ASSESSING THE EFFECTS OF FRESHWATER INFLOWS AND OTHER KEY DRIVERS ON THE POPULATION DYNAMICS OF BLUE CRAB AND WHITE SHRIMP USING A MULTIVARIATE TIME-SERIES MODELING FRAMEWORK: PHASE 2

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PURSUANT TO HOUSE BILL 1 AS APPROVED BY THE 84RD TEXAS LEGISLATURE, THIS STUDY REPORT WAS FUNDED FOR THE PURPOSE OF STUDYING ENVIRONMENTAL FLOW NEEDS FOR TEXAS RIVERS AND ESTUARIES AS PART OF THE ADAPTIVE MANAGEMENT PHASE OF THE SENATE BILL 3 PROCESS FOR ENVIRONMENTAL FLOWS ESTABLISHED BY THE 80TH TEXAS LEGISLATURE. THE VIEWS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE AUTHOR(S) AND DO NOT NECESSARILY REFLECT THE VIEWS OF THE TEXAS WATER DEVELOPMENT BOARD.

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1.0.0 PROJECT OVERVIEW

This project is a continuation of the Phase 1 effort (conducted in the previous biennium, fiscal years 2014-2015) that used the Texas Parks and Wildlife Department (TPWD) Coastal Fisheries monitoring data and a multivariate autoregressive (MAR) modeling framework to verify that the effects of freshwater inflows on blue crab (*Callinectes sapidus*) and white shrimp (*Litopenaeus setiferus*) abundances must be assessed in conjunction with other drivers and at time lags of up to two years.

MAR models have proven to be useful tools to evaluate drivers of species abundances in systems where there are many potentially interacting variables with potentially lagged and confounding effects (Hampton et al. 2013). MAR analysis uses long-term monitoring data to estimate the directions and strengths of interactions among species and environmental factors within a community, therefore the use of this model is limited to cases in which such time-series data are available. Several state and federal long-term monitoring programs that are maintained along the Texas coast have generated datasets that fit the criteria for potential analysis with MAR models.

Phase 1 of this project used the MAR framework with TPWD Coastal Fisheries monitoring data from the Mission-Aransas and Guadalupe estuaries to assess potential drivers of the abundances of two identified key species, blue crab and white shrimp (Buskey et al. 2015). Due to the short duration of the project, variability in the TPWD dataset was managed by averaging values over relatively large spatial and temporal scales, and a limited number of temporal increments and model configurations were examined. The time-series used in the models were averaged into 1 year, 6 month, and 1 month increments, and effects of potential drivers were tested for at lags of 0, 1, and 2 time-steps for each of the averaged datasets. However, the Texas Commission on Environmental Quality (TCEQ) establishes environmental flow standards for surface water within three-month increments defined as winter (January-March), spring (April-June), summer (July-September), and fall (October-December).

Although the results of Phase 1 were informative in pointing to specific lagged effects of drivers on blue crab and white shrimp abundances, results from models run on time-series divided into the seasonal increments used by TCEQ to set instream flow standards could be more readily used to inform freshwater flow management decisions. In addition, further refinement of the variability in the datasets and the extension of the length of the time-series since the completion of Phase 1 of the project better allow for these finer temporal increments to be modeled.

The goal of Phase 2 was to refine the models developed during the previous study to improve their utility in informing freshwater inflow recommendations. Specifically, this project aimed to:

1. Update the datasets used in the original models with 2014-2015 data and rerun the models to verify the previous results.

2. Reformat the datasets from the seasonal divisions used in the original study to reflect the seasonal divisions used in the Texas Commission on Environmental Quality (TCEQ) instream flow standards.
3. Generate MAR models using the new seasonal divisions.
4. Attempt to identify whether conditions during particular seasons are more influential on overall focal species abundances.
5. Modify the analysis so that trends in focal species abundances can be estimated as a function of different hypothetical freshwater inflow conditions.

Coefficients and R^2 values were very similar between the original and updated MAR models, verifying that the extension of the time-series did not modify the species interaction patterns detected in the original study. It could therefore be expected that similar patterns would emerge from MAR models of the seasonally divided time-series.

Monthly time-series for all variables used in the final models of the Phase 1 project were averaged into 3-month seasonal increments: January-March (winter), April-June (spring), July-September (summer), and October-December (fall). Using the MAR model structure to analyse these seasonal time-series presented several challenges, and ultimately the model was simplified to a linear autoregressive formulation. The final models included the TPWD trawl gear blue crab and white shrimp abundance time-series as dependent variables, and each season up to a 2-year lag of water temperature (TPWD) and river discharge (U.S. Geological Survey) as predictor variables.

Estimated abundance time-series calculated from the final model coefficients explained 52% of the variability in the measured blue crab time-series and 51% of the variability in the white shrimp time-series. The coefficient values from the models and abundance time-series estimated from averaged water temperature or river discharge time-series indicated that trends in blue crab abundance were primarily driven by water temperature, while trends in white shrimp abundance were primarily driven by river discharge.

Results from estimating blue crab and white shrimp abundance after either increasing water temperature by 1°C or decreasing river discharge by 25% for each season over the entire time-series were used to determine how conditions in specific seasons affected the overall abundance of each species. Increased water temperatures in summer negatively affected both blue crab and white shrimp. Blue crab were also negatively impacted by increases in temperature in all other seasons, while white shrimp had either positive or no responses to temperature increases in the other seasons. A decrease in winter river discharge had a negative effect on blue crab abundance, but decreased discharge in the other seasons did not affect their abundance. White shrimp showed a positive response to decreased winter discharge, but negative responses to decreased discharge in all other seasons.

The method used in this study to estimate species abundance trends resulting from simple manipulations of the seasonal river discharge time-series can be used to evaluate species responses to more complex hypothetical discharge scenarios.

2.0.0 Background

2.1.0 Texas Parks and Wildlife Department coastal monitoring data

The Texas Parks and Wildlife Department (TPWD) Coastal Fisheries monitoring program maintains a valuable long-term record of the abundances of hundreds of fish and invertebrate species that inhabit Texas coastal waters. Species samples are collected using gill nets, otter trawls, and bag seines, and counts of captured individuals are converted to catch per unit effort (CPUE) as a measure of abundance. Basic water quality parameters, such as temperature and salinity, are recorded in conjunction with each sample. For Copano and Aransas bays in the Mission-Aransas Estuary and San Antonio and Espiritu Santo bays in the Guadalupe Estuary, species abundance data for blue crab (*Callinectes sapidus*) and white shrimp (*Litopenaeus setiferus*) are available starting in the late 70s and early 80s. For these key species, the trawl net time-series is considered particularly useful for examining long-term trends because this gear type samples a calculable volume of water at sites throughout the bays rather than passively sampling or only sampling near shore (e.g., Ward 2012).

2.2.0 Previous studies

Several previous studies have used the TPWD time-series to investigate possible connections between blue crab and white shrimp abundances and freshwater inflows in the Mission-Aransas and Guadalupe estuaries. For white shrimp, the trends in the time-series indicate a strong positive connection between their abundance and freshwater inputs. By dividing the bays into areas of 5 ppt average salinity increments for months of peak species abundance, TPWD found strong spatial relationships between white shrimp abundance and these calculated salinity zones in San Antonio Bay (TPWD 1998) and Copano and Aransas bays (TPWD 2010) using the TPWD dataset. Since white shrimp are physiologically tolerant to a wide range of salinities, it has been suggested that the apparent relationship between shrimp abundance and salinity is due to an underlying correlation between salinity and habitat structure such as vegetation (e.g., Howe et al. 1999). However, an analysis of the TPWD dataset by the Guadalupe-San Antonio Basin and Bay Expert Science Team (GSA BBEST 2011), which related spatial and temporal white shrimp abundance to different freshwater inflow regimes, indicated that shrimp do indeed tend to select fresher habitats throughout San Antonio Bay under different inflow regimes. There may therefore be additional factors covarying with salinity that affect the distribution of white shrimp.

Direct temporal correlations between blue crab abundance and freshwater inflows have been less apparent. Ward (2012) examined the TPWD otter trawl data for San Antonio Bay and found that neither the individual sampling values nor the monthly averages of the data showed any correlations between blue crab abundances and salinity values. Correlations between monthly averaged crab abundance and monthly averaged freshwater inflow at lags up to one year were also relatively poor. The San Antonio Guadalupe Estuarine System project modeled blue crab abundance based on data collected in the Aransas National Wildlife Refuge (Slack et al. 2009). A linear mixed effects model was found to adequately explain short-term variance in juvenile blue crab abundance in shallow water, but salinity was a minor component of the model relative to other variables such as habitat type and structural complexity.

Generalized relationships between freshwater inflows and blue crab abundance have been found with coarser-scale analyses of the TPWD data. In their final Environmental Flows Recommendations Report, the GSA BBEST (2011) reviewed a study by TPWD in which a probabilistic analysis of blue crab abundance in relation to freshwater inflows was conducted. This analysis revealed that the probability of exceeding the mean catch per unit effort (CPUE) increases with increasing freshwater inflows. The TPWD (1998) study that found strong spatial correlations between white shrimp and calculated salinity zones reported very similar results for blue crab. Hamlin (2005) also found that higher blue crab CPUE in the Guadalupe Estuary was associated with calculated zones of lower salinity, which shifted spatially depending on inflow regime. Therefore, despite the elusiveness of any direct correlation, it appears that blue crab are impacted by some aspect of freshwater inflow or perhaps a combination of covarying drivers.

2.3.0 Phase 1 summary

During Phase 1 of this project, completed in August 2015, data from the Texas Parks and Wildlife Department (TPWD) Coastal Fisheries monitoring program, U.S. Geological Survey (USGS) flow gage stations, and several other sources were acquired for 1982–2013 and analysed using multivariate autoregressive (MAR) models to assess the effects of various predators and environmental parameters on blue crab and white shrimp abundances in the Mission-Aransas and Guadalupe estuaries (Buskey et al. 2015).

Potential predictor variables of blue crab and white shrimp (focal species) abundances were selected for inclusion in preliminary models based on their identification as drivers in previous studies, the quality of data available, and their correlations with one another (Table 2-1). Species abundance time-series and river discharge values were log transformed, and the time-series for all variables included in the models were z-scored to have means of 0 and standard deviations of 1. Coefficients resulting from MAR analysis of these z-scored values could then be interpreted as the strengths and directions of interactions between model variables and directly compared to one another without additional scaling. Final model configurations were selected by removing predictor variables that exhibited weak or ecologically implausible interactions in preliminary models until more simplified and predominantly ecologically feasible models were produced. The time-series for the variables included in the final MAR models were averaged into 1 year, 6 month, and 1 month increments and models were run at lags of 0, 1, and 2 time-steps.

Table 2-1 List of variables included in Phase 1 blue crab and white shrimp MAR models. All variables were considered in preliminary models. Variables retained in final models are in black.

	Blue Crab Model Variables	**White Shrimp Model Variables**
Focal Species Abundances	Blue crab gill Blue crab trawl Blue crab seine	White shrimp trawl White shrimp seine
Predator Species Abundances (gill net)	Red drum Black drum Spotted seatrout Sheepshead Gafftopsail catfish Ladyfish	Spotted seatrout Gafftopsail catfish Hardhead catfish Southern flounder
Commercial Catch Data	Crab catch	Shrimp catch
Water Quality (trawl)	Salinity Temperature Dissolved oxygen Turbidity	Salinity Temperature Dissolved oxygen Turbidity
Climate	River discharge North wind prevalence	River discharge North wind prevalence

For blue crab, negative effects of predator fish species (Table 2-1), temperature, and salinity were present in all lag 0 models. Since blue crabs have an approximate life span of up to 2 years, the monthly time increment was too short to effectively detect the effects of drivers on crab abundance at lags greater than 0. For the yearly and 6 month divisions, however, positive effects of river discharge were seen at lags of both 1 and 2 time-steps.

For white shrimp, strong negative effects of salinity dominated all lag 0 and monthly temporal increment models. Negative effects of predators and positive effects of river discharge were seen at lags of 1 and 2 for the 6 month averaged time-series and at a lag of 1 for the yearly time-series.

Overall, the models detected significant lagged effects of predators (Table 2-1), water temperature, salinity, and river discharge on the abundances of both blue crab and white shrimp, indicating that the effects of freshwater inflows on focal species abundances must be assessed in conjunction with other drivers and at time lags of up to two years.

3.0.0 Methods

3.1.0 Data acquisition and preparation

The final multivariate autoregressive (MAR) models from the Phase 1 portion of the project included data from the Texas Parks and Wildlife Department (TPWD) Coastal Fisheries monitoring program and from U.S. Geological Survey (USGS) flow gage stations for the time period of 1982-2013. The TPWD and USGS datasets used in the original sets of models were updated with 2014-2015 data to yield a 34-year time-series. Species count data and water quality parameter measurements were acquired through email contact with TPWD, and USGS flow gage station discharge values were downloaded from https://waterdata.usgs.gov.

To prepare the data for analysis, the raw, newly acquired data were merged with the raw datasets from the original study to create complete time-series spanning 1982-2015. The species abundance survey data provided by TPWD included catch per unit effort (CPUE) values for gill net samples, but the values for the otter trawl and seine net samples were raw counts of the number of each species caught in each sample. To calculate CPUE, the trawl values were divided by the tow time (in hours) for each sample, and the seine values were divided by the area swept by the gear (in hectares) for each sample. All samples taken in Aransas Bay, Copano Bay, San Antonio Bay (including Hynes Bay), and Espiritu Santo Bay were extracted from the datasets, thereby excluding samples taken in small, shallow bays and lakes that were not consistently sampled from month to month due to the randomized spatial sampling scheme of the survey program. A time-series of monthly mean CPUE values within each bay was calculated for all species included in the original MAR models. The salinity and water temperature (°C) measurements taken with the trawl samples were aggregated into corresponding monthly time-series.

River discharge data downloaded from the USGS website contained daily mean river discharge values in cubic feet per second. Stations to extract data from were selected based on their downstream proximity to the Mission-Aransas and Guadalupe estuaries and whether their temporal coverage corresponded to that of the TPWD time-series. Data from the Aransas River near Skidmore (08189700), Mission River at Refugio (08189500), and Copano Creek near Refugio (08189200) gage stations were summed to approximate discharge to the Mission-Aransas Estuary. Data from the Guadalupe River at Victoria (08176500) and San Antonio River at Goliad (08188500) gage stations were summed to approximate discharge to the Guadalupe Estuary.

Although the Guadalupe River near Tivoli (08188800) gage station is much closer to the Guadalupe Estuary than the Victoria and Goliad stations and would provide a more accurate approximation of flows into the estuary, the discharge measurement time-series from this station begins in 2000 and therefore only overlaps about half of the TPWD species abundance time-series. A comparison of the logged seasonal time-series between the summed Victoria and Goliad station discharge and the Tivoli station discharge indicates that mean logged discharge at Tivoli is 4% lower than the mean logged discharge at the Victoria/Goliad stations, primarily due to diminished pulse flows at the downstream station. Most notably, mean discharge values from 3,000-11,700 cubic feet per second in the Victoria/Goliad time-series are reflected in the Tivoli time-series at or near a maximum value of 3,000 cubic feet per second. Despite these differences, there is a strong correlation between the two discharge time-series (Pearson's product-moment correlation 0.94, $p<0.001$), which indicates that the summed discharge from the Victoria/Goliad stations should approximate flow into the Guadalupe Estuary nearly as well as discharge measurements from the Tivoli station further downstream.

