each model represented different monthly combinations that tested for a possible effect of river stage and local precipitation on subsequent crawfish landings. For each model, the response variable was log-transformed wild crawfish landings regressed against the predictor of stage height or precipitation. Residuals for all models were evaluated for a mean near zero and a symmetrical (normal) distribution. All predictors were standardized (mean centered and divided by one standard deviation) so that we could compare effect sizes among models and so that we were not limited to only a result of (binary) significance. Effect sizes (Nakagawa and Cuthill 2007) are recommended beyond just significance statistics, as they more effectively quantify the relationship between a predictor and response and, when standardized, can be directly compared against other predictors for magnitude. All data manipulation and models were run in R (R Core Team 2023). Our approach of exploring combinations of months was developed as a compromise between regressing all possible combinations of months (many of which we did not have specific hypotheses for) and limiting combinations to very specific months that might mask larger trends. The months that we included in both the crawfish landings and the environmental variables represented a reasonable time frame over which relationships could occur while minimizing the potential for detecting spurious correlations.

RESULTS

From the beginning of the LDWF Trip Ticket Program (in 1999) through 2022, a total of 116,399,043 kg of wild crawfish landings were recorded across multiple basins in Louisiana. The total landings had an overall value of $236,961,015. Average annual landings and value were estimated at 5,060,828 kg and $10,302,653 (Figure 1A,B). Annual landings followed a very predicable increase during March and April, with a peak in May and a rapid decrease in June and July (Figure 1C). Although the May landings peak can shift earlier or later within a given year or basin, the overall temporal pattern was consistent through time. Ninety percent of the total landings occurred within the Atchafalaya River basin (104,149,103 kg, with a value of $213,078,401; Figure 1D). Because most of the state's total landings are contained within the Atchafalaya River basin, further analysis exclusively focused on landings from this basin. To compare, the basin with the most landings after the Atchafalaya River basin was the Vermilion River–Bayou Teche basin, with 6% of statewide landings. After the Atchafalaya River basin and Vermilion River–Bayou Teche basin, only the Mississippi

