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MANAGEMENT BRIEF

Spatiotemporal Variability of Fishery-Dependent Indices for the Declining Louisiana Southern Flounder Fishery

David R. Smith
Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, Louisiana 70803, USA; and Texas Parks and Wildlife Department, Tyler, Texas 75707, USA

Michael A. Dance
Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, Louisiana 70803, USA

Joe West
Louisiana Department of Wildlife and Fisheries, Baton Rouge, Louisiana 70802, USA

Stephen R. Midway*
Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, Louisiana 70803, USA

Abstract
In recent years, management agencies across the Gulf of Mexico and southern U.S. Atlantic have recognized Southern Flounder *Paralichthys lethostigma* as a declining fish stock. Population declines in coastal Louisiana are exhibited by indices of recruitment and biomass, which have reached levels that present management concerns. To develop a better understanding of this declining fishery, we examined fishery-dependent data collected by the Louisiana Department of Wildlife and Fisheries' recreational angler harvest survey (referred to as "LA Creel"). Data were modeled using generalized additive models to estimate temporal components of recreational Southern Flounder landings in both seasonality and trend. Over the study period (2014–2019), recreational landings exhibited a declining trend statewide. Strong seasonal peaks in the fall occurred statewide and regionally in every coastal management zone (i.e., estuary). Understanding the current fishery with the fine-scale resolution provided by the LA Creel survey can be used to help guide future management decisions in the pursuit of a sustainable management strategy inclusive of fishery-dependent information.

Indices of abundance developed from fishery-independent data sources are often preferred over indices developed from fishery-dependent sources in determining the status of fish stocks. Fishery-independent data are collected using systematic and random survey designs that attempt to keep spatial, temporal, and effort elements consistent so as to gather unbiased abundance data that allow for proportionality between survey catch rates and stock abundance to be reasonably assumed (Hilborn and Walters 1992; Hubert and Fabrizio 2007). The nonrandom aspects of commercial and recreational fisheries, along with any regulatory changes in the fishery through time, can lead to nonproportionality between fishery catch rates and stock abundance, which creates biases when interpreting fishery-dependent data as a measure of stock abundance (Grüss et al. 2019; Tate et al. 2020). Additionally, the nonlinear relationship between catchability and stock abundance (Crecco and Overholtz 1990; Wilberg et al. 2009) can potentially lead to hyperstability, in which indices of stock abundance ostensibly appear stable while a decline in stock size is occurring (Hilborn and Walters 1992).

Despite the inferential limitations of fishery-dependent data as a measure of stock abundance, broad applications exist for the use of fishery-dependent data in assessing fish populations. A classic example of applying fishery-dependent data as a source of stock size is through the

*Corresponding author: smidway@lsu.edu
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standardization of CPUE to remove the factors not related to changes in abundance; this approach is often used in stock assessments when fishery-independent data are lacking or unavailable (Winker et al. 2013; Okamura et al. 2018; Grüss et al. 2019; Tate et al. 2020). Another popular application of fishery-dependent data includes characterizing the spatial structure of fish distributions and habitats (Pilar-Fonseca et al. 2014; Pennino et al. 2016; Sculley and Brodziak 2020). Fishery-dependent data can also be used to elucidate drivers of fish population fluctuations by evaluating the relationships observed between fishery effort, landings, and stock abundance (Askey and Johnston 2013; van Poorten et al. 2016; Dassow et al. 2020; Feiner et al. 2020). Composition information (e.g., size, age, and sex) collected directly from the fishery is also frequently applied to characterize how fish populations and landings within specific regions are structured (Ajemian et al. 2016; Bada-Sánchez et al. 2019; Herdter et al. 2019). Nevertheless, fishery-dependent data remain underutilized in the management of many fisheries, particularly those for which substantial fishery-independent data exist.

In recent years, numerous U.S. state management agencies have recognized Southern Flounder *Paralichthys lethostigma* as a declining fish stock throughout much of the Gulf of Mexico and U.S. southeast Atlantic (Froeschke et al. 2011; Powers et al. 2018; Flowers et al. 2019; West et al. 2020; Erickson et al. 2021). In response to this decline, significant regulatory changes have been implemented in recent years for multiple Southern Flounder fisheries. Although Southern Flounder regulatory changes have not yet been implemented in Louisiana, the most recent stock assessment by the Louisiana Department of Wildlife and Fisheries stated that management actions will be necessary to recover the depleted stock (West et al. 2020). The decline in the Louisiana Southern Flounder population is underscored by the most recent estimates of spawning stock biomass, abundance of age-1 recruits, and total female stock size, all of which reached the lowest observed levels in the terminal year of each time series reported (West et al. 2020; Figure 1).

Fishery-dependent data for marine recreational fisheries in Louisiana are currently collected through the Louisiana Department of Wildlife and Fisheries' recreational angler harvest survey (hereafter, "LA Creel"), which was developed in 2014 to produce timely recreational landings estimates with a fine temporal resolution (weekly) and a basin-level spatial resolution. Data collected by LA Creel, which utilizes a stratified random survey design, have provided a substantial reference for estimates of recreational fishery harvest in Louisiana. The LA Creel survey became the first Gulf of Mexico recreational state survey to receive full certification from National Oceanic and Atmospheric Administration Fisheries for the estimation of harvest of all recreationally pursued marine fish species (NOAA Fisheries 2018). With fishery-independent abundance indices depicting a declining Southern Flounder stock in Louisiana (West et al. 2020; Erickson et al. 2021), this study evaluated indices developed from LA Creel to better characterize the Louisiana recreational fishery for