3.2.0 Re-run original MAR models

MAR models with the same temporal divisions, time lags, and variables selected for the final models in the original study (Buskey et al. 2015) were run using the updated time-series to verify that the major relationships identified by the original models did not change with the addition of new data. For each set of models, all data were averaged into either 1 year, 6 month, or 1 month time-steps. Focal and predator species abundance values (Table 2-1) and river discharge values were log-transformed to more closely conform to a normal distribution. The time-series for all model variables were then z-scored to have a means of 0 and a standard deviations of 1. For the yearly time-series, this was done for each variable by subtracting its overall mean for the time-series from each value, then dividing by its overall standard deviation for the time-series. For the 6 month and 1 month time-series, this was done by subtracting the overall mean for the corresponding 6 or 1 month division from each value, then dividing by the overall standard deviation for the corresponding division. For example, the z-score for a February value would be calculated by subtracting the mean of all February values in the time-series and dividing by the standard deviation of all the February values. This method of standardization removes seasonal signals from the time-series and thereby prevents seasonal successions from being interpreted as interactions within the MAR models.

The MAR model described by Ives et al. (2003) can be thought of as a series of regression equations with each equation describing the abundance of one of the species included in the model. Within each equation, the abundance value for a species at a specific time-step is predicted by its abundance value at the previous time-step plus or minus the influences of other species (variates) and environmental factors (covariates) included in the model. In the matrix formulation, $\mathbf{X}_t$ is a vector of abundance values at time t for the species included in the model, $\mathbf{A}$ is a vector in intrinsic productivities, $\mathbf{X}_{t\text{-}1}$ is a vector of abundance values for each species at time t-1, $\mathbf{U}_{t\text{-}1}$ is a vector of values at time t-1 for the environmental factors included in the model, and $\mathbf{E}$ is a vector of process errors. $\mathbf{B}$ and $\mathbf{C}$ are matrices of coefficients that represent the influence of each species and environmental factor, respectively, on the abundances of the species in the model.

$$\boldsymbol{X}_t = \boldsymbol{A} + \boldsymbol{B}\boldsymbol{X}_{t-1} + \boldsymbol{C}\boldsymbol{U}_{t-1} + \boldsymbol{E}_t$$

Models were run in R using the code submitted with the Phase 1 study report (Buskey et al. 2015). This code consists of modified functions from the MAR1 R package (Scheef 2013) that enable the

MAR models to assess potential lag 0 and 2 interactions between variables in addition to lag 1 interactions.

As in previous ecological studies that have used MAR analysis (e.g., Hampton et al. 2008), the 95% confidence bounds for each coefficient in the best-fit models produced by the analysis were estimated through bootstrapping (n=500), and only coefficients with confidence bounds not overlapping 0 were retained. The coefficients retained in the bootstrapped models were then compared between models run with the original data and models run with the updated data.

3.3.0 Reformat data into seasonal increments

To divide the focal species, predator, and environmental variable time-series into the winter, spring, summer, and fall increments defined by Texas Commission on Environmental Quality (TCEQ) environmental flow standards, the data were first averaged into monthly time-steps.

All variables included values for every month of each year except for the gill net-sampled blue crab and predator fish species. Gill net samples are only taken during the spring and fall each year, so dividing the data into 4 time-steps per year would leave winter and summer gaps in the time-series for species sampled with this gear type. Time-steps with missing values are omitted during model calculations, so the missing predator values would make it impossible to determine, for example, how winter conditions affect blue crab abundance in the spring. To attempt to include the gill net-sampled species in the seasonal models, their abundances for all months were estimated by fitting a cubic smoothing spline to the spring and fall sample abundances. Ultimately, however, these estimated species abundance values were not used in the final models and are therefore not relevant to the results presented in this report (see section 3.4.2).

The monthly time-series for each variable to be included in the models was then averaged into 3-month time-steps: January-March (winter), April-June (spring), July-September (summer), and October-December (fall).

3.4.0 Seasonal models

3.4.1 Challenges

The purpose of using the 3-month seasonal time-steps in the MAR models was to determine the effects of conditions during each individual season on focal species abundances. One of the challenges to running the MAR models with the seasonally divided time-series was that the original code estimated the coefficients for each species in the model by shifting its time-series backward one time-step relative to the time-series for all of the other variables included in the model. If the seasonal time-series are left intact such that all seasons are included in the same sequence (i.e., a repeating sequence of winter, spring, summer, and fall values), then shifting the time-series of a species backward relative to the other variables in the model will result in coefficient estimates that pool the effects of all seasons on its abundance during all corresponding lagged seasons. In other words, it is not possible to separate out the effects of individual seasons with this method.

An alternative method that still allows for the use of the original code is to separate the time-series for each variable into 4 time-series: 1 for each season. One issue with this method is that using all 4 time-series for each variable in the same MAR analysis results in a very large number of model parameters. For example, the original blue crab models included the 3 different gear type time-series for blue crab, 3 potential predator species, and 3 environmental variables, resulting in 9 total time-series and 54 potential coefficients to be estimated in the 6×6 **B** and 6×3 **C** matrices. If the data for each of these variables were divided into 4 time-series, there would be 36 total time-series in the model and 864 potential coefficients to be estimated. Another issue is that there is no straightforward way to set up the input data such that lagging one time-series would align it with the appropriate sequence of preceding seasons.

An attempt was made to run a series of MAR models in which each possible pair of seasons were analysed individually, with the set of variables for one season designated as predictors and the set for the other season designated as response variables. For example, a set of models was run to determine the effects of conditions during winter, spring, summer, and fall, individually, on the abundances of species in the winter, and another set was run to determine the effects of each individual season on species abundances in the spring, etc. These models were run for all lags up to 2 years, resulting in 48 separate models for each focal species. The results of these models were somewhat informative, in that large coefficients in some models pointed to strong effects of certain variables during specific seasons and lags, and some models had much better fits (higher R^2 values) than others, which indicated that conditions during specific seasons were generally important. However, because the coefficients were spread between many different models with varying fits, it was difficult to make direct comparisons between them and draw specific conclusions about which variables, seasons, and lags had the strongest effects on blue crab and white shrimp abundances.

To make direct comparisons between the effects of variables during different seasons and lags on focal species abundances, it is therefore necessary to include the values for all variables in all seasons at all lags in the same model. As discussed above, this is not possible with the MAR code used in Phase 1 of this study. In addition, the ultimate goal of this analysis was to provide a model that can estimate focal species abundance trends by using different freshwater inflow time-series as input. Several features of the original analysis, such as the z-scoring of the data and the inclusion of multiple interacting variables potentially affected by freshwater inputs, presented challenges to accomplishing this objective. Therefore, to accomplish the goals of this Phase 2 study, it was necessary to restructure the analysis used in Phase 1.

3.4.2 Revised methods

To include potential influences of all variables within all seasons at all lags, it was necessary to simplify the structure of the MAR model used during Phase 1 of the study. The model in Phase 1 produced an interaction matrix representing the influences of all species in the model on one another. Since we are primarily interested in drivers of focal species abundances, we first eliminated the portions of the model assessing drivers of non-focal species (i.e., the predator species) abundances.

The model structure was further simplified by focusing on the otter trawl gear time-series for the focal species abundance estimates and omitting the gill net and bag seine time-series for blue crab and the bag seine time-series for white shrimp. Several considerations led to the decision to omit the gill and seine data: 1) Preliminary models for the seine time-series of both focal species had very poor fits (low R^2 values), as was the case for the final models in the Phase 1 study (see section 4.2.0, Figures 4-7 and 4-8). 2) As discussed above, the gill net time-series for blue crab contained estimated values for 2 of the 4 seasons, so omitting this time-series prevented the use estimated abundance values in the final models. 3) Samples for the gill net and bag seine gear types were only collected along shorelines, so data from these gears would be expected to be less representative of abundances throughout the bays than the trawl gear data. 4) The otter trawl selectively samples for larger blue crab (1^{st}-3^{rd} quartile range ~45-99 mm) and white shrimp (~81-107 mm) than the bag seine (~18-38 mm for blue crab and ~42-69 mm for white shrimp). Assuming larger individuals are usually older, the lagged effects of previous conditions should be better reflected by abundances based on trawl samples than abundances based on seine samples. Therefore, the trawl data were considered the most appropriate estimates of seasonal focal species abundances for the models in this study.

Eliminating the parts of the original model that addressed drivers of non-focal species abundances and omitting the gill and seine focal species data shifted the original model structure from a matrix formulation to independent linear models of the trawl abundances of each focal species. In other words, the trawl abundance time-series for each species was the only response variable left in the model formula. Since the coefficients in these models no longer represented interactions between species that needed to be directly comparable to one another, it was no longer necessary to z-score the time-series prior to analysis. Using non-z-scored data in these models makes the results easier to interpret and facilitates comparisons to models estimated in other studies.

Although the response variables were reduced to a single time-series for each focal species, the number of predictor variables in the models for each species was still very large (73 for blue crab, 49 for white shrimp) due to all of the time-series being split by season. In addition, several of the predictor variables, including salinity and predator species abundances, are also affected by freshwater inflows. This means that to include these variables as predictors of focal species abundances in the final models with varying freshwater input scenarios, their values would have to be estimated as a function of freshwater inflows as well. Such estimations would introduce increased error and cross-correlations into these final models, and preliminary analyses revealed that removing the effects of these variables did not greatly reduce model fits (decreases in R^2 values were less than 0.05). Therefore, predator species and salinity were omitted as predictor variables.

The omission of gill net, bag seine, predator species, and salinity time-series from the analysis resulted in relatively simplified structures for the blue crab and white shrimp models, with 25 potential coefficient estimates within each blue crab model and 17 potential coefficient estimates within each white shrimp model. For blue crab, the trawl sample abundance for each season was estimated as a function of blue crab trawl abundance during the preceding season, temperature for each season at lags of 0, 1, and 2 years, and river discharge for each season at lags of 0, 1, and 2 years. White shrimp trawl sample abundance was estimated the same way, except since the white shrimp life cycle takes place within the span of a single year, lags greater than 1 year were not included. White shrimp abundance for each season was therefore estimated as a function of its abundance during the preceding season, temperature for each season at lags of 0 and 1 years, and river discharge for each season at lags of 0 and 1 years. Cross-correlations between the seasonal time-series for the 2 remaining environmental variables included in these models, water temperature and river discharge, were minimal (Pearson's correlation coefficients <0.1) and not significant at any lag up to 2 years ($p>0.05$).

Data from Espiritu Santo Bay were included in the original models, but correlations between this bay and Aransas, Copano, and San Antonio bays for many measured parameters were low relative to correlations between the latter three bays (Table 3-1). These mismatched correlations indicate that conditions in Espiritu Santo Bay are not well-aligned with the rest of the system, possibly due to southward water flow tending to isolate this northernmost bay from the rest of the estuary (GSA BBEST 2011). Inclusion of data from this bay in the new models could therefore obscure relationships, so it was decided to omit data from this bay from the analysis.

Table 3-1 Pearson correlation coefficients between bays for seasonally averaged time-series of parameters measured during TPWD trawl surveys.

Parameter	**Bay Correlations**			
		Copano	San Antonio	Espiritu Santo
ln Blue crab abundance	Aransas	0.78	0.64	0.44
	Copano	-	0.66	0.35
	San Antonio	-	-	0.59
ln White shrimp abundance	Aransas	0.71	0.63	0.62
	Copano	-	0.74	0.54
	San Antonio	-	-	0.63
Water temperature	Aransas	0.99	0.99	0.97
	Copano	-	0.99	0.97
	San Antonio	-	-	0.98
Salinity	Aransas	0.86	0.77	0.66
	Copano	-	0.85	0.67
	San Antonio	-	-	0.84

Best-fit models were selected by conducting an exhaustive search of possible model configurations and using the Bayesian Information Criterion (BIC) as an assessment of model complexity versus fit. Although the Akaike Information Criterion (AIC) is commonly used for model selection, it imposes a smaller penalty for model complexity than BIC, which, in this analysis, resulted in larger model structures with seemingly redundant terms that did not greatly improve model fit and made the results more difficult to interpret than the models selected with BIC.

All data and R code used to compose the final models were annotated and submitted with this report.

3.5.0 Model input time-series manipulation

The final best-fit models were used to calculate hypothetical focal species time-series by altering the predictor variable time-series. This was done in two ways to assess: a) the relative influence of each predictor variable on focal species abundance trends, and b) how focal species abundances might be affected if the mean values of the predictor variables change in the future.

To determine the relative influences of river discharge and water temperature on the abundance trends of each focal species, the final models were used to calculate new species abundance time-series for runs where one of the predictor variables was set to its seasonal averages and the other variable remained unaltered. For example, to examine the effects of river discharge on blue crab abundance, each value in the water temperature time-series was set to its overall seasonal average, and a new blue crab time-series was calculated based on the original discharge input and the averaged water temperature input. By replacing the temperature time-series with average values, any non-seasonal temporal trends in temperature were removed, and therefore any non-seasonal trends in the newly calculated species abundance time-series can be attributed solely to temporal variability in river discharge. How well each newly calculated species abundance time-series matches up with the original estimated abundance time-series can then be compared to determine the relative influence of each predictor variable on species abundance trends.

How focal species abundances might change in response to future water temperature increases or river discharge decreases is of interest in the context of climate and land use change. To determine the effects of temperature increase, separate models were run with a 1°C temperature increase for each individual season. For river discharge, individual models were run for a 25% decrease in discharge in each season. This method not only allows for an assessment of how changes in each variable affect species abundance overall, but also provides a measure of how the importance of the variable differs between seasons.

4.0.0 ANALYSIS AND RESULTS

4.1.0 Updated data

Data used in the final models of the Phase 1 study included time-series of focal and predator species abundances as well as temperature, salinity, and river discharge that spanned 1982–2013. The Texas Parks and Wildlife Department (TPWD) Costal Fisheries monitoring program was the source for the species abundance data and water quality data, and river discharge data were derived from U.S. Geological Survey (USGS) flow gage station measurements. Below are plots of these time-series updated with 2014-2015 values. General temporal trends as well as multivariate autoregressive (MAR) model results generated from these updated data are similar to those seen in the results of the Phase 1 study.

4.1.1 Focal Species

Overall temporal trends for blue crab and white shrimp were not greatly affected by the addition of the new data (Figure 4-1). Generally, decreasing trends persisted in the blue crab time-series, and no increasing or decreasing trends emerged in the white shrimp time-series. For the 2014-2015 time period, blue crab abundance estimates were below the overall average during 2014, and, with the exception of blue crab in the otter trawl samples, values were above average during 2015. For white shrimp, trawl sample estimates were below average in 2014 and slightly above average in 2015, and seine sample estimates were above average for both years.