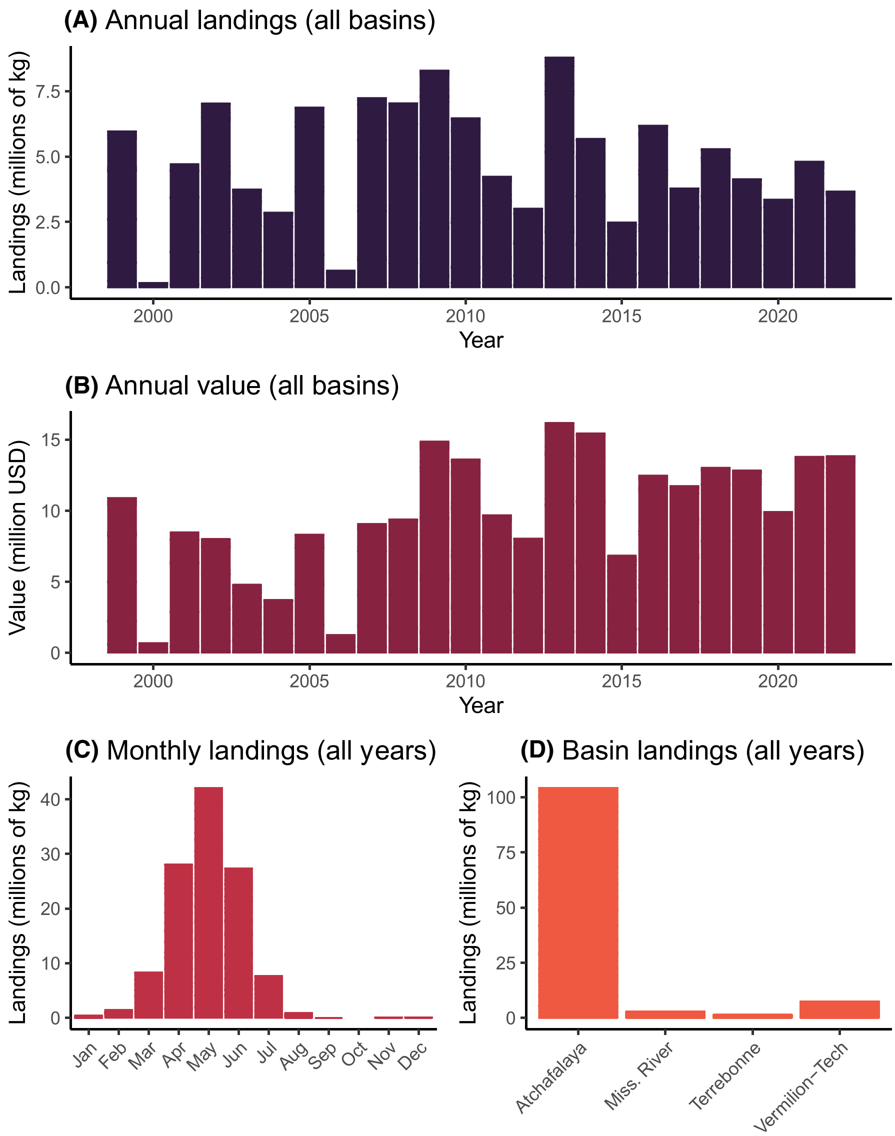

FIGURE 1 Descriptions of landings and value (US$) of wild-captured crawfish in Louisiana from 1999 to 2022: (A) total landings summed across all basins by year; (B) total landings value summed across all basins by year; (C) monthly landings summed across all basins and all years (note that we present months on a calendar year order, but throughout the study, we analyze crawfish landings beginning on November 1, which makes sense for both hydrological cycles and crawfish life history); and (D) landings summed across all years for the top-four reporting basins (Atchafalaya River basin, Mississippi River basin, Terrebonne Basin, and Vermilion River–Bayou Teche basin).

River basin and Terrebonne Basin reported greater than 1% of statewide landings.

We ran a total of 19 linear regression models that explored the main effects of mean river stage and monthly cumulative precipitation on monthly landings (Figure 2). The vast majority of estimated effects (27 of 38 [74%]) were positive in direction (although not all of the estimates were significant). Only one monthly combination that we examined for precipitation was significant (December precipitation and March landings; $p < 0.05$), while 7 of the 19 monthly combinations of mean river stage were significant (Figure 2). May is typically the peak month of harvest, yet May landings showed some of the weakest effects of river stage.

DISCUSSION

Our work represents one of the first attempts to document the long-term characteristics of a small but culturally and economically valuable regional shellfish fishery while also evaluating the empirical relationship between crawfish relative abundance and environmental conditions. We documented a clear and positive relationship between mean river stage in the Atchafalaya River basin and wild crawfish landings in the following months. Based on 23 years of data, we detected evidence for both a late-fall relationship and a late-winter relationship, in which higher river stages significantly increased crawfish landings 2–3 months later. We cannot totally discount an effect