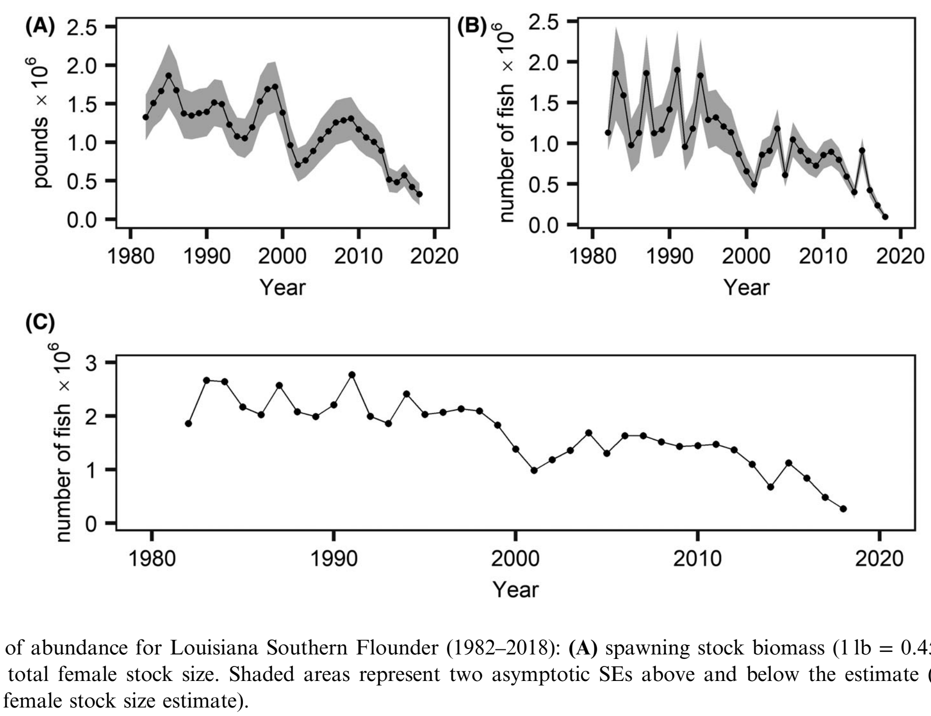

FIGURE 1. Estimates of abundance for Louisiana Southern Flounder (1982–2018): **(A)** spawning stock biomass (1 lb = 0.4536 kg), **(B)** abundance of age-1 recruits, and **(C)** total female stock size. Shaded areas represent two asymptotic SEs above and below the estimate (asymptotic SEs were not calculated for the total female stock size estimate).