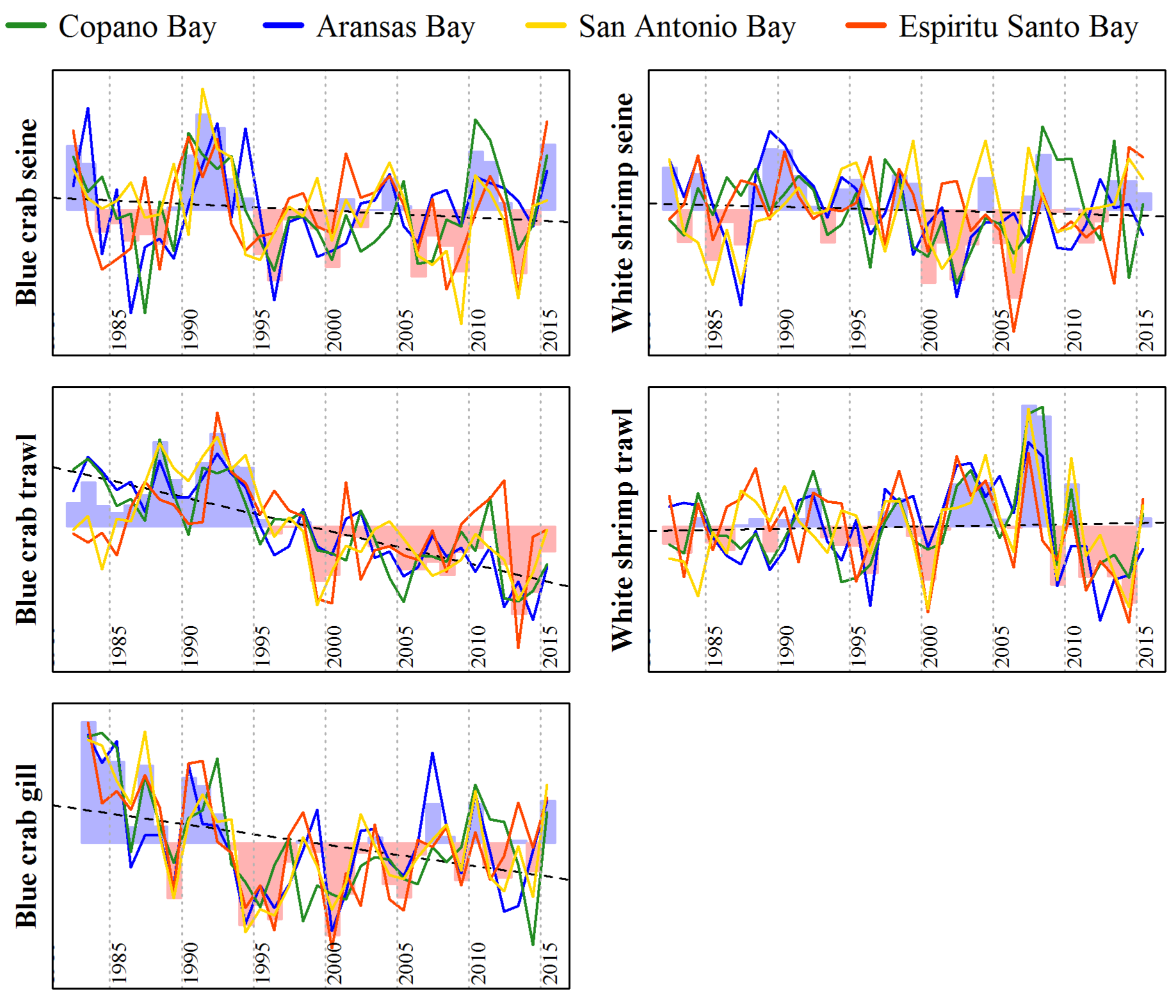

Figure 4-1 Updated focal species abundance trends (z-scored yearly means) for blue crab seine, trawl, and gill samples and white shrimp seine and trawl samples. Lines represent mean abundances for Copano (green), Aransas (blue), San Antonio (yellow), and Espiritu Santo (red) bays. Yearly means across all four bays are represented by bars colored to indicate whether values fall above (blue) or below (red) the overall mean for the time-series. Regression lines for the bay-averaged time-series are shown as black dotted lines.

4.1.2 Predator Species

Overall, increasing abundance trends continue to be seen for all of the selected predators, with the exception of southern flounder, which demonstrates a decreasing trend (Figure 4-2). Red drum abundance estimates were consistently below average for 2014-2015, extending a sequence of below average abundance values at the end of the time-series to 4 years. After a 7 year period of above average abundances starting in 2008, black drum abundance fell below average in 2015. Spotted seatrout abundance estimates were slightly above average in 2014 and slightly below average in 2015. Southern flounder abundance was below average in 2014 and above average in 2015, making 2015 one of only 3 years of above average abundance since 2005.

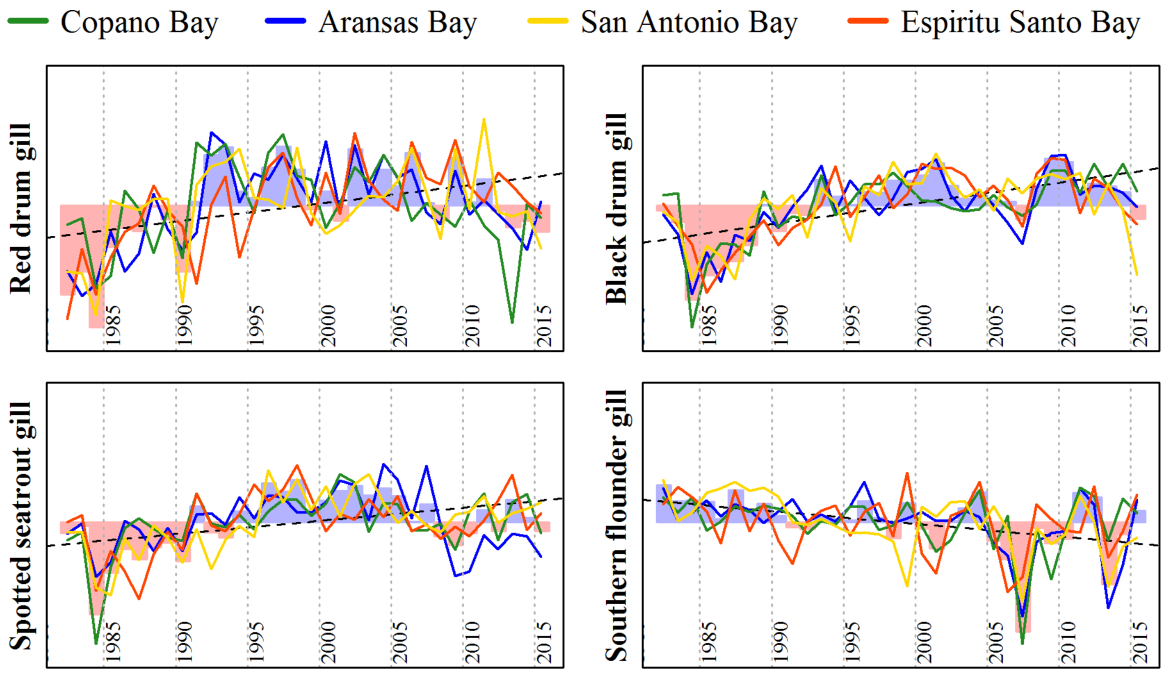

Figure 4-2 Updated abundance trends (z-scored yearly means) for predator species included in final MAR models in Phase 1 of the project. Lines represent mean abundances for Copano (green), Aransas (blue), San Antonio (yellow), and Espiritu Santo (red) bays. Yearly means across all four bays are represented by bars colored to indicate whether values fall above (blue) or below (red) the overall mean for the time-series. Regression lines for the bay-averaged time-series are shown as black dotted lines.

4.1.3 Water Quality

The overall increasing trends in both water salinity and temperature persist with the additional 2014-2015 data (Figure 4-3). A sequence of above average water salinities that began in 2011 continued through 2014, but heavy rains in early 2015 drove mean salinity for the year below average. Water temperature was below average in 2014, as it had been in 2013, but was above average again in 2015.

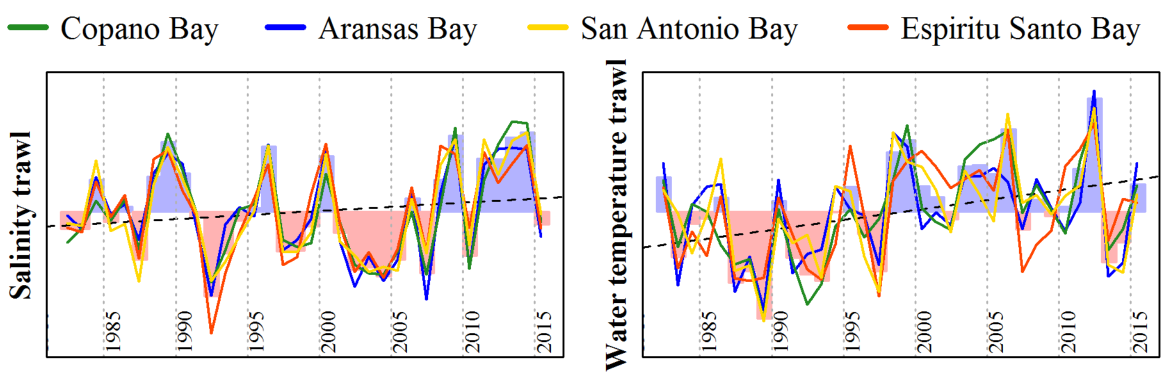

Figure 4-3 Updated temporal trends (z-scored yearly means) for TPWD trawl sample water quality parameters included in final MAR models in Phase 1 of the project.

Lines represent means for Copano (green), Aransas (blue), San Antonio (yellow), and Espiritu Santo (red) bays. Yearly means across all four bays are represented by bars colored to indicate whether values fall above (blue) or below (red) the overall mean for the time-series. Regression lines for the bay-averaged time-series are shown as black dotted lines.

4.1.4 River Discharge

A slight decreasing trend is seen in the updated river discharge time-series (Figure 4-4). A period of below average river discharge that began in 2011 continued through 2014. River discharge was above average in 2015.

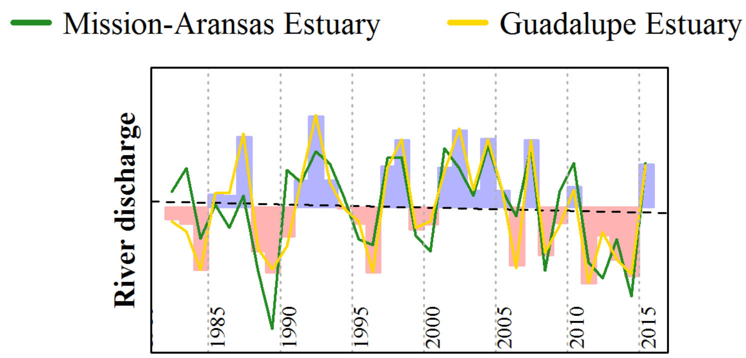

Figure 4-4 Updated temporal trends (z-scored yearly means) for river discharge. Lines represent means for the Mission-Aransas Estuary (green) and Guadalupe Estuary (yellow). Overall yearly means for each variable are represented by bars colored to indicate whether values fall above (blue) or below (red) the overall mean for the time-series. Regression lines for the averaged time-series are shown as black dotted lines.

4.2.0 Updated MAR models

There was generally very good agreement between the results of the MAR analyses run with the updated data and the original MAR models. Overall, comparisons of coefficient values between the original and updated focal species models revealed strong correlations and no significant differences between the final model structures at any lag or temporal division (Table 4-1).

Table 4-1 Kendall rank correlation coefficients for comparisons between original and updated MAR model coefficient values for blue crab and white shrimp. All *p*-values are <0.001.

Temporal division	Lag	Kendall's τ Blue crab models	Kendall's τ White Shrimp models
	0	0.90	0.81
years	1	0.84	0.76
	2	0.75	0.84
	0	0.91	0.93
6-month	1	0.74	0.91
	2	0.86	0.88
	0	0.91	0.98
months	1	0.85	0.94
	2	0.72	0.90

However, slight differences between coefficient values did occur. Several coefficients that were present in the original models were omitted from the updated models or vice versa. This happened in the models for both blue crab (Figure 4-5) and white shrimp (Figure 4-6) and resulted in slightly lower correlation values between models where it occurred most frequently. In the majority of these cases the non-zero coefficients were <0.1 (see Appendix A for coefficient values of original and updated MAR models). In a few of the blue crab models, coefficients switched signs from positive to negative or negative to positive between the original and updated models (Figure 4-5). However, this did not happen frequently and all of the coefficient values for which this occurred were <0.06, so it did not greatly affect model comparisons. None of the coefficients in the white shrimp models switched signs between the original and updated models (Figure 4-6).

Since the coefficients between original and updated models were extremely similar, the R^2 values for the regressions for each species included in the models were also very similar. For the blue crab models, all differences between R^2 values were <0.1 (Figure 4-7). For the white shrimp models, all differences between R^2 values were <0.05 (Figure 4-8). See Appendix B for R^2 and conditional R^2 values for the regressions for each species included in the original and updated blue crab and white shrimp MAR models.

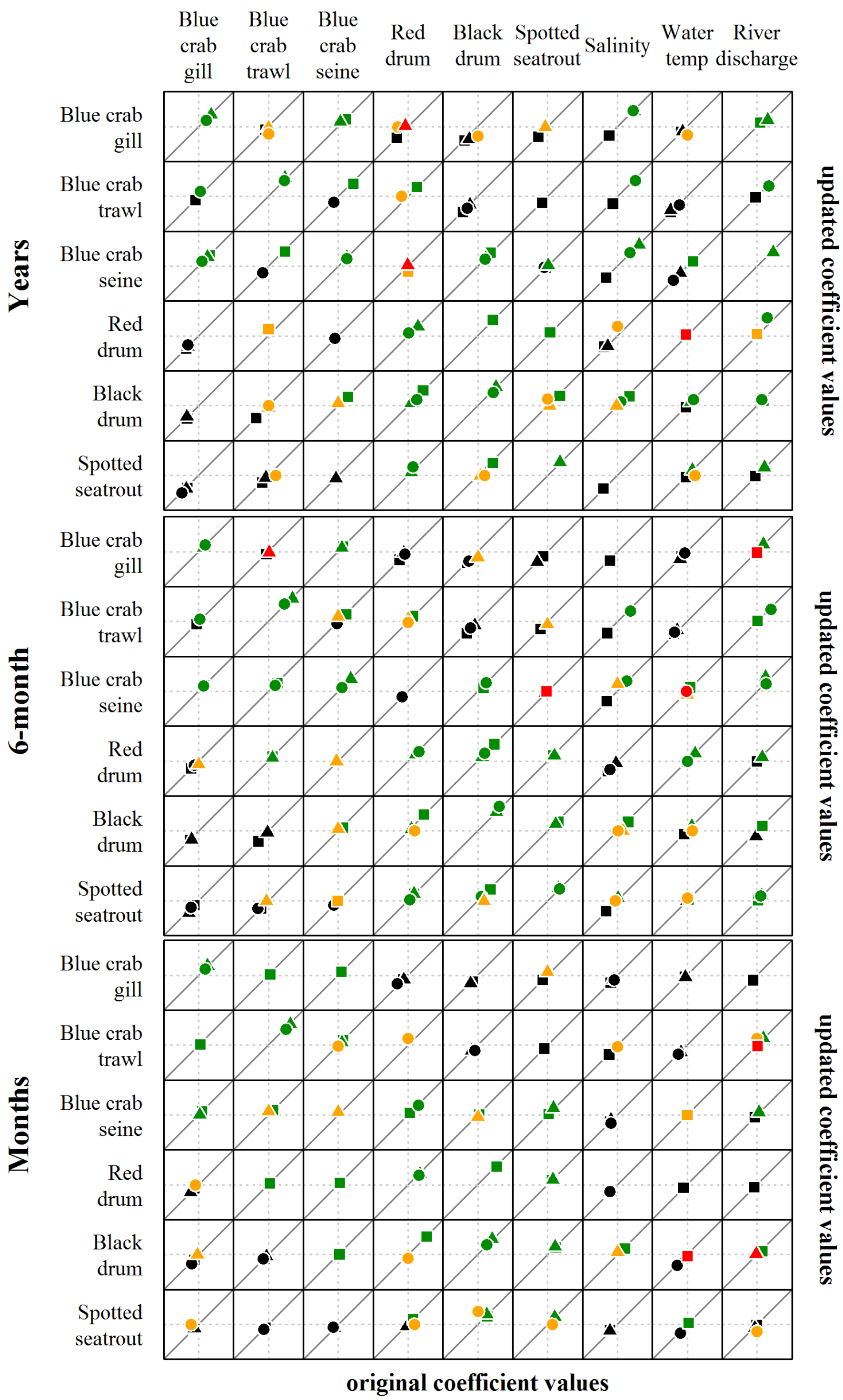

Figure 4-5 Plots of updated vs. original interaction coefficient values (effects of column variables on row variables) for lag 0 (squares), lag 1 (triangles), and lag 2 (circles) blue crab MAR models run on yearly, 6-month, and monthly time-series. Colors indicate whether coefficients were positive in both original and updated models (green), negative in both models (black), 0 in one model and non-zero in the other (yellow), or switched signs between models (red). For each individual interaction plot, axis limits are ±0.75, horizontal and vertical dotted lines mark 0 on each axis, and a solid diagonal line marks the 1:1 ratio.