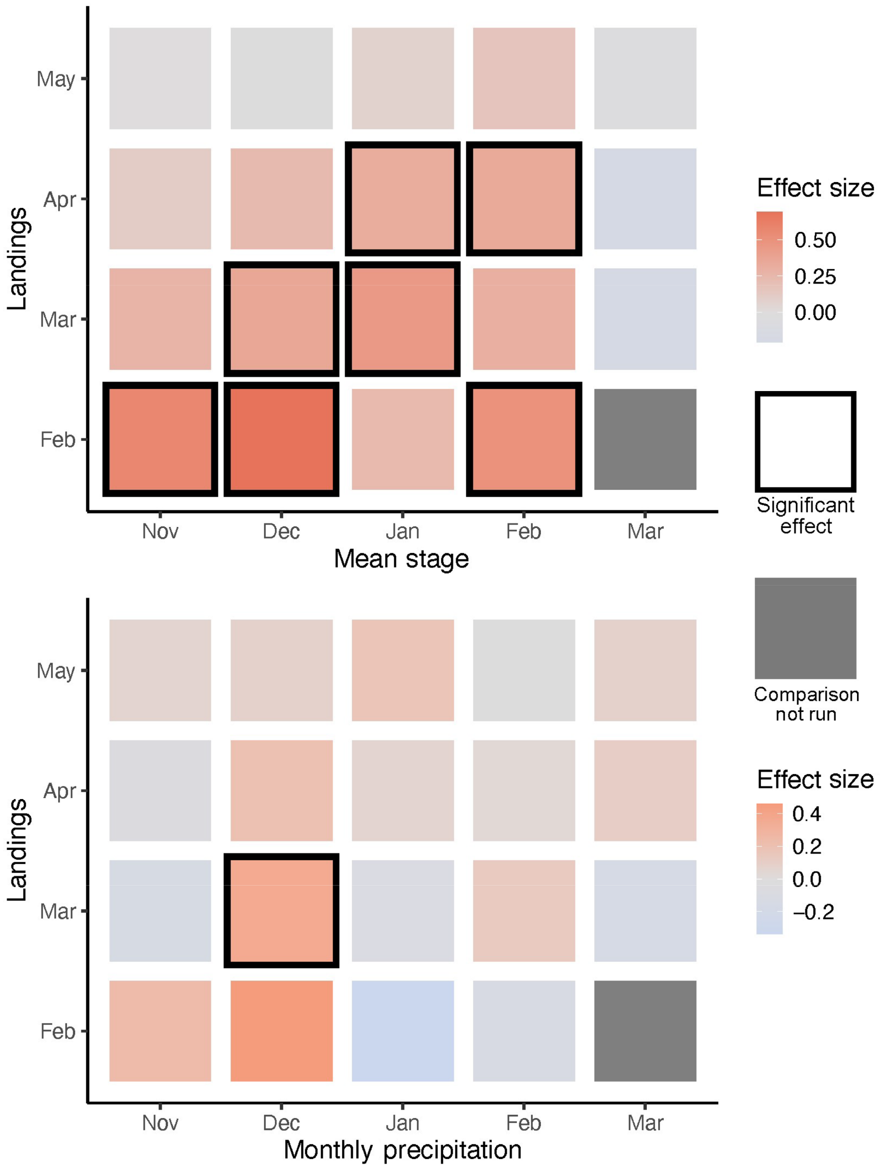

FIGURE 2 Heatmap-style results for models estimating the effect of mean monthly Atchafalaya River stage height (top panel) and cumulative monthly precipitation (bottom panel) on monthly Atchafalaya River basin crawfish landings. Square fill color represents the magnitude of the effect for a given combination, and a thick black border indicates statistically significant ($p < 0.05$) effects.

of monthly precipitation and we know that soil moisture is likely an important factor for the crawfish life cycle, yet our analysis showed relatively little effect of monthly precipitation on crawfish landings. Initially, we had questions about drought; however, drought operates at irregular time intervals and varying intensities, which led us to model precipitation as a proxy for drought.

Our work builds on recent efforts by Vargas-Lopez et al. (2020) to better quantify the effects of environmental conditions on crawfish abundance and harvest. Vargas-Lopez et al. (2020) found that floodplain connectivity plays a role in harvesters' behaviors. The positive association that we documented between river stage and harvest aligns with the findings of Vargas-Lopez et al. (2020) on the importance of hydrology for crawfish. Our work adds to this field because we were able to quantify the lag effect that river stage has on putative crawfish abundance. However, many other factors outside the scope of our study likely influence crawfish abundance and harvest. The exact conditions present where traps are fished, such as depth and turbidity, are known to be meaningful factors (Vargas-Lopez et al. 2020), but they are not documented in landings. Market price is another factor that certainly influences effort and landings; 90% of the crawfish supply comes from aquaculture, so price may be considered an external force to the wild-capture fishery. This could have implications during May, which is a time of high harvest in most years yet is typically the month during which the price begins to decline. These economic forces may also explain why the environmental factors in our study were not influential for May landings. Another factor that is difficult to quantify is low water—particularly when water is so low that access to the fishing grounds may be limited. Low water combined with the vast private ownership of much of the Atchafalaya River basin suggests that there could be complex nonlinearities to environmental conditions and subsequent landings. Despite these factors that warrant further investigation, we find it compelling that we still detected a clear effect of river stage on subsequent crawfish landings.