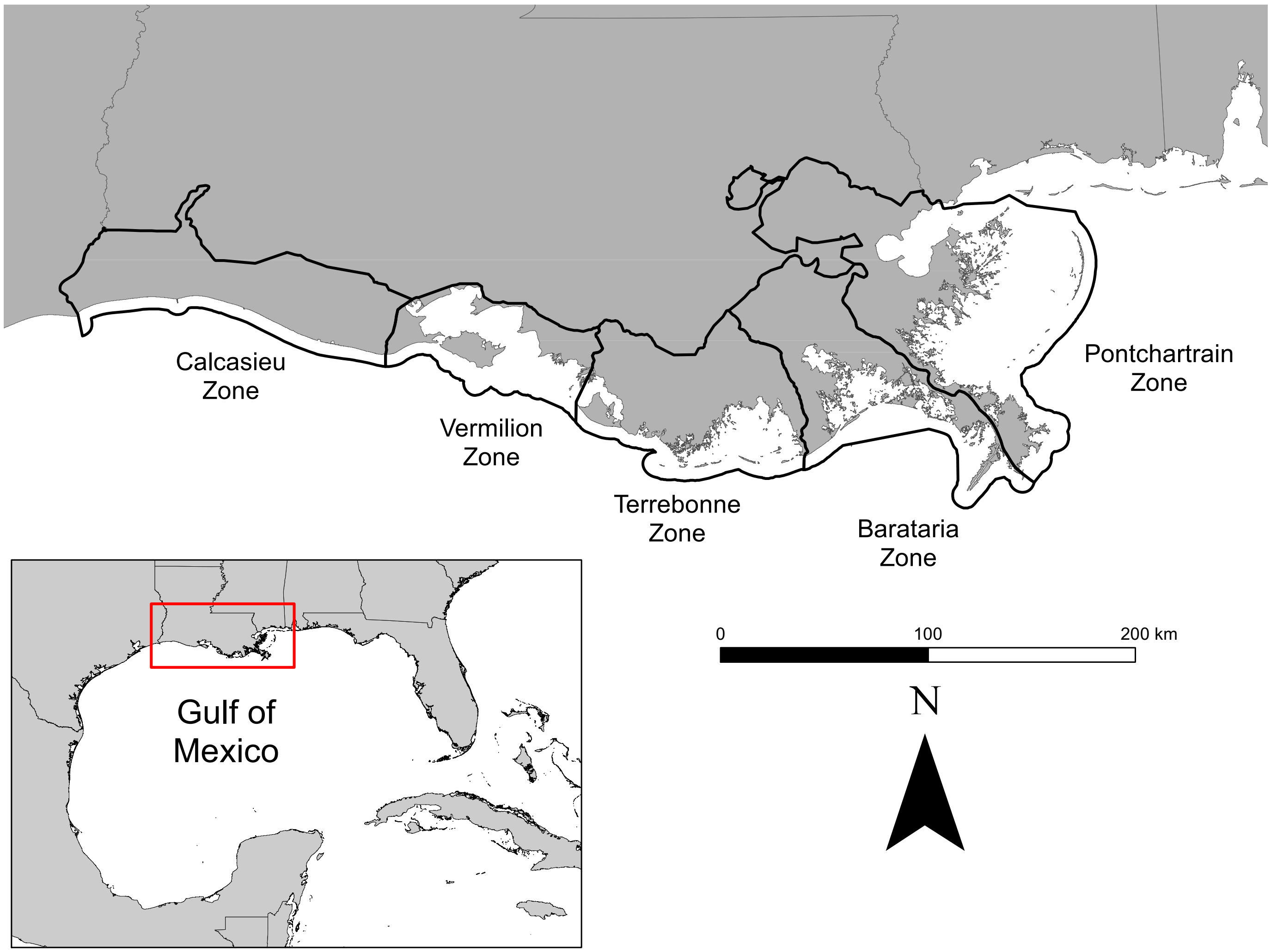

FIGURE 2. Map of the Louisiana coast, regionally segmented into Louisiana Department of Wildlife and Fisheries coastal management zones.

Southern Flounder and determine whether the observed decline in fishery-independent indices is reflected within fishery-dependent indices. Due to the biases associated with using fishery-dependent data as an index of stock size without a form of standardization, our evaluation did not seek to provide an additional measure of stock abundance. Instead, our study objectives were confined to evaluating trends within the fishery by answering three primary questions: (1) "How have fishery-dependent indices fluctuated annually?"; (2) "How does exploitation of the species vary on a seasonal basis?"; and (3) "What similarities and differences exist regionally throughout coastal Louisiana when examining the temporal variations in this fishery?" Results of this analysis may inform future policy changes based on the angler harvest behaviors elucidated within this fishery and provide a useful approach for assessing spatial and temporal aspects of fishery-dependent data.

METHODS

Data.— We confined our study to the recreational fishery for Southern Flounder in Louisiana, which is the primary source of directed fishery removals statewide (West et al. 2020). Moreover, our study was focused on recreational landings of Southern Flounder within coastal Louisiana, as offshore landings account for a negligible proportion of the total recreational landings (LA Creel, unpublished data). For the purposes of this study, LA Creel estimates of landings (the number of Southern Flounder estimated to have been harvested each week) and effort (the number of angler trips estimated to occur each week) were evaluated. The LA Creel estimates are regionally stratified into five coastal management zones: Calcasieu, Vermilion, Terrebonne, Barataria, and Pontchartrain (Figure 2). The Calcasieu Zone contains the Calcasieu/Sabine and Mermentau River basins; the Vermilion Zone encompasses the Vermilion/Teche and western

Atchafalaya River basins; the Terrebonne Zone contains the eastern Atchafalaya River and Terrebonne basins; the Barataria Zone includes the Barataria and western Mississippi River delta basins; and the Pontchartrain Zone encompasses the eastern Mississippi River delta, Breton Sound, and Pontchartrain basins.

The LA Creel survey generates landings estimates of recreationally targeted marine fish species by using a complemented survey design, which combines an on-site dockside intercept survey with an off-site effort survey that utilizes both telephone and e-mail contacts. Both the on-site and off-site surveys follow a stratified random sampling structure. Access points utilized within the LA Creel survey include all public sites (e.g., boat ramps, piers, and beaches) in coastal Louisiana that are utilized by saltwater anglers. The number of weekly assignments is held constant within each coastal management zone and is based upon the diversity and level of angling activity. Because more angling activity occurs during the weekend, assignments fall more frequently during the weekend. During the dockside intercept survey, information on the number of each species harvested is collected from anglers at access points, which are randomly assigned using a "probability proportional to size" methodology based on the level of angling activity. Angling activity within each site is assessed monthly to optimize site selection. Species-specific harvest rates are calculated from the information collected in the dockside intercept survey, weighted by the day type (weekend or weekday), site location, and time of each interview (AM or PM). During the off-site effort survey, a random sample of private Louisiana saltwater fishing license holders and Louisiana charter boat license holders is contacted by e-mail or telephone to collect information about the dates and locations of saltwater angling trips. The private angler effort survey sample frame is stratified into five sections based on geographic area, license density, and license type (north Louisiana, southeast Louisiana, southwest Louisiana, nonresident, and Recreational Offshore Landing Permit [ROLP]). One-thousand six-hundred private Louisiana saltwater fishing license holders are randomly selected from the sample frame each week for interviews (400 from the ROLP stratum and 300 from the four remaining strata). The weekly call list from this sample frame is randomized, and anglers are contacted until a quota of 800 license holders is reached. For the charter boat survey, 30% of ROLP captains and 10% of non-ROLP captains are randomly selected from the sample frame of Louisiana charter boat license holders and contacted for interviews each week. Angler effort within each coastal zone is estimated by determining the mean effort per angler interviewed and applying this estimate to the total population of licensed anglers, with a correction factor for license compliance rates. The harvest rates estimated from the on-site dockside intercept survey and the effort levels estimated from the off-site effort survey are combined to develop a complemented weekly harvest estimate for each coastal zone. In addition to the data provided by the LA Creel survey (2014–2019), our study also analyzed data collected by the earlier federal recreational marine creel programs (Marine Recreational Information Program and the previous Marine Recreational Fishery Statistics Survey; 2000–2013). Due to the differences in estimation procedures between the LA Creel and the federal surveys, the LA Creel harvest estimates were calibrated to the historic estimates to develop a continuous time series of estimates in a common currency (West and Zhang 2018).