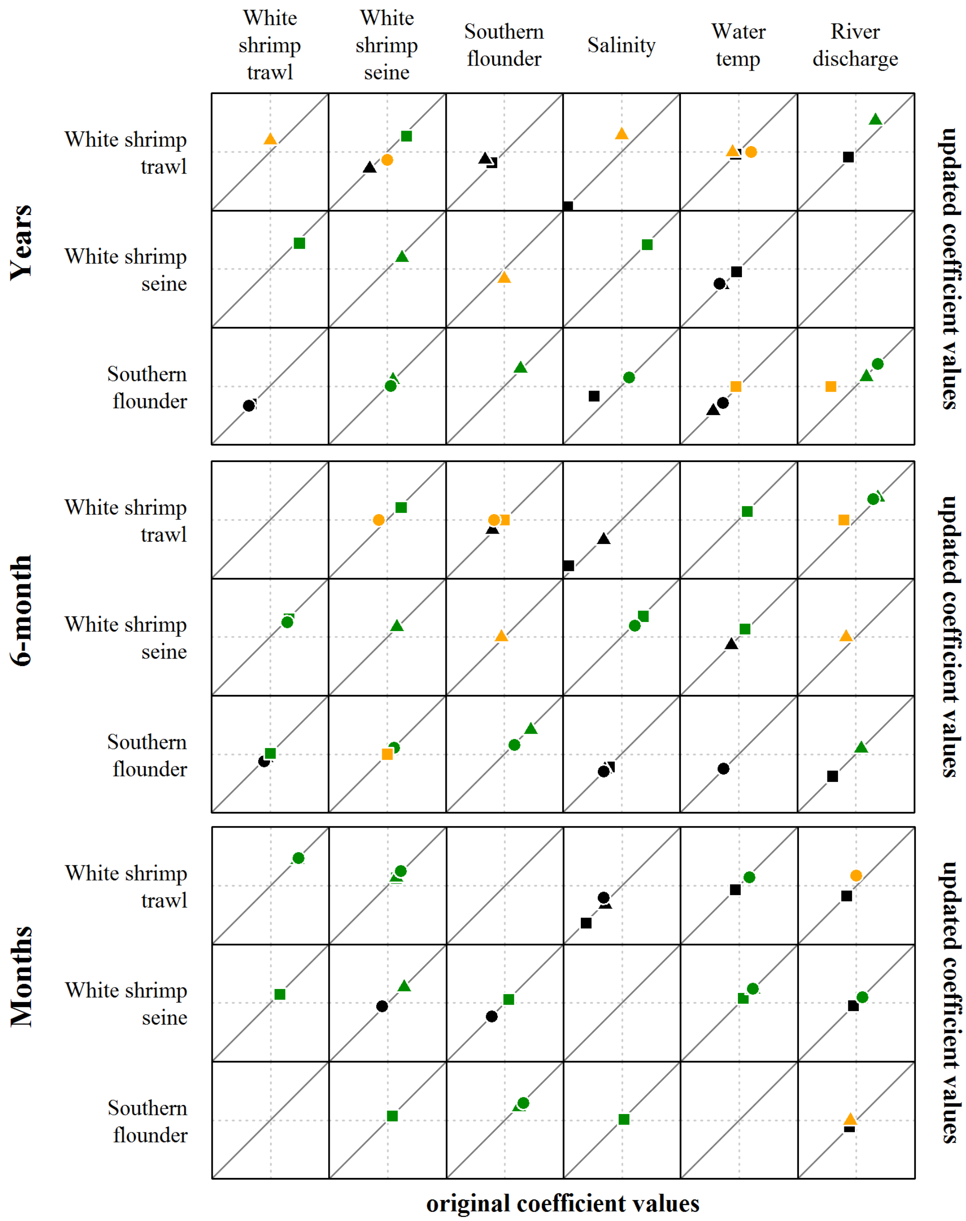

Figure 4-6 Plots of updated vs. original interaction coefficient values (effects of column variables on row variables) for lag 0 (squares), lag 1 (triangles), and lag 2 (circles) white shrimp MAR models run on yearly, 6-month, and monthly time-series. Colors indicate whether coefficients were positive in both original and updated models (green), negative in both models (black), 0 in one model and non-zero in the other (yellow), or switched signs between models (red). For each individual interaction plot, axis limits are ±0.75, horizontal and vertical dotted lines mark 0 on each axis, and a solid diagonal line marks the 1:1 ratio.

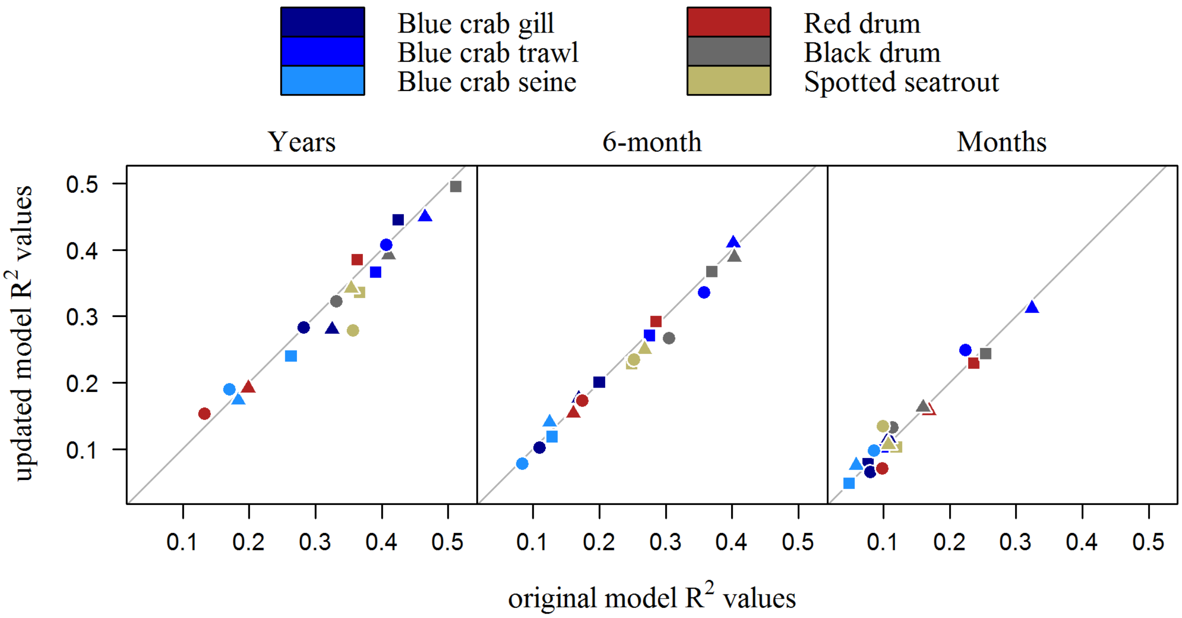

Figure 4-7 Plots of updated vs. original R^2 values for the regressions for each species included in the lag 0 (squares), lag 1 (triangles), and lag 2 (circles) blue crab MAR models run on yearly, 6-month, and monthly time-series. Colors indicate which species each point represents (see key).

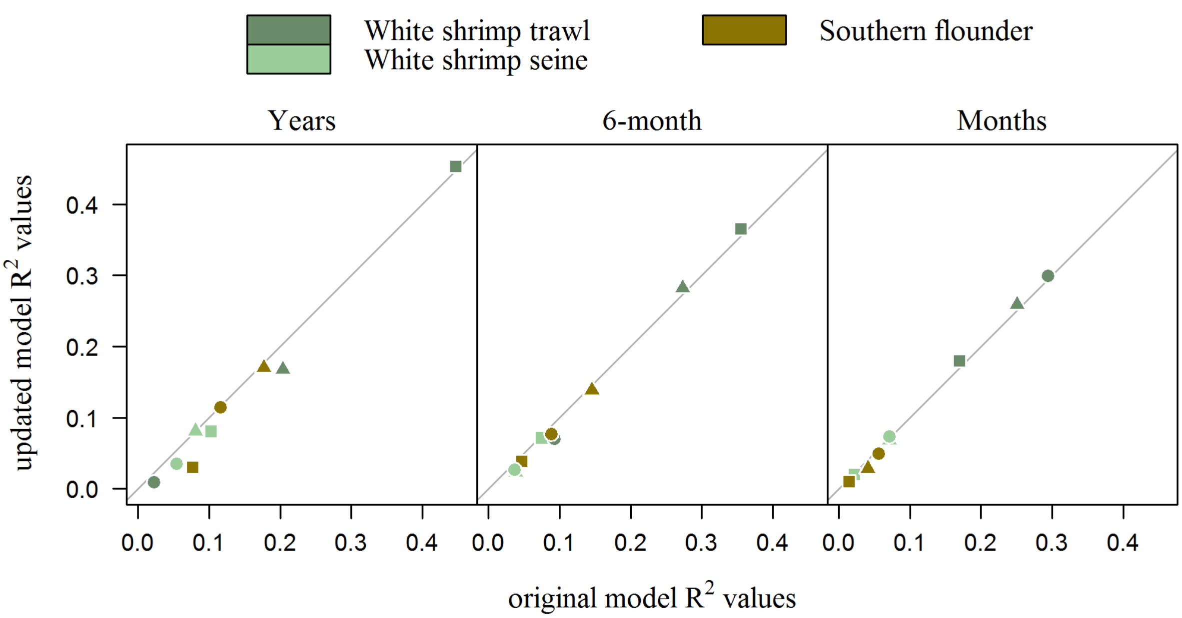

Figure 4-8 Plots of updated vs. original R^2 values for the regressions for each species included in the lag 0 (squares), lag 1 (triangles), and lag 2 (circles) white shrimp MAR models run on yearly, 6-month, and monthly time-series. Colors indicate which species each point represents (see key).

4.3.0 Seasonal time-series

Of the four variables selected for inclusion in the seasonal models (blue crab trawl abundance, white shrimp trawl abundance, river discharge, and water temperature), river discharge was the only variable that did not demonstrate a clear seasonal trend (Figure 4-9). Blue crab and white shrimp abundances demonstrated clear seasonal cycles, and, for both species, abundances in the winter and spring and in the summer and fall tended to follow similar temporal trends between years.

Blue crab abundance usually peaks in the spring, although the peak occurs in the winter during a few years. On average, lowest abundance occurs in the fall, and intermediate values are seen in the winter and spring. The overall decreasing trend in blue crab abundance is strongest for winter abundances, but also much stronger in the spring relative to fall and winter (Figure 4-10).

White shrimp abundance peaks in the summer and fall and is lowest during the winter and spring. Although slightly higher abundance values occur in the fall than in the summer on average, summer abundance has been higher than fall abundance for most years since 2004 (Figure 4-9). This pattern can also be seen as a decreasing trend in fall shrimp abundance anomalies (Figure 4-10).

River discharge does not follow any distinct seasonal trends (Figure 4-9) or any clear differences in anomaly trends between seasons (Figure 4-10). The only discernible seasonal pattern is that during years of relatively low flow for all seasons, summer discharge values are often lowest (Figure 4-9). A slight decreasing trend in discharge over time occurs for all seasons, but it is relatively stronger for the winter and spring seasons (Figure 4-10).

Water temperature demonstrated the strongest seasonal trend of any of the variables, with a clear peak in the summer and low in the winter (Figure 4-9). For consecutive seasons, value ranges overlap from spring to summer and from fall to winter, but not from winter to spring or summer to fall, creating a clear division between fall/winter and spring/summer water temperature conditions. The fall/winter temperature values are also more variable between years than the spring/summer values. The overall increasing trend of water temperature over time is most strongly reflected in values for the spring season (Figure 4-10).

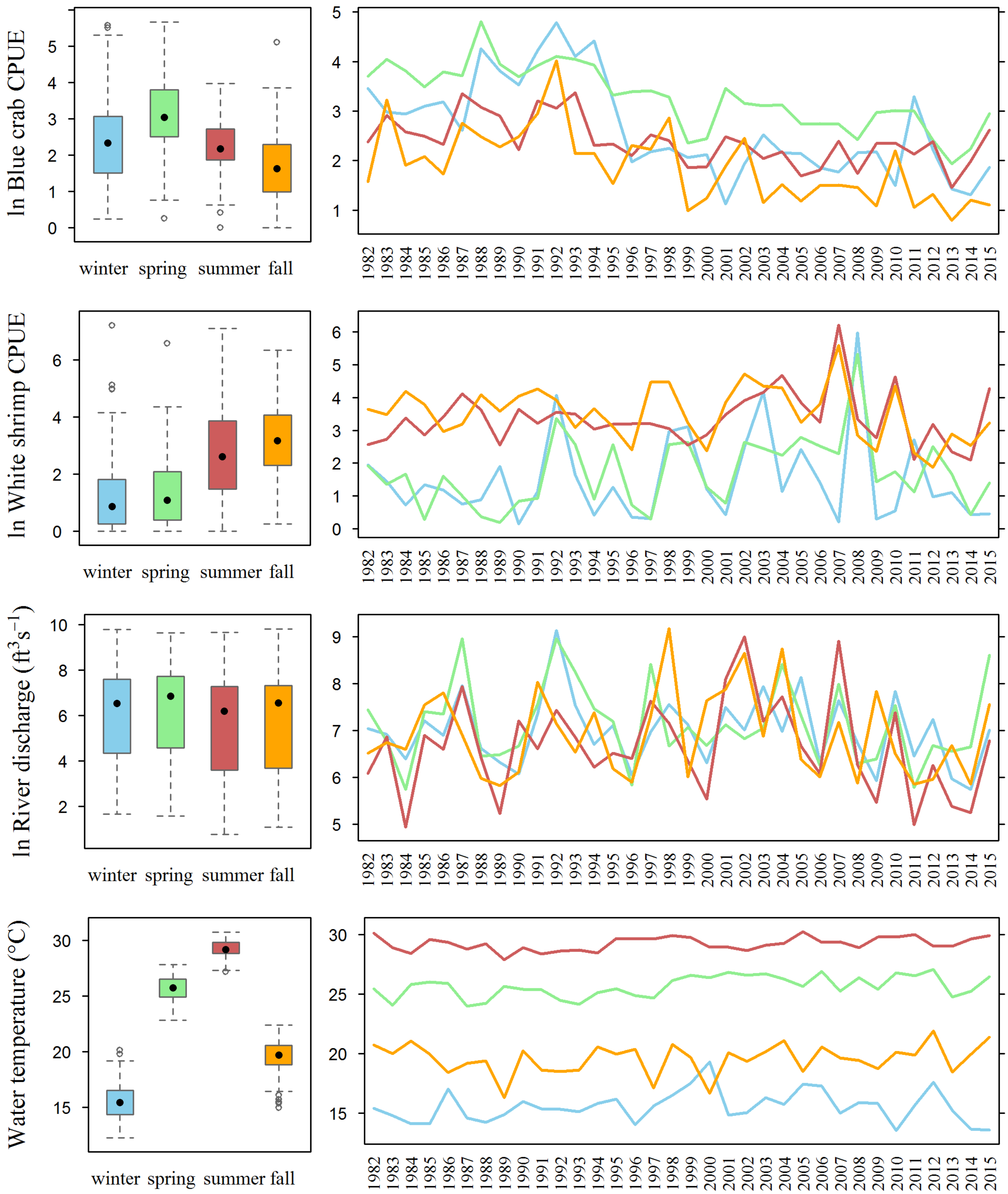

Figure 4-9 Average seasonal trends in blue crab abundance, white shrimp abundance, river discharge, and water temperature time-series. Winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep), and fall (Oct-Dec) values are shown in blue, green, red, and orange, respectively.