Null hypothesis significance testing always needs to consider the outcome of false positives. Although we recognize that one or more of our significant effects could be a false positive, our significance level ($\alpha = 0.05$) suggests that not all of our significant effects are likely to be false. In other words, at this level of significance we might expect 1 of 20 significant effects to be a false positive, yet we had 8 significant effects out of 19 models, thus providing strong evidence that we were not detecting false positives. Another practical limitation is the arbitrariness of months. Not only are some months different in duration, but months are also ultimately an effort to discretize an otherwise continuous temporal scale. Despite the limitations that are inherent to a monthly unit, we think that months are still a reasonable time scale; we did not have any finer temporal resolution, but we also did not necessarily expect the river stage (or precipitation) and wild crawfish landings to be highly variable at the daily or even weekly scale. Crawfish life cycles play out over a year, and short-term changes in river stage or precipitation are unlikely to have strong or immediate population-level effects, whereas extended periods of wet or dry conditions could influence growth and survival. Essentially, months serve to integrate several weeks of conditions and likely represent a reasonable time step for this natural system.

Harvest of wild crawfish has occurred in Louisiana for over a century. In recent years, however, many of the traditional areas of wild harvest do not reflect the abundance of crawfish that are present to harvest. Since 2000, less than 20% (on average) of Louisiana's crawfish harvests have come from the wild-capture fishery (LDWF, personal communication), which suggests (1) environmental changes resulting in low catch, (2) the dominance of the crawfish aquaculture industry, or (3) a combination of both. Also of importance is the effort within the wild crawfish industry, yet the number of wild crawfish harvesters in operation is not documented within the available data. Additional investigation into the level of effort that has occurred since 2000 could further address the relationships between crawfish landings reporting and crawfish production.

Today, it is generally thought that farm-raised and wild-caught crawfish crops complement each other. Farm-raised crawfish are available later in the season during low-flow periods (summer), when natural habitats lose much of their hydrologic connectivity and the circulation of flow throughout many river networks is severed (e.g., the Atchafalaya River basin; Alford and Walker 2013). Although the annual timing, amplitude, and duration of the flood pulse are variable, peak water levels and Atchafalaya River basin floodplain inundation typically tend to occur in the late spring, with the drawdown period taking place from late summer through early fall (Fontenot et al. 2001; Bonvillain et al. 2008; Piazza 2014). As such, the effect of time on wild crawfish landings is likely related to the growth of crawfish aquaculture within the industry.

Louisiana is well known for its wild-capture crawfish fishery, where recreational and commercial fishermen have harvested crawfish from the lower Mississippi River floodplain since at least the late 1800s. However, the future of wild-captured crawfish in Louisiana is unknown. Evidence suggests a decline in recent years, although without a reliable metric of effort, it is hard to attribute modest changes in crawfish landings to the fishery or the environment (or both). On a larger scale, climate change is expected to increase the frequency, intensity, and impacts of some types of extreme weather events (Stott 2016). Even before climate change was thought to influence weather, south Louisiana commonly experienced both severe drought conditions and extreme river flooding, which suggests that climate change may bring new extremes. The more information that we can collect on how the wild crawfish fishery is executed and the nuances between crawfish populations and their environment, the better the foundation managers will have to sustain the cultural and economic values that crawfish represent.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest associated with the work presented in this study.

DATA AVAILABILITY STATEMENT

No new data were collected for this study. Data that support the findings of this study are available from the public agencies cited within the document.

ETHICS STATEMENT

There were no ethical guidelines applicable to this study.

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REFERENCES

Alford, J. B., & Walker, M. R. (2013). Managing the flood pulse for optimal fisheries production in the Atchafalaya River basin, Louisiana (USA). *River Research and Applications*, *29*(3), 279–296. https://doi.org/10.1002/rra.1610

Bonatakis, L. (2019). *Characterizing Louisiana's freshwater commercial fisheries* [Master's thesis, Louisiana State University]. https://repository.lsu.edu/gradschool_theses/5005

Bonvillain, C. P., Ferrara, A. M., & Fontenot, Q. C. (2008). Relative abundance and biomass estimate of a Spotted Gar population in a seasonally connected large river floodplain lake. *Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies*, *62*, 177–182.