Generalized additive models.— We chose generalized additive models (GAMs) to assess the temporal components within the LA Creel data for a variety of reasons, including the following: (1) GAMs are capable of exhibiting nonlinear and complex relationships between response and predictor variables (Wood 2006); (2) GAMs provide easily interpreted visualizations of these complex relationships; and (3) GAMs offer the flexibility to analyze data within a variety of statistical distributions (Guisan et al. 2002). Weekly landings estimates derived from the LA Creel survey within each coastal management zone were best characterized as count data with overdispersion and frequently contained landings values of zero for each week. Zero-inflated models were explored to evaluate whether the frequent zero values in our data were adequately modeled. Results using a zero-inflated negative binomial model were virtually indistinguishable from the results using a negative binomial distribution. Due to the prevalence of the negative binomial distribution in the use of modeling fisheries count data with overdispersion and moderate zero inflation (Barry and Welsh 2002; Drexler and Ainsworth 2013; Dance and Rooker 2019) and the potential overutilization of zero-inflated models (Wood 2020), we opted to model the LA Creel estimates using the negative binomial distribution. All statistical analyses were performed using R (R Core Team 2020) and the package *mgcv* (Wood 2006).

The GAMs were built under the equation

$$E\left(y_{ij}\right) = g^{-1}\left[\beta_0 + \sum_k S_k(x_k)\right],$$

where $E\left(y_{ij}\right)$ is the expected value of the response variable as the number of Southern Flounder landed within each coastal zone j during each corresponding weekly period i. The link function is represented by g, β_0 is the intercept, and S_k is the smoothing function of each predictor variable x. Temporal components of landings were included as predictor variables within each model in *year* (the corresponding year) and *season* (the corresponding week of the year). Smoothing terms for each predictor variable were represented using thin-plate regression splines (*year*) and cyclic cubic regression splines (*season*) penalized from a maximum basis dimension (k). The value of k was restricted to 6 (one for each year of data) for *year* and 10 for *season*. Smoothing parameters were selected using maximum likelihood (Wood 2011). The natural logarithm of effort (weekly number of angler trips within each coastal zone j) was applied as an offset within each model. Models were specified for estimations within two frameworks: one framework for a coastal zone-specific model and one framework for a statewide model. Within the coastal zone-specific model, weekly recreational landings from all coastal zones were pooled as the dependent variable and five smoothing terms were produced for each coastal zone for *year* and *season*. A random effect for each coastal zone j was applied within the coastal zone-specific model, allowing variation to occur within each smooth in shape. Within the statewide model, weekly recreational landings from all coastal zones were pooled as the dependent variable and a smoothing term was produced for *year* and *season*. A random effect for each coastal zone j was applied within the statewide model to account for the variability within each zone. Significance of each smoothing term was evaluated at an α of 0.05. Within both statewide and coastal zone-specific models, substantial positive residual autocorrelation provided evidence of serial correlation, a common issue confounding time series analysis (Hamilton 1994). To account for serial correlation within LA Creel landings estimates, a first-order autoregressive term (Wood 2006) was nested within each coastal zone time series for both the statewide and coastal zone-specific model frameworks.

Synchrony.— To quantify the similarity of temporal patterns in Southern Flounder landings throughout Louisiana, the synchrony of coastal zone-specific model predictions was quantified through the calculation of Spearman's rank correlation coefficients with corresponding asymptotic P-values approximated using the t-distribution (Harrell 2020). Significant relationships were evaluated at an α of 0.05. Weekly predictions from 2014 to 2019 were used in this analysis, making each weekly time series 313 periods long. With five total time series (Pontchartrain, Barataria, Terrebonne, Vermilion, and Calcasieu zones), 10 unique correlation coefficients were calculated.

RESULTS

From 2000 to 2016, estimates of Southern Flounder annual landings in Louisiana remained relatively close to the 20-year average (2000–2020) of 200,000 fish/year. During the years 2017–2019, estimates of annual landings substantially declined to levels approaching or below 50% of the 20-year average (Figure 3). Estimated landings of Southern Flounder were driven by harvest within the

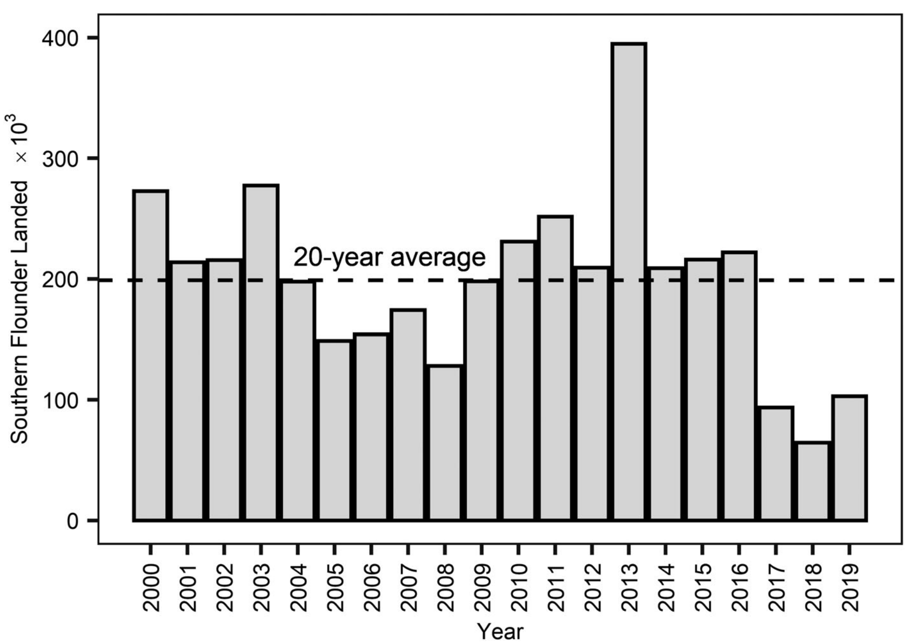

FIGURE 3. Estimates of annual Southern Flounder landings from the LA Creel survey (Louisiana Department of Wildlife and Fisheries; 2014–2019) and estimates hindcast to the historic Marine Recreational Information Program time series (2000–2013).