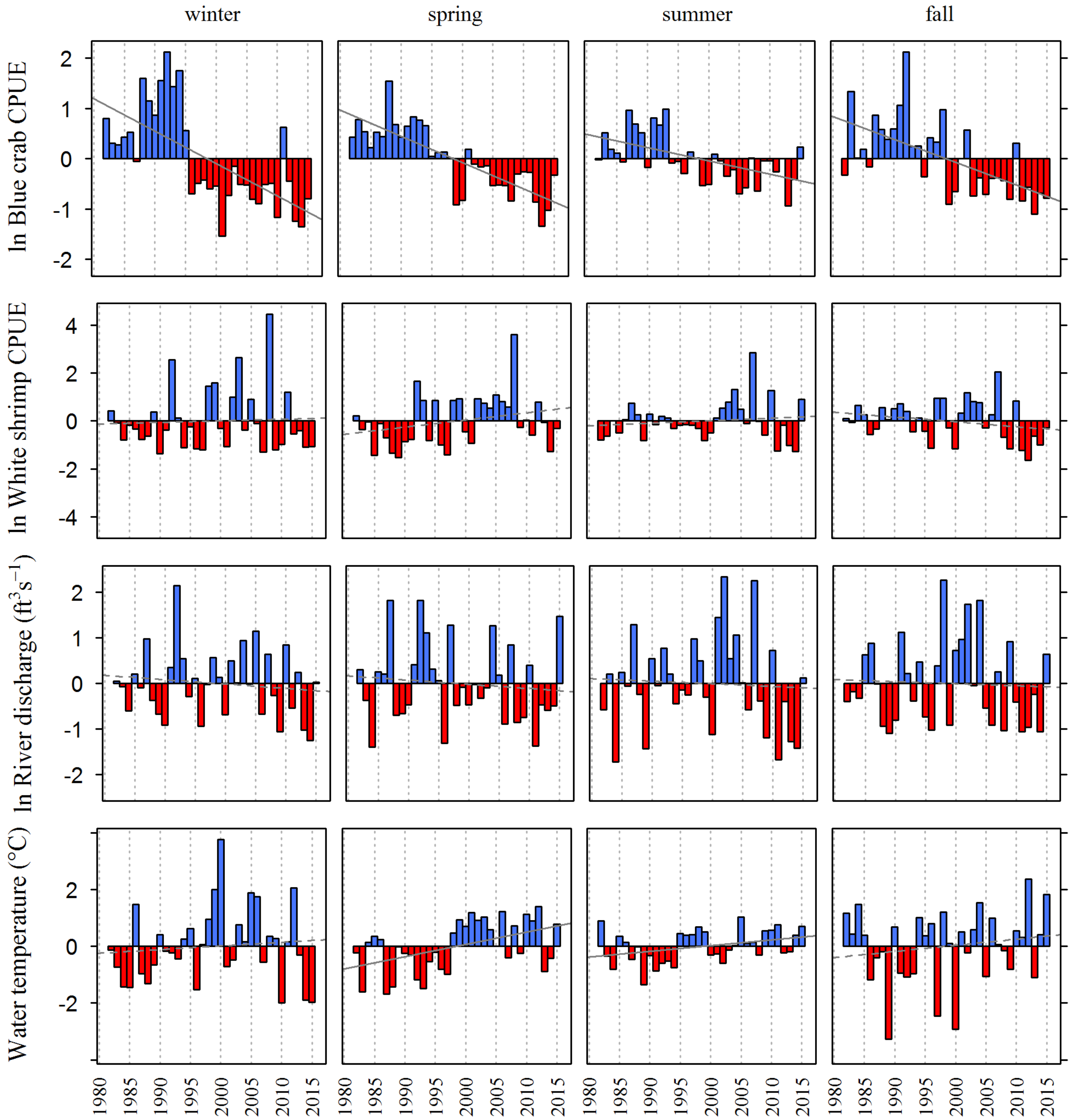

Figure 4-10 Yearly positive (blue) and negative (red) deviations from mean values by season for blue crab abundance, white shrimp abundance, river discharge, and water temperature. Regression lines for each season and variable are shown as solid gray lines (p<0.05) or dotted gray lines (p>0.05).

4.4.0 Seasonal models

4.4.1 Blue crab

Each of the seasonal models for blue crab explained at least half of the variance in the blue crab abundance time-series for the respective season, except for the fall model (Table 4-2). The lower R^2 value for the fall model is not surprising, however, since fall is the season of lowest abundance for blue crab (Figure 4-9) and the model was unable to account for losses due to reproductive females migrating out of the estuary.

The largest coefficients in the crab abundance models (Table 4-2) indicate that their abundance was strongly dependent on how many crabs were present in the preceding season, that freshwater inputs in winter at a lag of 1 year had a positive influence on their abundance, and that summer water temperatures at a 2 year lag had a negative influence on their abundance. While all water temperature coefficients are negative, river discharge coefficients are a mix of positive and negative coefficients that mostly cancel one another out. A possible explanation for this is that freshwater inputs may have different effects on different life stages of blue crab. For example, adult crabs may enjoy immediate benefits of higher inflows, but perhaps their recruitment or survival as juveniles suffered negative effects of inflows during a previous year. It is also possible that freshwater inputs are having the same effects on crabs and their predators, but at different lags, so the effects of predation are manifesting indirectly as negative discharge coefficients.

Table 4-2 Blue crab (trawl) model coefficients and R^2 values. Positive coefficients are shown in green, negative coefficients are shown in red. For each Y season model, p<0.001. For each model coefficient, p<0.05 except for water temperature in the summer Y season model (p=0.06).

			X variable, year lag, and season													
			ln Blue Crab *t*-1				**ln Discharge**				**Water Temperature**				
Y season	**Intercept**	year lag	winter	spring	summer	fall	winter	spring	summer	fall	winter	spring	summer	fall	**R^2**
Winter	13.65	0				+0.73				-0.15					**0.61**
		-1					+0.23				-0.13				
		-2											-0.37		
Spring	10.46	0	+0.41						+0.08		-0.11			-0.14	**0.68**
		-1							-0.07						
		-2								+0.11		-0.17			
Summer	1.38	0		+0.58							-0.06				**0.50**
		-1													
		-2													
Fall	3.03	0			+0.58										**0.43**
		-1								+0.12				-0.12	
		-2								-0.13					

When the fitted values from the 4 seasonal models are realigned into a single continuous time-series, there is good overall agreement with the original measured crab abundance time-series (Figure 4-11; Table 4-3). Although the R^2 value for the whole estimated time-series is relatively high, indicating that 67% of the variance in measured blue crab abundance is explained, this time-series was fitted using the measured values of crab abundance as a density dependent term. The coefficients for density dependence in the models were relatively large (Table 4-2), so at least part of the fit can be attributed to the model using the actual measured abundance values to generate the estimated abundance values.

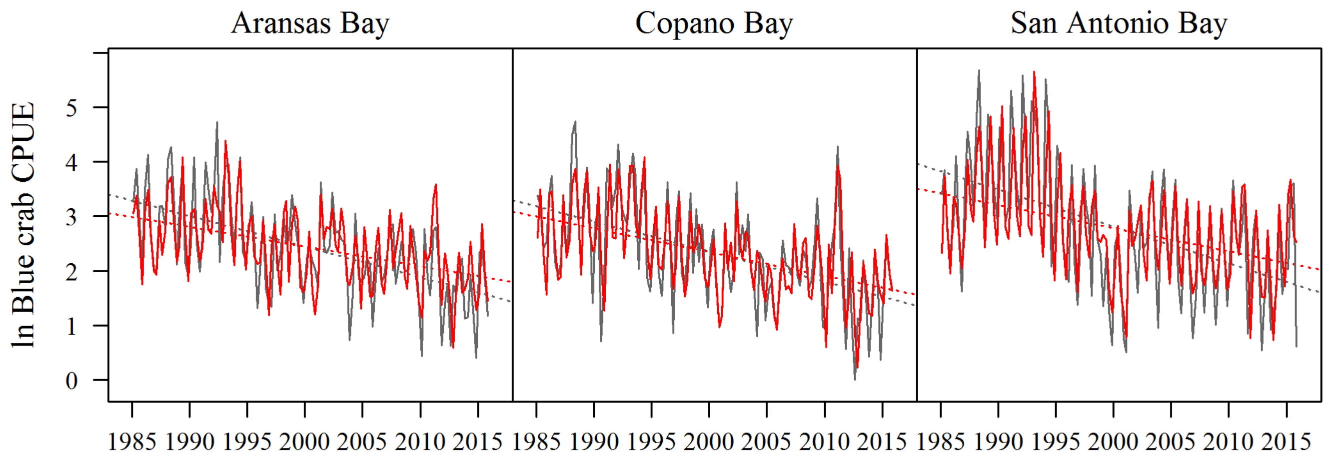

Figure 4-11 Measured time-series of blue crab abundance (gray) and fitted value time-series of model-estimated blue crab abundance (red) by bay. Regression lines of abundance over time for each time-series are shown as dotted lines.

Table 4-3 Sums of squares and R^2 values for fitted value time-series of model-estimated blue crab abundance for each bay and all bays together.

	Regression SS	Residual SS	R^2
Aransas Bay	58	34	0.67
Copano Bay	75	35	0.63
San Antonio Bay	114	59	0.66
All bays	260	127	0.67

A better assessment of model performance is to use the model coefficients to calculate a new abundance time-series one time-step at a time, so that each new estimate is based off of the estimated abundance value at the previous time-step rather than measured abundance. For each bay, overall mean blue crab abundance for fall was used to calculate the initial winter abundance estimate in the time-series. As expected, this calculated time-series did not follow the measured abundance time-series as well as the fitted model values did, but over half of the overall variance in abundance is still explained and the overall decreasing trend in abundance is reproduced (Figure

4-12; Table 4-4). The R^2 values for this calculated time-series are relatively low because the model was unable to account for some of the higher peaks in abundance in the first half of the time-series and some of the lower abundances later in the time-series (Figure 4-12). This may be due to non-linear effects of temperature or effects of other variables not included in the model. The R^2 for Aransas Bay was also low relative to the other bays (Table 4-4), possibly because it is affected by freshwater inflows in both estuaries, but in the model it was set to respond to discharge values for the Mission-Aransas Estuary.

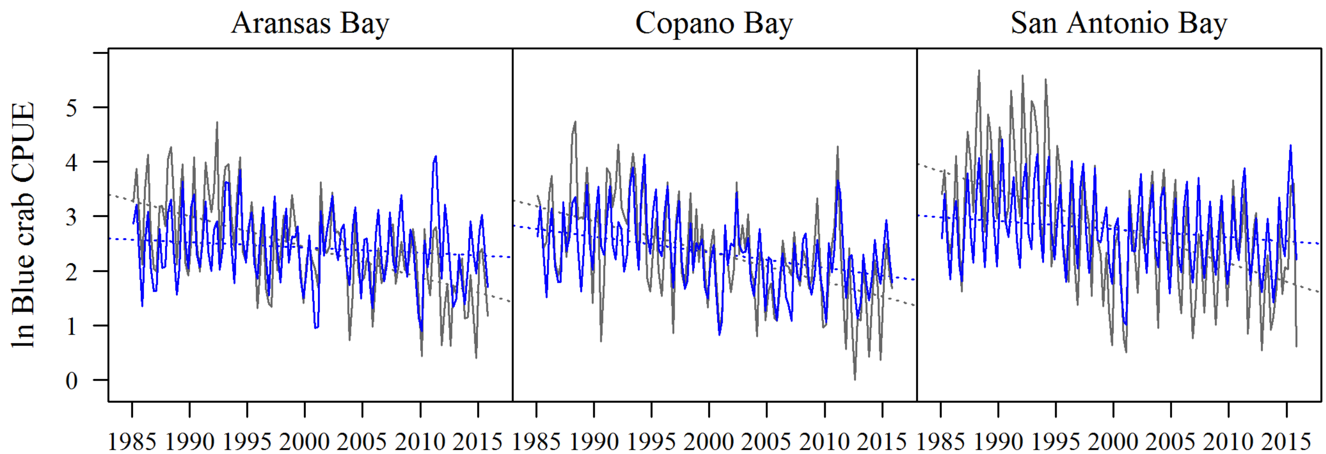

Figure 4-12 Measured time-series of blue crab abundance (gray) and calculated time-series of blue crab abundance based on step-wise crab abundance estimates (blue) by bay. Regression lines of abundance over time for each time-series are shown as dotted lines.

Table 4-4 Sums of squares and R^2 values for calculated time-series of blue crab abundance based on step-wise crab abundance estimates for each bay and all bays together.

	Regression SS	**Residual SS**	**R^2**
Aransas Bay	35	56	0.38
Copano Bay	63	47	0.58
San Antonio Bay	89	83	0.52
All bays	201	186	0.52

4.4.2 White shrimp

The spring and summer models for white shrimp explained about half of the variance in the white shrimp abundance time-series for the respective seasons, and the fall and winter models explained just under 40% of variance in white shrimp abundance during those seasons (Table 4-5). As with the fall blue crab model, the lower R^2 values for the fall and winter white shrimp models may be related to their inability to account for changes in abundance due to migratory movement during those seasons.

The largest coefficients in the shrimp abundance models (Table 4-5) indicate strong density dependence of winter and spring shrimp abundances on their abundances during the respective preceding seasons, freshwater inputs in summer had a positive effect on abundances during the same summer and fall, winter discharge had a strong negative effect on summer abundances at a lag of 1 year, and summer water temperatures had a negative effect on fall abundances the same year. Aside from the negative coefficient in the fall model, all water temperature coefficients consisted of positive winter and spring values in the winter and spring models. River discharge coefficients were all positive except for the large coefficient for 1 year lag winter discharge in the summer model. As with the blue crab model, this coefficient may be the result of freshwater inputs negatively affecting recruitment or survival of an earlier life stage of the shrimp.

Table 4-5 White shrimp (trawl) model coefficients and R^2 values. Positive coefficients are shown in green, negative coefficients are shown in red. For each Y season model, $p<0.001$. For each model coefficient, $p<0.05$.

			X variable, year lag, and season													
			ln White Shrimp *t*-1				**ln Discharge**				**Water Temperature**				
Y season	**Intercept**	year lag	winter	spring	summer	fall	winter	spring	summer	fall	winter	spring	summer	fall	**R^2**
winter	-7.21	0				+0.74									**0.37**
		-1										+0.24			
spring	-4.12	0	+0.51				+0.09				+0.15				**0.49**
		-1									+0.15				
summer	1.17	0		+0.39					+0.31						**0.48**
		-1					-0.48	+0.22		+0.24					
fall	11.08	0			+0.32				+0.15				-0.32		**0.39**
		-1													

When the fitted values from the 4 seasonal models are realigned into a single continuous time-series, there is good overall agreement with the original measured shrimp abundance time-series (Figure 4-13; Table 4-6). Similar to the blue crab model, the R^2 value for the whole estimated time-series is relatively high, indicating that 63% of the variance in measured white shrimp abundance is explained (Table 4-6). However, this time-series was fitted using the measured values of shrimp abundance as a density dependent term, so at least part of the fit can be attributed to the model using the actual measured abundance values to generate the estimated abundance values.

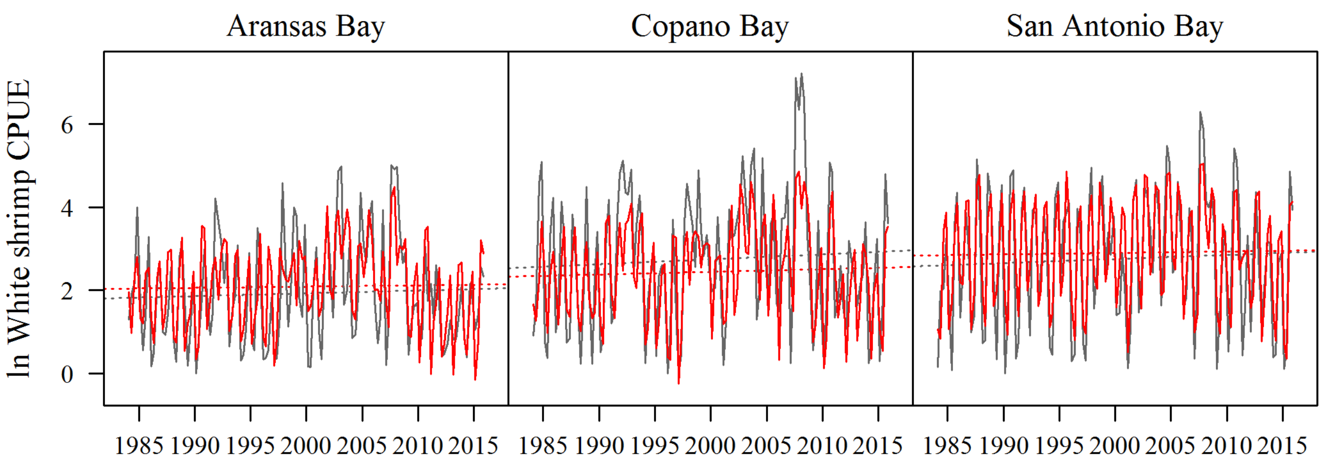

Figure 4-13 Measured time-series of white shrimp abundance (gray) and fitted value time-series of model-estimated white shrimp abundance (red) by bay. Regression lines of abundance over time for each time-series are shown as dotted lines.