Correia, A. M., & Ferreira, Ó. (1995). Burrowing behavior of the introduced red swamp crayfish *Procambarus clarkii* (Decapoda: Cambaridae) in Portugal. *Journal of Crustacean Biology*, *15*(2), 248–257. https://doi.org/10.2307/1548953

Duffy, J. E., & Thiel, M. (Eds.). (2007). *Evolutionary ecology of social and sexual systems: Crustaceans as model organisms*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195179927.001.0001

Fontenot, Q. C., Rutherford, D. A., & Kelso, W. E. (2001). Physicochemical influences on the distribution of larval fishes in the Atchafalaya River basin, Louisiana. *Transactions of the American Fisheries Society*, *130*, 107–116. https://doi.org/10.1577/1548-8659(2001)130<0107:EOEHAW>2.0.CO;2

Isaacs, J. C., & Lavergne, D. R. (2010). *Louisiana commercial crawfish harvester's survey report*. Louisiana Department of Wildlife and Fisheries, Socioeconomic Research and Development Section.

Leslie, B., & Shelmerdine, R. L. (2012). *Management measures for self propagated future recovery of crawfish, Palinurus elephas, in Welsh waters*. Countryside Council for Wales.

Longshaw, M., & Stebbing, P. (Eds.). (2016). *Biology and ecology of crayfish*. CRC Press. https://doi.org/10.1201/b20073

Louisiana Department of Wildlife and Fisheries. (2021). *2022 Louisiana commercial and for-hire fisheries rules & regulations*. Louisiana Department of Wildlife and Fisheries.

McClain, W. R., & Romaire, R. P. (2004). Crawfish culture: A Louisiana aquaculture success story. *World Aquaculture*, *35*(4), 31–35.

McClain, W. R., Romaire, R. P., Lutz, C. G., & Shirley, M. G. (2007). *Louisiana crawfish production manual* (Publication 2637). Louisiana State University Agricultural Center.

Nakagawa, S., & Cuthill, I. C. (2007). Effect size, confidence interval and statistical significance: A practical guide for biologists. *Biological Reviews*, *82*(4), 591–605. https://doi.org/10.1111/j.1469-185X.2007.00027.x

Ochwada-Doyle, F. A., Johnson, D. D., & Lowry, M. (2016). Comparing the utility of fishery-independent and fishery-dependent methods in assessing the relative abundance of estuarine fish species in partial protection areas. *Fisheries Management and Ecology*, *23*(5), 390–406. https://doi.org/10.1111/fme.12182

Oficialdegui, F. J., Sánchez, M. I., & Clavero, M. (2020). One century away from home: How the red swamp crayfish took over the world. *Reviews in Fish Biology and Fisheries*, *30*(1), 121–135. https://doi.org/10.1007/s11160-020-09594-z

Piazza, B. P. (2014). *The Atchafalaya River basin: History and ecology of an American wetland*. A&M University Press.

R Core Team. (2023). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Stott, P. (2016). How climate change affects extreme weather events. *Science*, *352*(6293), 1517–1518. https://doi.org/10.1126/science.aaf7271

Vargas-Lopez, I. A., Kelso, W. E., Bonvillain, C. P., Keim, R. F., & Kaller, M. D. (2020). Influence of water quality, local knowledge and river–floodplain connectivity on commercial wild crayfish harvesting in the Atchafalaya River basin. *Fisheries Management and Ecology*, *27*(4), 417–428. https://doi.org/10.1111/fme.12422

Walls, J. G. (2009). *Crawfishes of Louisiana*. Louisiana State University Press.

Welby, P. R. (2016). *Crab and lobster stock assessment* (Research Report 2016). Eastern Inshore Fisheries and Conservation Authority.

Wildlife and Fisheries: Records; Confidentiality, La. R. S. § 56:301.4. (2022). https://law.justia.com/codes/louisiana/2022/revised-statutes/title-56/rs-56-301-4/