Calcasieu Zone, where at least 55% of the annual Southern Flounder landings in Louisiana were estimated to occur over the LA Creel period (Figure 4).

For the GAM applied to statewide data, the smoothing term for *year* was significant ($P < 0.001$; Table 1), indicating variability in landings over the time series examined. The statewide time series displayed a sharp decline in 2017 and a modest increase in 2019 (Figure 5). Over the entire time series, Southern Flounder landings declined statewide during the LA Creel period. A significant smoothing term ($P < 0.05$; Table 1) for *year* indicated variability in landings over the time series in the Calcasieu, Pontchartrain, Barataria, and Terrebonne zones (Figure 5). Landings in the Barataria and Terrebonne zones exhibited declines beginning in approximately 2017, with subsequent increases in 2019. The Calcasieu and Pontchartrain zones exhibited a moderate decline in landings over the entire time series. Within the Vermilion Zone, landings did not display significant variability over the time series.

The smoothing term for *season* was significant ($P < 0.001$; Table 1) in the statewide model and displayed a strong peak in fall landings (Figure 6). In the coastal zone-specific model, the smoothing terms for *season* were significant ($P < 0.05$; Table 1) within every coastal zone, with strong landings peaks in the fall, specifically during the month of November (Figure 6).

The relationships between each coastal zone-specific prediction time series were all significant ($P < 0.001$) and positive correlations. Values of Spearman's rank correlation coefficient ranged from 0.22 to 0.67 (Figure 7).

TABLE 1. Generalized additive model smoothing term significance within the Louisiana statewide model and coastal zone-specific model of Southern Flounder landings. Significant terms ($P < 0.05$) are in bold italics.

Region	Smoothing term	*P*
Statewide	*Year*	***<0.001***
	Season	***<0.001***
Calcasieu	*Year*	***0.028***
	Season	***<0.001***
Vermilion	*Year*	0.269
	Season	***<0.001***
Terrebonne	*Year*	***<0.001***
	Season	***0.008***
Barataria	*Year*	***<0.001***
	Season	***<0.001***
Pontchartrain	*Year*	***0.008***
	Season	***<0.001***

DISCUSSION

This study examined recreational landings in the Louisiana Southern Flounder fishery, indicating that landings have declined statewide in recent years, but more importantly our results provided a fine-scale spatial and temporal understanding of this decline. While only using data from the 6-year LA Creel time series, the observed decline in landings is significant statewide and consistent with the rangewide declines reported by numerous state agencies (Erickson et al. 2021). Extending the LA Creel time period

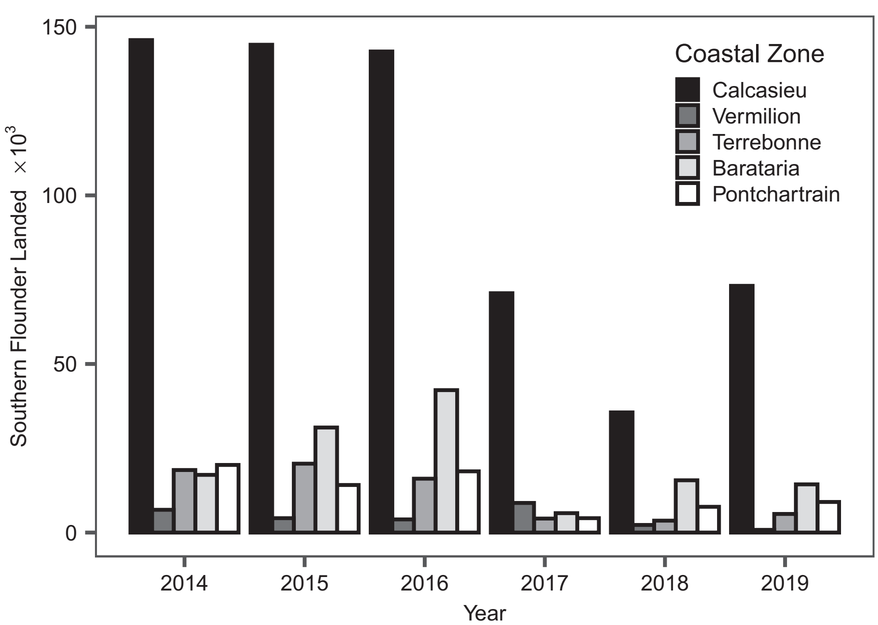

FIGURE 4. Annual Southern Flounder landings within each Louisiana coastal management zone.