Table 4-6 Sums of squares and R^2 values for fitted value time-series of model-estimated white shrimp abundance for each bay and all bays together.

	Regression SS	**Residual SS**	**R^2**
Aransas Bay	98	112	0.63
Copano Bay	195	142	0.47
San Antonio Bay	229	89	0.72
All bays	579	342	0.63

A less biased assessment of model performance was attained by using the model coefficients to calculate a new abundance time-series one time-step at a time, so that each new estimate was based off of the estimated abundance value at the previous time-step rather than measured abundance. For each bay, mean white shrimp abundance for fall was used to calculate the initial winter abundance estimate in the time-series. As expected, this calculated time-series did not follow the measured abundance time-series as well as the fitted model values did, but over half of the overall variance in abundance is still explained (Figure 4-14; Table 4-7). The R^2 values for this calculated time-series are relatively low because the model was unable to account for some anomalous high and low values in Aransas and Copano bays and some of the lower abundances in the San Antonio bay time-series (Figure 4-14).

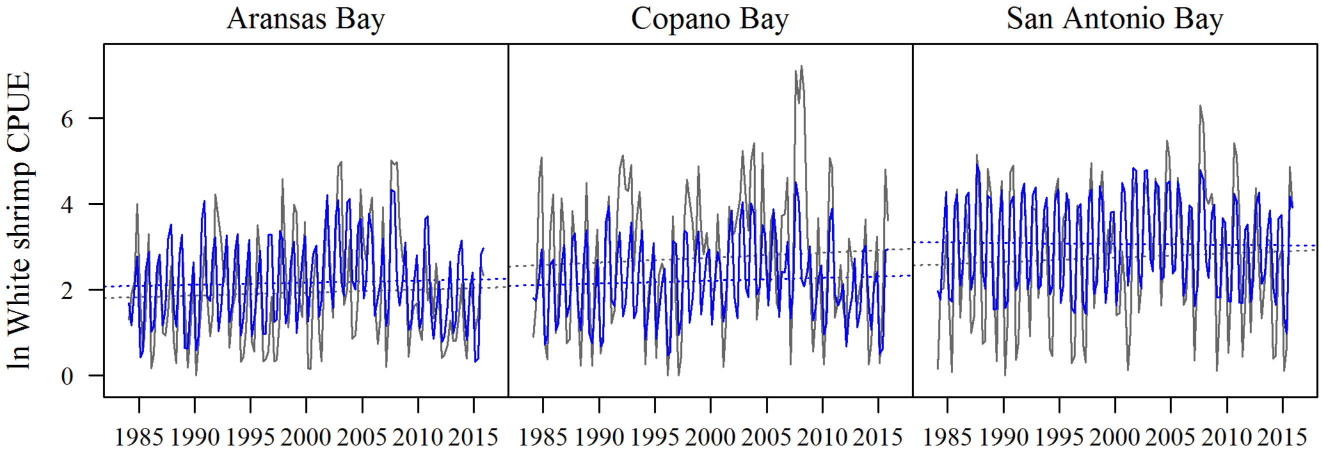

Figure 4-14 Measured time-series of white shrimp abundance (gray) and calculated time-series of white shrimp abundance based on step-wise shrimp abundance estimates (blue) by bay. Regression lines of abundance over time for each time-series are shown as dotted lines.

Table 4-7 Sums of squares and R^2 values for calculated time-series of white shrimp abundance based on step-wise shrimp abundance estimates for each bay and all bays together.

	Regression SS	**Residual SS**	$\mathbf{R^2}$
Aransas Bay	75	135	0.36
Copano Bay	132	205	0.39
San Antonio Bay	203	114	0.64
All bays	467	454	0.51

4.5.0 Effects of changes in river discharge and water temperature

4.5.1 Blue crab

To assess the effects of water temperature on non-seasonal temporal trends in blue crab abundance, the values for river discharge in the time-series were set to their overall seasonal means and a new time-series of crab abundance was calculated. Likewise, to assess the effects of discharge on blue crab abundance trends, the long-term effects of temperature were neutralized by setting all temperature values to their overall seasonal means. A visual comparison of the original calculated abundance time-series, the calculated temperature effects time-series, and the calculated discharge effects time-series reveals that water temperature is responsible for the primary long-term trends seen in the blue crab abundance time-series (Figure 4-15). A clear decreasing trend is still apparent when the effects of water temperature are isolated, but disappears when the effects of river discharge are isolated.

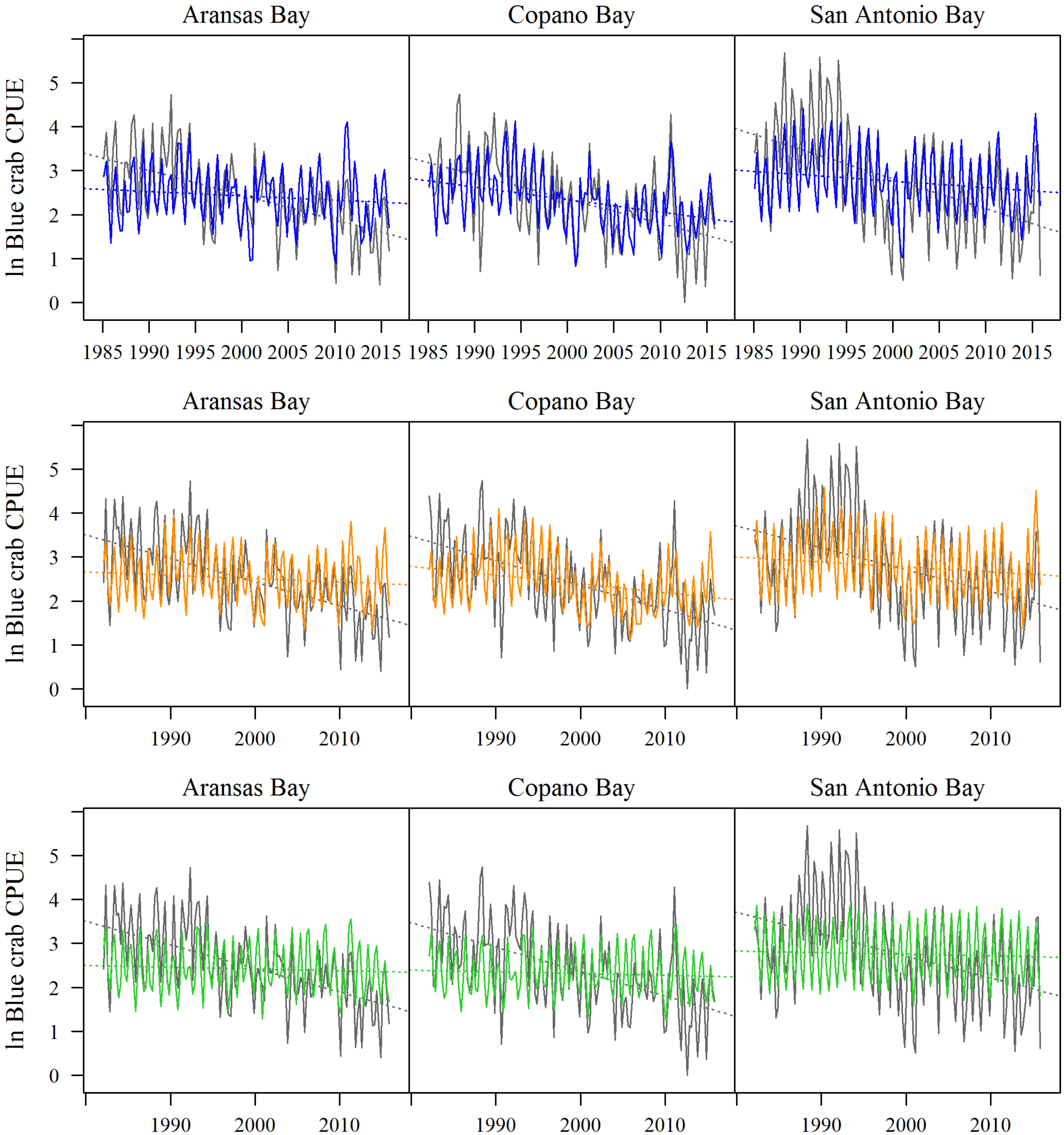

Figure 4-15 Time-series of measured blue crab abundance (gray), calculated blue crab abundance (blue), calculated blue crab abundance with the non-seasonal effects of river discharge removed (orange) to isolate the effects of water temperature on abundance trends, and calculated blue crab abundance with the non-seasonal effects of water temperature removed (green) to isolate the effects of river discharge on abundance trends.

The response of mean blue crab abundance to changes in water temperature during each season was tested by increasing temperature values by 1°C for each season individually and calculating new crab abundance time-series based on these altered values. A 1°C increase in water temperature in any season resulted in overall decreases in blue crab abundance by at least 13% compared to abundance with no temperature change (Figure 4-16). This was primarily due to negative impacts on spring abundances across the board, but additional negative effects on winter abundances with increased winter and summer water temperatures resulted in the largest overall abundance decreases of 18 and 19%, respectively.

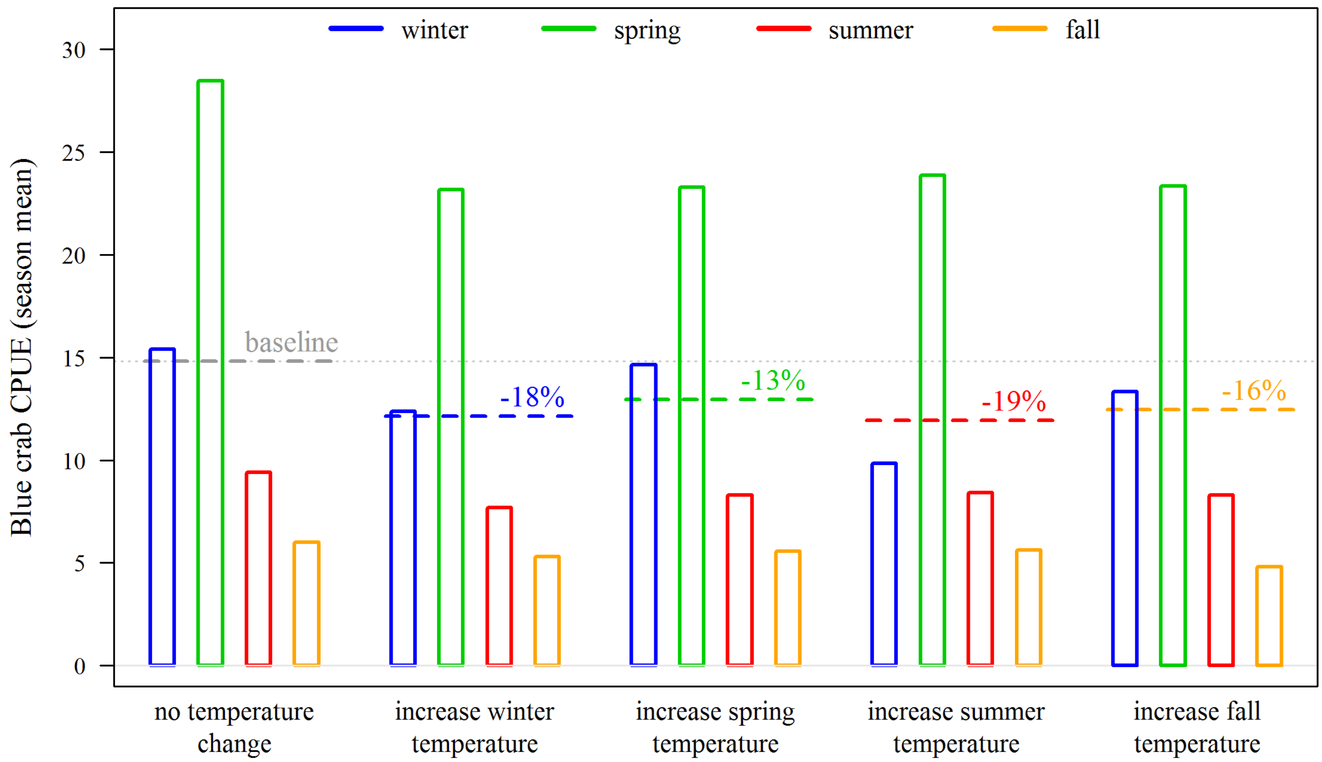

Figure 4-16 Seasonal and overall blue crab abundance means calculated using water temperature time-series in which a 1°C increase was applied to each season individually. Each set of bars represents seasonal abundance means that resulted from altering the conditions for a specific season. Horizontal dotted lines represent the overall abundance mean for each set of bars, and the corresponding percentage values give the change in mean abundance relative to a baseline value associated with no change in seasonal conditions.

The response of mean blue crab abundance to changes in river discharge during each season was tested by decreasing river discharge by 25% for each season individually and calculating new crab abundance time-series based on these altered values. For examples of blue crab abundance estimation based on river discharge time-series from various TCEQ Water Availability Model flow scenarios, see Appendix C. Mean blue crab abundance only responded to a winter discharge decrease, with a decrease in overall abundance by about 4% due to negative impacts on their winter and spring abundances (Figure 4-17).

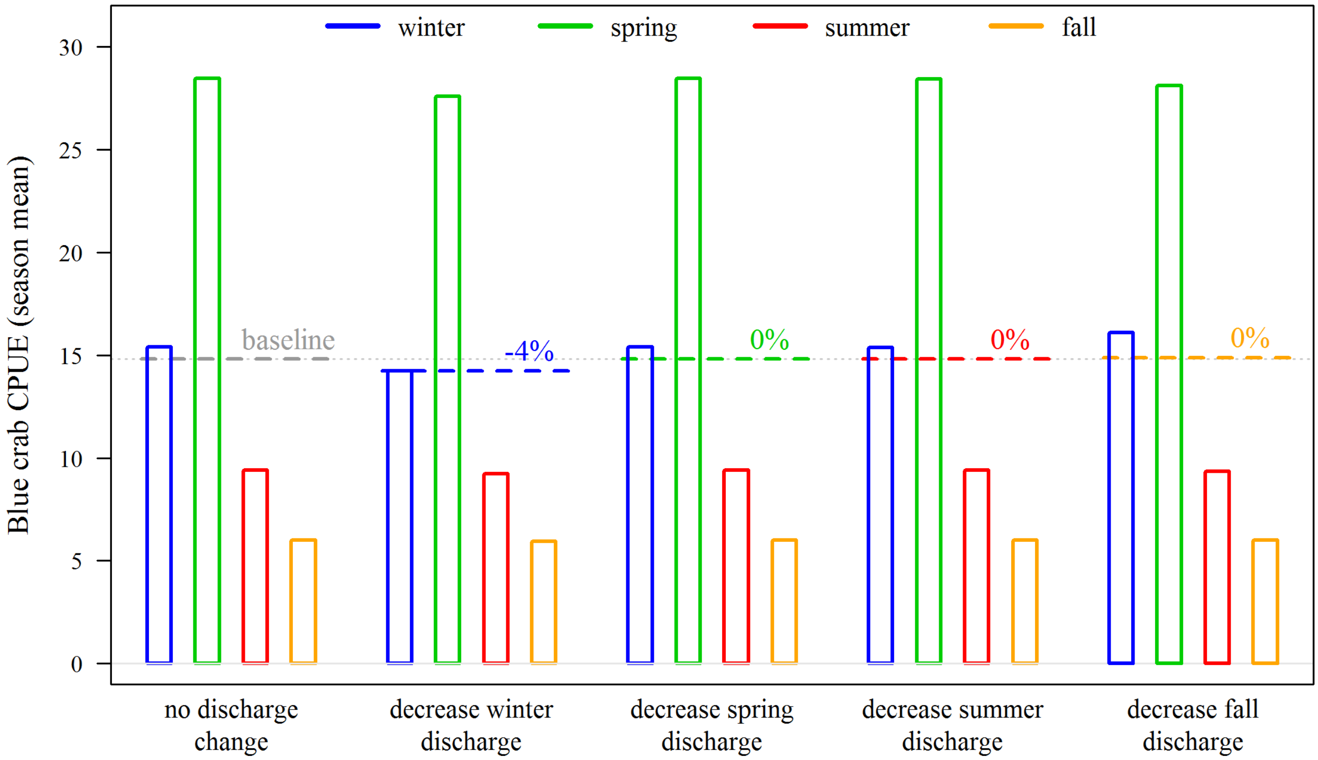

Figure 4-17 Seasonal and overall blue crab abundance means calculated using river discharge time-series in which a 25% decrease was applied to each season individually. Each set of bars represents seasonal abundance means that resulted from altering the conditions for a specific season. Horizontal dotted lines represent the overall abundance mean for each set of bars, and the corresponding percentage values give the change in mean abundance relative to a baseline value associated with no change in seasonal conditions.

Overall, these results indicate that blue crab abundance is more sensitive to changes in water temperature than to changes in freshwater inflow conditions, and, correspondingly, their long-term abundance trends reflect variability in temperature trends. Although river discharge does affect blue crab abundance, it would take relatively large changes in discharge conditions to have a substantial impact on blue crab abundance. For example, to see the same level of impact that a temperature increase of 1°C had on crab abundance, discharge would have to be reduced by 80%.

4.5.2 *White shrimp*

To assess the effects of water temperature on non-seasonal temporal trends in white shrimp abundance, the values for river discharge in the time-series were set to their overall seasonal means and a new time-series of shrimp abundance was calculated. Likewise, to assess the effects of discharge on white shrimp abundance trends, the long-term effects of temperature were neutralized by setting all temperature values to their overall seasonal means. A visual comparison of the original calculated abundance time-series, the calculated temperature effects time-series, and the calculated discharge effects time-series reveals that, while water temperature is responsible for some of the inter-annual variability seen in the white shrimp abundance time-series, the primary long-term abundance patterns more closely follow the isolated effects of river discharge (Figure 4-18).

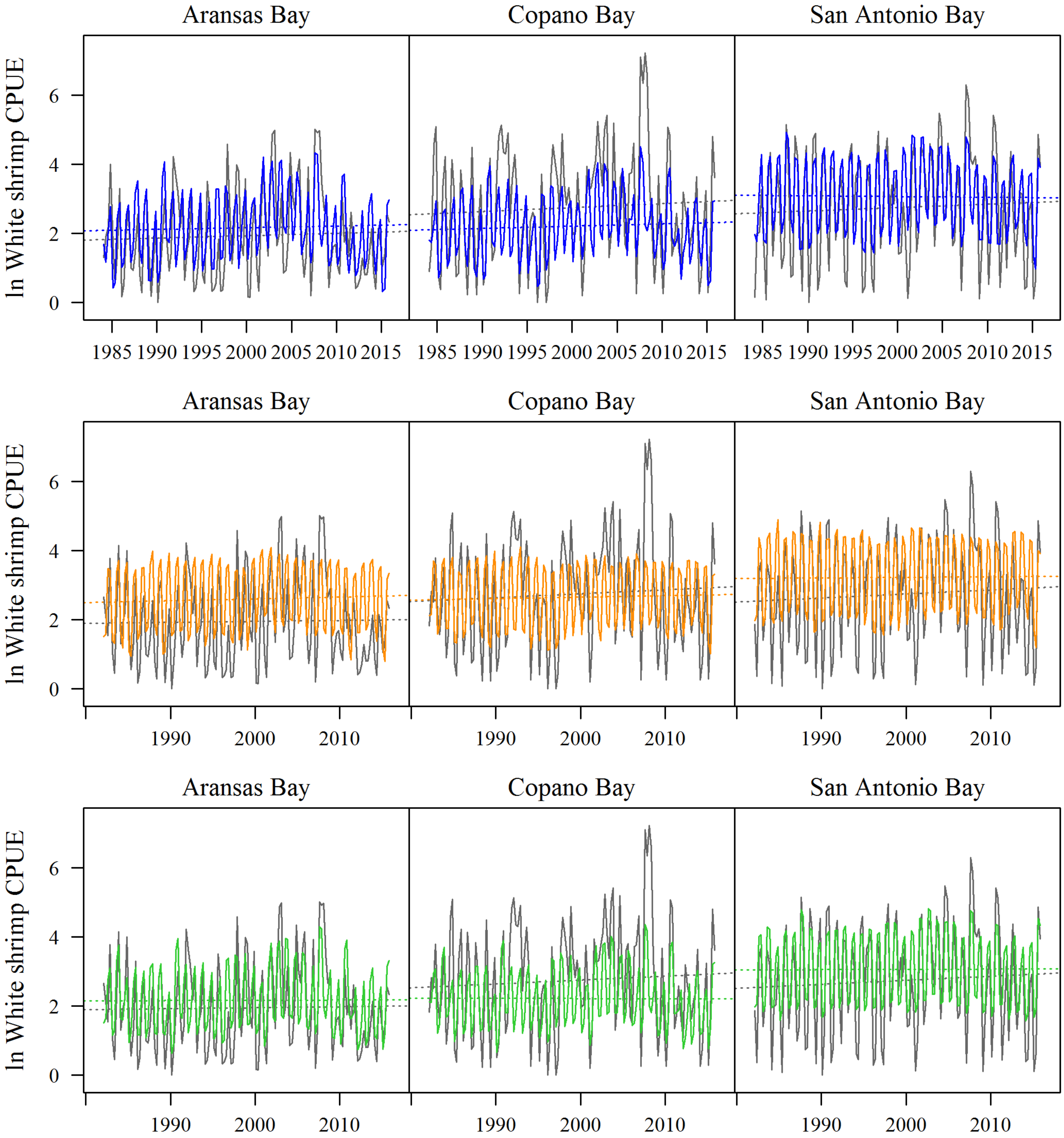

Figure 4-18 Time-series of measured white shrimp abundance (gray), calculated white shrimp abundance (blue), calculated white shrimp abundance with the non-seasonal effects of river discharge removed (orange) to isolate the effects of water temperature on abundance trends, and calculated white shrimp abundance with the non-seasonal effects of water temperature removed (green) to isolate the effects of river discharge on abundance trends.

The response of mean white shrimp abundance to changes in water temperature during each season was tested by increasing temperature values by 1°C for each season individually and calculating new shrimp abundance time-series based on these altered values. Higher temperatures in the winter and spring resulted in increases in white shrimp abundance by 10 and 6%, respectively (Figure 4-19). The largest impact on abundance was an 18% decrease due to higher summer water temperatures. Increasing fall water temperature had no impact on shrimp abundance.

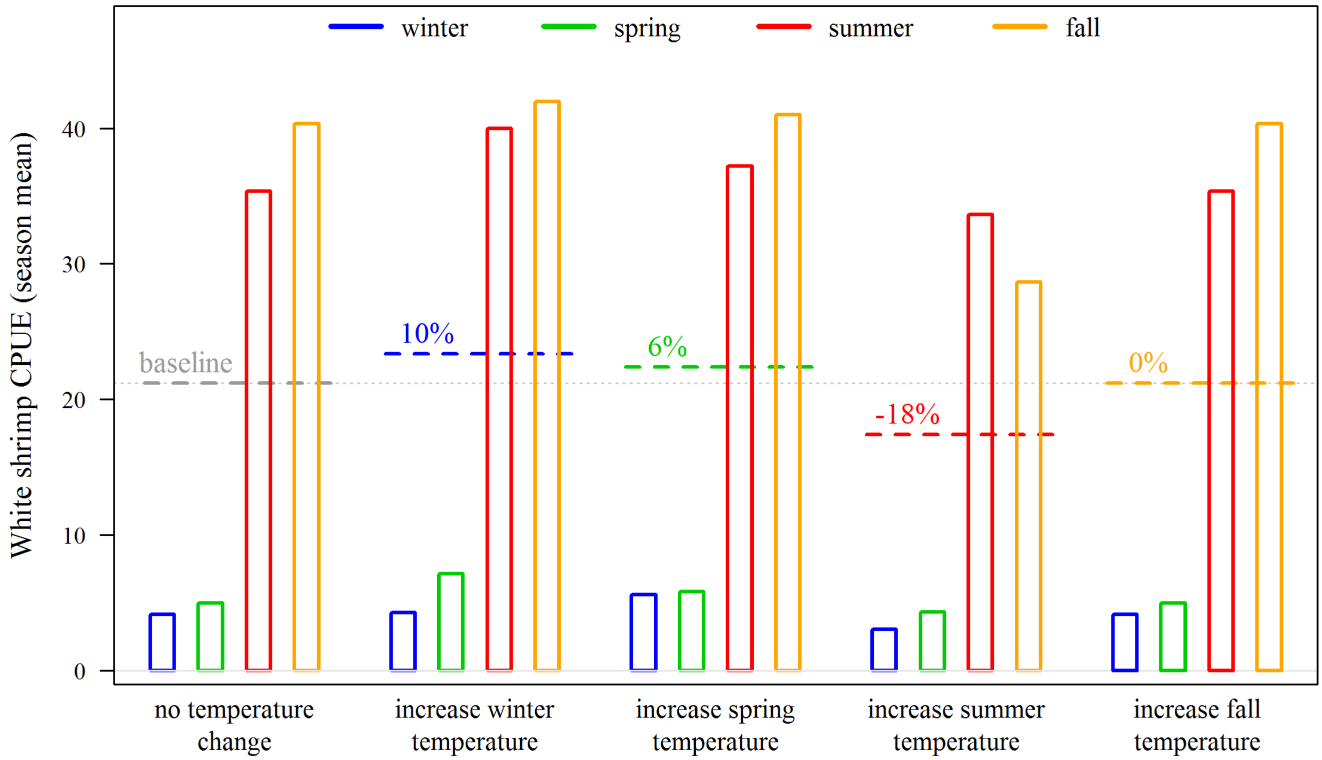

Figure 4-19 Seasonal and overall white shrimp abundance means calculated using water temperature time-series in which a 1°C increase was applied to each season individually. Each set of bars represents seasonal abundance means that resulted from altering the conditions for a specific season. Horizontal dotted lines represent the overall abundance mean for each set of bars, and the corresponding percentage values give the change in mean abundance relative to a baseline value associated with no change in seasonal conditions.

The response of mean white shrimp abundance to changes in river discharge during each season was tested by decreasing river discharge by 25% for each season individually and calculating new shrimp abundance time-series based on these altered values. For examples of white shrimp abundance estimation based on river discharge time-series from various TCEQ Water Availability Model flow scenarios, see Appendix C. White shrimp abundance responded negatively to decreases in discharge, with the exception of an 8% positive response to the decrease in winter discharge (Figure 4-20). The largest decrease in abundance (8%) was seen for the decrease in summer discharge. All changes in mean abundance resulted from changes in summer and fall abundances.

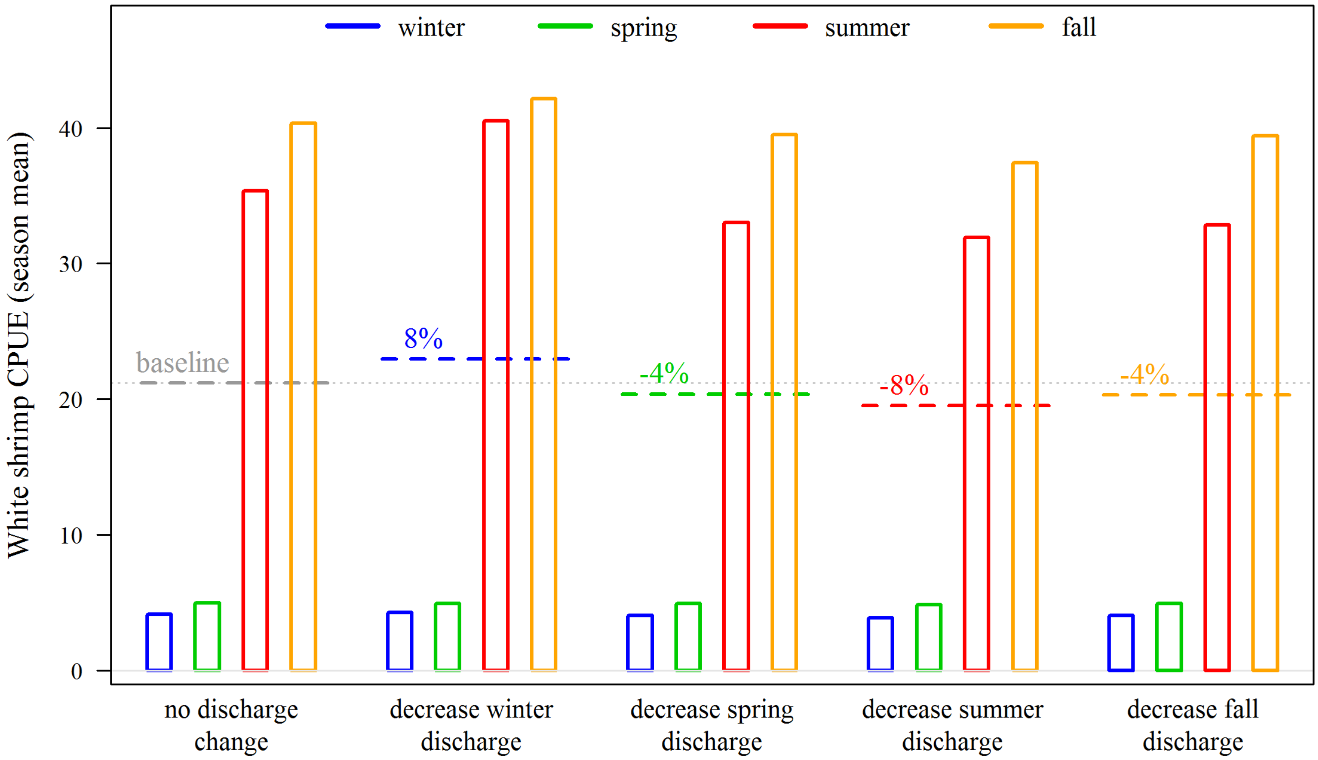

Figure 4-20 Seasonal and overall white shrimp abundance means calculated using river discharge time-series in which a 25% decrease was applied to each season individually. Each set of bars represents seasonal abundance means that resulted from altering the conditions for a specific season. Horizontal dotted lines represent the overall abundance mean for each set of bars, and the corresponding percentage values give the change in mean abundance relative to a baseline value associated with no change in seasonal conditions.

Overall, white shrimp abundance responds to both water temperature and river discharge, and the direction of their response depends on which season fluctuations in those variables occur. However, since their long-term trends more closely follow variation in discharge, it appears their abundance is more sensitive overall to changes in freshwater inflows than to changes in water temperature.

5.0.0 CONCLUSIONS

The division of the time-series for blue crab abundance, white shrimp abundance, and the other model variables into seasonal time-steps presented obstacles to using the original multivariate autoregressive (MAR) analysis methods from Phase 1 of the project. While the original methods employed a matrix formulation in which interactions between multiple species in the model were estimated, the seasonal temporal divisions of the data made it necessary to simplify the model structure such that only density dependence and the effects of water temperature and river discharge on the focal species were considered. The omission of predator species and salinity as predictors in the models had minimal effects on overall model fits (decreases in $R^2 < 0.05$).