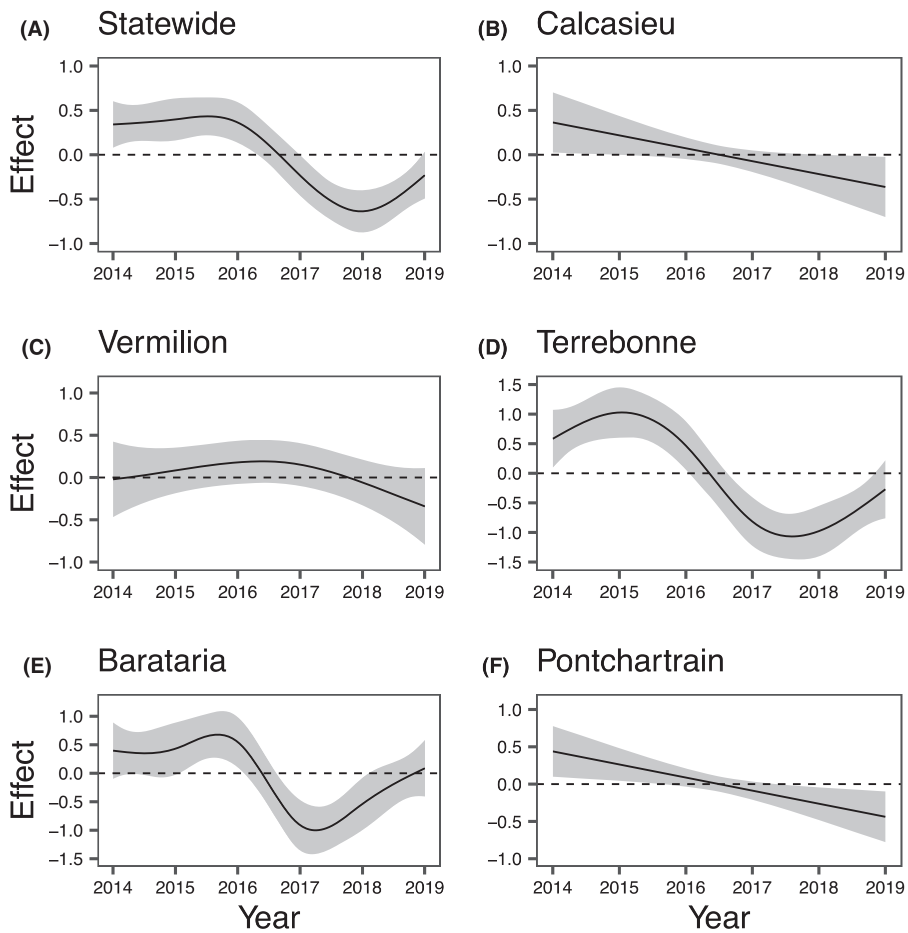

FIGURE 5. Partial effect plots for the smoothing term *year* in the Louisiana statewide model and in the coastal zone-specific model of Southern Flounder landings. Shaded areas represent 2 SEs above and below the smooth curve estimate. Dashed lines mark zero effect. Panel A includes data aggregated from all coastal management zones and panels B–F include only the respective zones.

to the time series of hindcast landings estimates places the context of the decline over a 20-year period.

Our analysis quantified and confirmed the impact of the fall harvest within the Southern Flounder recreational fishery in coastal Louisiana. Although the fall harvest is well defined by those familiar with the resource (GSMFC 2015), the seasonality of recreationally harvested Southern Flounder in coastal Louisiana had not been documented in the published literature and our study provides a baseline for understanding future seasonal shifts within this fishery. The peak in fall harvest coincides with the large-scale seasonal migration that Southern Flounder make to offshore waters from the estuarine environment as water temperatures cool (Craig et al. 2015). As Southern Flounder move through restricted passes to reach offshore spawning grounds, concentrations of fish become increasingly vulnerable to recreational harvest, as indicated by the peaks observed in the fall landings.

The resolution of data characterizing specific coastal zones within Louisiana provided the opportunity to evaluate the unique spatial variability that exists in the state's Southern Flounder fishery. Our analysis provided evidence of the substantial influence that the Calcasieu Zone holds on recreational landings of Southern Flounder in coastal Louisiana. Additionally, the Vermilion Zone did not display significant variability over the LA Creel period in our analysis of annual trend, in contrast with the variability observed within all other coastal zones and statewide. The Vermilion Zone also provided the smallest magnitude of landings within any coastal zone, with total landings accounting for less than 3% of statewide landings over the entire LA Creel period. The small scale of landings in the Vermilion Zone may be a driving force behind the diverging variability in annual trend. Moreover, our analysis of synchrony displayed significant positive correlations between the Vermilion Zone and all other coastal zones, providing some additional evidence of variability within this zone. A further evaluation of estuary-specific habitat and bay morphology may provide evidence to explain the differential exploitation, in both magnitude

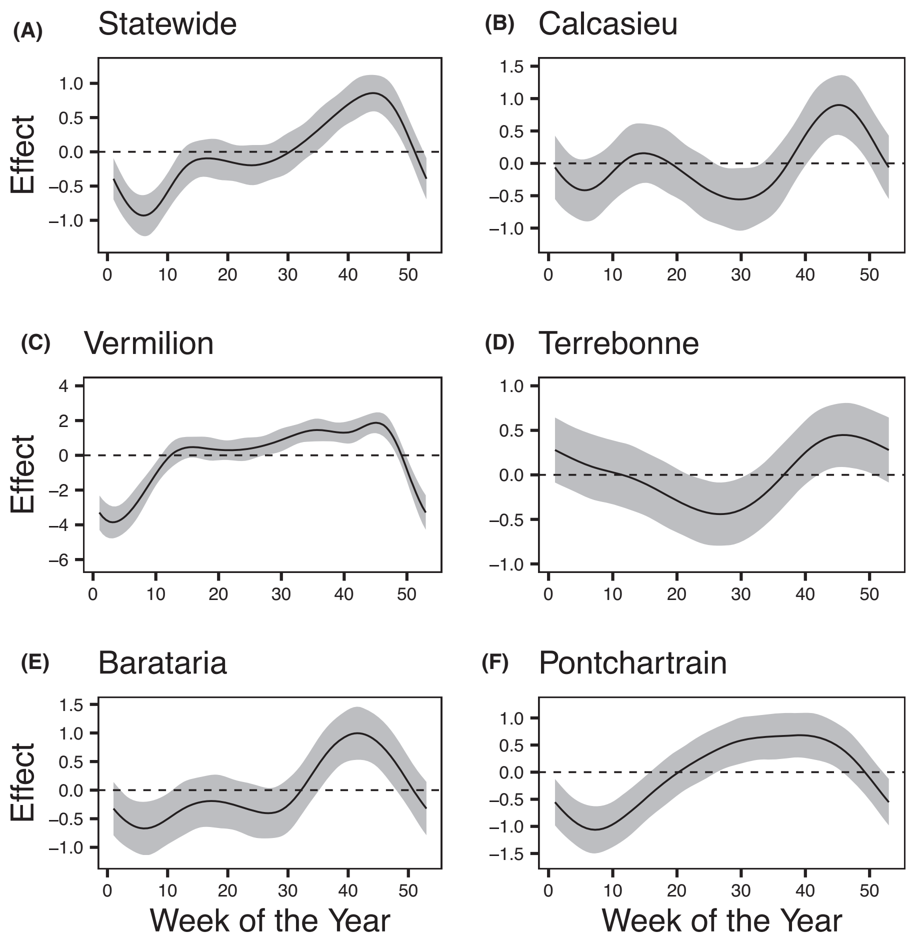

FIGURE 6. Partial effect plots for the smoothing term *season* in the Louisiana statewide model and in the coastal zone-specific model of Southern Flounder landings. Shaded areas represent 2 SEs above and below the smooth curve estimate. Dashed lines mark zero effect. Panel A includes data aggregated from all coastal management zones and panels B–F include only the respective zones.

and annual trend, within the Calcasieu and Vermilion zones. To further evaluate the potential for coastal zone-specific stock structure, age and size composition data could be evaluated within each coastal zone to determine whether subpopulations exist within the statewide stock.

Study Limitations and Strengths

This study was reliant upon probabilistic sampling methods that are commonplace in the estimation of recreational effort and landings. Although there are limitations to this type of data collection, namely in the inferences that must be made from a fixed number of interviews over a sampling period (e.g., Midway et al. 2020), no substitutable alternatives (e.g., electronic self-reporting) currently exist in the collection of recreational fishery-dependent data, specifically within coastal Louisiana. Absent significant advances in nonprobabilistic sampling designs and the willingness of users to adopt new technologies (Midway et al. 2020), robust probabilistic sampling methods for fishery-dependent data must continue in order to characterize and understand changes in harvest through time and space.

With the availability of only 6 years of data at the spatial and temporal resolutions of the LA Creel survey, the trends displayed by our models can only be placed in this limited context. However, the fine temporal resolution of the LA Creel survey data allows for inferences to be made over the 6-year window. The decline displayed statewide over this period highlights the magnitude of the reduction that is occurring in the Louisiana fishery for Southern Flounder. Additionally, the spatial resolution of the LA Creel survey allows coastal zone-specific inferences to be made throughout coastal Louisiana—a spatial distinction that was not previously available with Louisiana recreational fishery estimates prior to the implementation of LA Creel. The LA Creel survey characterizes recreational fisheries with greater resolution, greatly improves the monitoring capabilities within coastal Louisiana fisheries, and

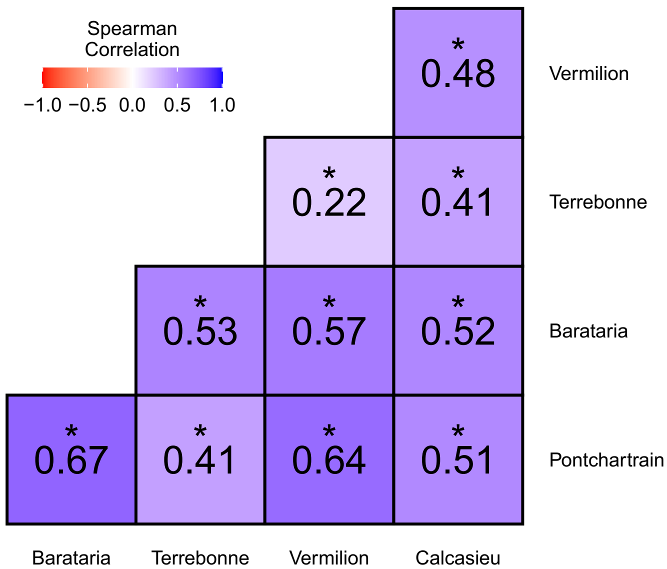

FIGURE 7. Correlation matrix of weekly recreational model predictions for Southern Flounder within each Louisiana coastal management zone. Significant relationships ($P < 0.05$) are indicated by an asterisk.

allows for real-time and impactful management decisions to be made in preserving the future of significant recreational fisheries.

The framework offered by a GAM statistical approach provided a significant strength in our evaluation. While other approaches were considered, particularly tree-based machine learning approaches and generalized linear models, the GAM approach was identified as the strongest statistical fit for our evaluation. The flexibility offered by a semi-parametric approach with the ability to provide data-driven response curves (Yee and Mitchell 1991) led to our decision to use a GAM over a generalized linear model. The simplicity offered by fitting the most parsimonious model (rather than risking overfitting with several models; Carvalho et al. 2018) and the improved accuracy in modeling smooth functions (Elith et al. 2008) led to our decision to use a GAM over a tree-based machine learning approach. The GAMs were identified as the best statistical tool for this investigation, with the ability to provide data-driven response curves of highly nonlinear and nonmonotonic relationships (Yee and Mitchell 1991; Wood 2006), the capacity to account for serial correlation (Wood 2006), and the flexibility to model data in a variety of statistical distributions (Guisan et al. 2002).

Future of the Fishery

The decline in landings of Southern Flounder in Louisiana may be the result of various drivers or the interactions among multiple drivers, including changing angler behavior or a decline in stock size, among other possibilities. Angler behavior, in terms of the number of angling trips, has not significantly changed during the LA Creel period within the Pontchartrain Zone or Terrebonne Zone; however, the Barataria, Vermilion, and Calcasieu zones all displayed significant changes in effort over this period. Effort within the Barataria Zone has increased, while effort in the Vermilion and Calcasieu zones has declined. These outcomes may have a significant effect on Southern Flounder landings, specifically within the Calcasieu Zone, as this coastal zone has the strongest influence on statewide landings. The Calcasieu Zone effort declined in mean weekly trip estimates from 7,104 trips in 2014 to 5,753 trips in 2019. Since 2017, the target species from each dockside intercept interview has been recorded by the LA Creel survey. The annual percentage of anglers targeting Southern Flounder in coastal Louisiana has remained relatively low from 2017 to 2020, annually ranging between 1.4% and 1.6% statewide. However, these percentages varied seasonally and spatially, particularly within the Calcasieu Zone and during the month of November. During November within the Calcasieu Zone, the percentage of anglers targeting Southern Flounder was 21.9% from 2017 to 2020. This percentage is a substantial increase from all other months during that period, which averaged 4.0%. Moderate increases in the percentage of anglers targeting Southern Flounder were exhibited in other coastal zones during November; however, those increases were negligible in comparison to the increases in the Calcasieu Zone. The substantial increase in targeting behavior during the month of November is likely a significant factor in the Calcasieu Zone's influence on statewide landings. Continued monitoring of Louisiana angling behaviors is necessary to precisely determine whether changes in angler behavior are driving fluctuations in Southern Flounder landings.

With estimates of recruitment and stock size for Louisiana Southern Flounder reaching the lowest levels recorded (West et al. 2020), it appears that the reduction in landings of Southern Flounder in Louisiana is related to a corresponding decline in stock size. Moreover, an important factor to consider when evaluating trends in fishery-dependent data is that declines in stock size may be masked by hyperstability. There are numerous examples of fisheries in which hyperstability has concealed declines among fish stocks that exhibit aggregating behaviors (Erisman et al. 2011; Sadovy de Mitcheson and Erisman 2012; Dassow et al. 2020). The aggregating behavior of Southern Flounder during the fall migration (GSMFC 2015) leads to increased vulnerability of the stock as Southern Flounder move through coastal bottlenecks to reach spawning grounds. The fact that statewide recreational estimates of the Louisiana Southern Flounder fishery currently depict a decline in landings is a meaningful indicator of potential overfishing and a depleted stock that warrants management attention.

Considering this species' marked decline, attributes of the Louisiana Southern Flounder recreational fishery demonstrated by the findings of this study can provide insight into future management strategies. The reduction of spawning stock size can significantly impact Southern Flounder populations during the fall migration and has resulted in seasonal restrictions applied to Southern Flounder recreational fisheries throughout much of their range. Our findings indicate that a seasonal restriction during the fall migration would likely produce a reduction in Southern Flounder harvest, an action that may be necessary for the recovery of this declining stock. All coastal zones indicated positively correlated time series, and strong similarities existed within the seasonal trends produced in each coastal zone, displaying the converging attributes of each zone. Moreover, the estuarine fidelity that Southern Flounder exhibit as they return to coastal Louisiana is unknown and future research is necessary to examine the level of connectivity among Louisiana coastal zones as well as the connectivity across state boundaries. For these reasons, the management of Southern Flounder in Louisiana would likely benefit from a statewide strategy rather than a region-specific approach.

With Southern Flounder declines occurring throughout the species' range, extending across multiple jurisdictional boundaries in which various regulatory strategies exist, there is a high capacity for a universal driver of the decline. Southern Flounder are susceptible to the effects of a changing climate, as this species exhibits environmental sex determination in which suboptimal water temperatures during larval development can lead to increased ratios of phenotypic males (Luckenbach et al. 2009; Honeycutt et al. 2019). Additionally, laboratory studies have shown that warming water temperatures significantly affect the success of hatching and larval development of Southern Flounder (van Maaren and Daniels 2001). As documented water temperatures have risen over the past few decades within the same locations and times that Southern Flounder develop after hatching (Erickson et al. 2021), the role that climate has played as a driver of stock size in Louisiana is likely to be significant. While future management strategies have the potential to help mitigate further declines in Louisiana Southern Flounder stock size, it is important to note that reduced exploitation may not have the potential to fully recover the stock considering the role that climate will continue to play in this species' decline.

Recreational fisheries are dynamic systems that provide numerous management challenges as changes occur in climate, environment, and culture (Elmer et al. 2017; Brownscombe et al. 2019; Holder et al. 2020). The approaching difficulties of managing recreational fisheries that will be heavily influenced by these changes underscore the importance of filling the information gap that exists between human dimensions studies and recreational fisheries (Hunt et al. 2013). One way in which managers can more closely understand the behaviors of anglers is through an evaluation of fishery-dependent data. Fishery-dependent data provide insights into fisheries that are often underutilized yet commonly collected by management agencies. When management action is required, understanding the various components of recreational fishery harvest can aid in making a management decision that not only is biologically sound, but also makes a meaningful impact in preserving the benefits that fisheries provide to anglers.

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ORCID

Stephen R. Midway https://orcid.org/0000-0003-0162-1995

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