Model results indicate that higher summer water temperatures negatively affect both blue crab and white shrimp. Simulations of a 1°C temperature increase for each season confirmed that the largest decreases in abundance for the focal species resulted from high summer temperatures. Blue crab abundance also decreased in response to temperature increases in all other seasons. White shrimp abundance responded negatively to higher spring and fall temperatures, but positively to higher winter water temperature. The overall negative impact of water temperature increase on both focal species is an important finding, in that the temperature time-series in this study exhibits an average increasing trend of about 0.024 °C per year.

The effects of river discharge on blue crab abundance were difficult to resolve from model results alone. Coefficients for the effects of discharge on blue crab often appeared with different signs in the same model, indicating the presence of both positive and negative effects at different time lags. A simulation of blue crab abundance with an altered discharge time-series revealed that a decrease in discharge has an overall negative impact on blue crab, but that relatively large changes in discharge would be necessary to influence their long-term abundance to the extent that water temperature does.

Model results for white shrimp indicate that river discharge has an overall positive effect on their abundance, although there was one negative coefficient indicating that high winter discharge at a 1 year lag negatively affects shrimp abundance. A simulation of a decrease in river discharge revealed a positive effect of winter discharge decrease on white shrimp abundance, but negative impacts of reduced discharge in all other seasons. Overall, the results of this study indicate that river discharge is the primary driver of long-term white shrimp abundance trends relative to water temperature, and decreases in discharge negatively impact white shrimp abundance.

6.0.0 FUTURE DIRECTIONS

This study was successful in developing a model in which different hypothetical freshwater flow conditions could be used to assess how various changes in flows would affect the abundances of blue crab and white shrimp. However, only a very basic simulation of an overall 25% decrease in discharge was tested in this study. Testing the effects of more complex flow patterns, such as altering the frequency of pulsed flows or magnitude of high flow events could potentially provide better insight into the effects of freshwater inflows on focal species. Use of output from the water availability model (WAM) that is used by Texas Commission on Environmental Quality (TCEQ) to evaluate water rights applications could also be used to assess the potential effects that different water right usage patterns could have on blue crab and white shrimp abundances. An example of such an analysis for 4 different WAM flow scenarios is presented in Appendix C. This same type of analysis could also be used to evaluate how flow scenarios resulting from changes to TCEQ instream flow standards might affect species abundances.

Although the original structure of the MAR model was not conducive to analysing seasonal time-series of species sampled by gill net in only the spring and fall, the revised modeling method developed in this study is able to handle missing seasons for the response variable without omitting the effects of corresponding seasons for the predictor variables. This means that the revised model could potentially be applied to gill net-sampled species, such as red drum, black drum, spotted seatrout, and southern flounder to assess the effects of water temperature and river discharge on their abundances. Additional species sampled by the other gear types, such as oysters, and the species size and sex data recorded for some of the sampled species could also be considered for future analysis with this model.

The spatial coverage of this study was restricted to the Mission-Aransas and Guadalupe estuaries. Extending the coverage to additional estuaries, such as the Colorado-Lavaca and Nueces estuaries would greatly increase the number of available data points the model can use to estimate the effects of temperature and discharge on species abundances. Additionally, since estuarine conditions are known to vary along a latitudinal gradient on the Texas coast, regional differences in how species respond to environmental conditions in different seasons could be assessed.

REFERENCES

Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Expert Science Team (GSA-BBEST), 2011: Environmental Flows Recommendations Report. Final submission to the Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Area Stakeholder Committee, Environmental Flows Advisory Group, and Texas Commission on Environmental Quality.

Hamlin, L. 2005. The abundance and spatial distribution of blue crabs (*Callinectes sapidus*) in the Guadalupe estuary related to low freshwater inflow conditions. M.S. Thesis, Texas State University, San Marcos.

Hampton, S.E., L.R. Izmest'Eva, M.V. Moore, S.L. Katz, B. Dennis, and E.A. Silow. 2008. Sixty years of environmental change in the world's largest freshwater lake – Lake Baikal, Siberia. *Global Change Biol.* 14: 1947-1958.

Hampton, S.E., E.H. Holmes, L.P. Scheef, M.D. Scheuerell, S.L. Katz, D.E. Pendleton, and E.J. Ward. 2013. Quantifying the effects of abiotic and biotic drivers on community dynamics with multivariate autoregressive (MAR) models. *Ecology* 94(12): 2263-2669.

Howe, J.C., R.K. Wallace, and F.S. Rikard. 1999. Habitat utilization by postlarval and juvenile Penaeid shrimps in Mobile Bay, Alabama. *Estuaries* 22(4): 971-979.

Ives, A.R., B. Dennis, K.L. Cottingham, and S.R. Carpenter. 2003. Estimating community stability and ecological interactions from time-series data. *Ecol. Monogr.* 73: 301-330.

Scheef, L.P. 2013. MAR1: Multivariate autoregressive modeling for analysis of community time-series data. R package version 1.0, Comprehensive R Archive Network.

Slack, R.D., W.E. Grant, S.E. Davis III, T.M. Swannack, J. Wozniak, D. Greer, and A. Snelgrove. 2009. Linking freshwater inflows and marsh community dynamics in San Antonio Bay to whooping cranes. Final Report. Texas A&M AgriLIFE. August 2009. Also known as the San Antonio Guadalupe Estuarine System (SAGES) study.

Texas Parks and Wildlife Department [TPWD] and Texas Water Development Board [TWDB]. 1998. Freshwater inflow recommendation for the Guadalupe Estuary of Texas. Coastal Studies Technical Report No. 98-1. Texas Parks and Wildlife Dept., Austin, Texas.

Texas Parks and Wildlife Department [TPWD] and Texas Water Development Board [TWDB]. 2010. Freshwater inflow recommendation for the Mission-Aransas estuarine system. Texas Parks and Wildlife Dept., Austin, Texas.

Ward, H.G. 2012. The Blue Crab: A Survey with Application to San Antonio Bay. Center for Research in Water Resources.

APPENDIX A

Coefficient values for the original (top) and new (bottom) blue crab and white shrimp MAR models. Coefficients with confidence bounds not overlapping 0 are shown in bold. Coefficients not estimated in the models are indicated by dots.

Blue Crab Years

	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
Lag 0	Blue crab gill	• •	-0.07 -0.06	0.16 0.16	**-0.24** **-0.24**	**-0.28** **-0.30**	**-0.20** **-0.21**	-0.18 -0.19	-0.13 -0.11	0.07 0.10
	Blue crab trawl	-0.07 -0.07	• •	**0.32** **0.28**	0.19 **0.21**	**-0.32** **-0.33**	-0.12 -0.13	-0.10 -0.15	**-0.36** **-0.33**	-0.03 -0.02
	Blue crab seine	**0.24** 0.23	**0.35** **0.32**	• •	• -0.12	**0.27** **0.29**	-0.05 -0.03	**-0.24** **-0.24**	0.13 0.11	• •
	Red drum	**-0.27** **-0.27**	• 0.15	• •	• •	**0.32** **0.35**	0.05 0.07	**-0.29** -0.23	-0.03 0.03	• 0.04
	Black drum	**-0.25** **-0.28**	**-0.26** **-0.27**	**0.21** **0.19**	**0.32** **0.34**	• •	**0.26** **0.21**	**0.26** 0.21	-0.03 -0.03	0.14 0.11
	Spotted seatrout	**-0.24** **-0.26**	-0.14 -0.15	• •	0.08 0.09	**0.32** **0.27**	• •	**-0.30** -0.28	-0.03 -0.04	-0.04 -0.01
Lag 1	Blue crab gill	**0.27** **0.26**	• -0.02	0.05 0.11	-0.06 0.02	-0.19 **-0.26**	-0.05 •	**0.36** **0.34**	-0.10 -0.10	**0.23** 0.15
	Blue crab trawl	• •	**0.35** **0.40**	• •	• •	**-0.17** **-0.18**	• •	• •	**-0.36** **-0.29**	• •
	Blue crab seine	0.19 0.20	• •	0.18 **0.20**	• 0.03	0.17 0.17	0.02 0.02	**0.46** **0.46**	**-0.14** -0.14	**0.35** **0.30**
	Red drum	**-0.23** **-0.22**	• •	• •	**0.22** **0.20**	• •	• •	**-0.20** **-0.22**	• •	• •
	Black drum	**-0.25** **-0.23**	• -0.04	• 0.06	0.07 0.07	**0.39** **0.41**	0.04 •	-0.02 •	0.07 0.09	• •
	Spotted seatrout	**-0.26** **-0.28**	-0.06 -0.04	-0.05 -0.06	0.07 0.06	0.05 •	**0.26** **0.29**	• •	0.11 0.12	**0.16** **0.18**
Lag 2	Blue crab gill	**0.17** 0.14	• -0.15	• •	**-0.22** •	• **-0.20**	• •	**0.34** **0.35**	• **-0.18**	• •
	Blue crab trawl	0.04 0.11	**0.34** **0.35**	-0.09 -0.12	-0.14 •	**-0.23** **-0.25**	• •	**0.38** **0.35**	**-0.17** **-0.18**	**0.26** 0.23
	Blue crab seine	0.08 0.11	-0.12 -0.13	0.19 0.17	• •	0.16 0.15	-0.07 -0.02	**0.27** **0.29**	**-0.29** **-0.30**	• •
	Red drum	**-0.23** **-0.19**	• •	-0.07 -0.05	0.02 0.06	• •	• •	• 0.21	• •	**0.22** **0.40**
	Black drum	• •	• •	• •	**0.19** 0.13	**0.34** **0.28**	• 0.14	0.07 0.08	0.13 0.14	0.11 0.13
	Spotted seatrout	**-0.36** **-0.38**	**0.16** •	• •	0.11 **0.18**	0.14 •	• •	• •	**0.17** •	• •

Blue Crab Seasons

Lag	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
Lag 0	Blue crab gill	• •	-0.05 -0.05	0.10 **0.12**	**-0.18** **-0.17**	**-0.23** **-0.24**	-0.10 -0.10	-0.16 **-0.19**	-0.12 -0.09	• -0.02
	Blue crab trawl	-0.04 -0.05	• •	**0.17** **0.15**	0.11 0.12	**-0.24** **-0.25**	**-0.16** **-0.16**	**-0.22** **-0.24**	**-0.28** **-0.26**	0.01 0.02
	Blue crab seine	0.11 **0.13**	**0.19** **0.17**	• •	• •	0.12 0.08	-0.02 0.01	**-0.23** **-0.21**	0.06 0.09	• •
	Red drum	**-0.16** **-0.15**	0.09 0.10	• •	• •	**0.35** **0.37**	0.12 **0.13**	**-0.21** **-0.21**	-0.01 -0.01	• •
	Black drum	**-0.19** **-0.20**	**-0.21** **-0.22**	0.11 0.08	**0.34** **0.35**	• •	**0.23** **0.20**	**0.23** **0.20**	-0.06 -0.06	0.11 0.11
	Spotted seatrout	-0.10 -0.09	**-0.16** **-0.17**	-0.02 •	0.13 **0.15**	**0.27** **0.24**	• •	**-0.24** **-0.22**	0.03 0.03	0.02 0.01
Lag 1	Blue crab gill	0.11 0.09	0.02 -0.01	0.08 0.09	-0.10 -0.02	• **-0.12**	**-0.22** **-0.21**	• •	**-0.15** **-0.16**	**0.14** **0.16**
	Blue crab trawl	• •	**0.52** **0.50**	• **0.11**	• 0.06	-0.07 -0.08	• -0.05	• •	**-0.22** **-0.18**	• •
	Blue crab seine	• •	• •	**0.27** **0.27**	• •	• •	-0.04 -0.03	• 0.16	• -0.08	**0.18** **0.31**
	Red drum	• -0.06	0.09 0.08	-0.03 •	**0.17** 0.15	0.09 0.09	**0.14** 0.13	-0.03 -0.04	**0.17** **0.17**	0.11 0.08
	Black drum	**-0.15** **-0.18**	-0.02 -0.03	• 0.05	0.07 0.04	**0.40** **0.42**	**0.18** **0.15**	0.11 •	**0.10** **0.10**	-0.02 **-0.11**
	Spotted seatrout	**-0.20** **-0.25**	-0.04 •	• •	**0.13** **0.15**	0.13 •	**0.23** **0.28**	0.01 0.06	-0.01 •	0.10 0.12
Lag 2	Blue crab gill	**0.14** **0.15**	• •	• •	-0.07 -0.04	**-0.19** **-0.20**	• •	• •	-0.05 -0.03	• •
	Blue crab trawl	0.03 0.05	**0.35** **0.38**	-0.03 -0.04	• -0.02	**-0.16** **-0.14**	• •	**0.29** **0.23**	**-0.27** **-0.23**	**0.30** **0.26**
	Blue crab seine	0.10 0.12	**0.14** **0.13**	0.08 0.09	-0.13 -0.12	**0.19** **0.19**	• •	**0.20** **0.22**	-0.01 •	**0.20** 0.16
	Red drum	-0.10 -0.08	• •	• •	**0.23** **0.21**	0.14 **0.17**	• •	**-0.16** **-0.17**	• •	• •
	Black drum	• •	• •	• •	**0.14** •	**0.46** **0.53**	• •	0.01 •	**0.11** •	• •
	Spotted seatrout	**-0.16** **-0.14**	**-0.23** **-0.16**	-0.09 -0.09	0.03 0.02	0.08 0.09	**0.25** **0.26**	-0.04 •	• 0.06	0.08 0.11

Blue Crab Months

	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
Lag 0	Blue crab gill	• •	0.04 0.02	0.07 **0.08**	**-0.11** **-0.08**	**-0.11** **-0.13**	**-0.10** **-0.10**	**-0.14** **-0.16**	-0.05 -0.03	**-0.09** **-0.10**
	Blue crab trawl	0.03 0.02	• •	**0.10** **0.11**	• •	**-0.09** **-0.08**	-0.07 -0.07	**-0.18** **-0.20**	**-0.18** **-0.18**	0.01 -0.01
	Blue crab seine	0.07 **0.08**	**0.10** **0.11**	• •	0.04 0.05	0.03 0.01	0.02 0.03	**-0.16** **-0.14**	• •	-0.05 -0.04
	Red drum	**-0.09** **-0.07**	0.03 0.03	0.03 0.04	• •	**0.40** **0.39**	**0.09** **0.10**	**-0.17** **-0.16**	**-0.08** -0.06	-0.06 -0.05
	Black drum	**-0.09** **-0.11**	**-0.08** **-0.08**	0.03 0.01	**0.40** **0.39**	• •	**0.17** **0.15**	**0.16** **0.13**	0.01 -0.03	**0.11** 0.08
	Spotted seatrout	**-0.09** **-0.09**	-0.06 -0.07	• •	**0.11** **0.12**	**0.20** **0.18**	• •	**-0.16** **-0.11**	0.03 0.04	-0.01 -0.01
Lag 1	Blue crab gill	**0.19** **0.21**	• •	• •	-0.09 -0.09	**-0.15** **-0.17**	• 0.08	-0.09 -0.09	-0.04 -0.04	• •
	Blue crab trawl	• •	**0.47** **0.46**	0.08 0.06	• •	**-0.13** **-0.12**	• •	• •	**-0.13** **-0.15**	**0.13** **0.15**
	Blue crab seine	0.02 0.01	• 0.08	• 0.07	• •	• -0.04	**0.13** **0.15**	**-0.14** -0.10	• •	0.05 0.06
	Red drum	**-0.17** **-0.16**	• •	• •	**0.25** **0.24**	• •	**0.11** **0.12**	**-0.16** **-0.15**	• •	• •
	Black drum	-0.03 •	-0.04 -0.03	• •	• -0.05	**0.31** **0.34**	**0.16** **0.17**	• 0.06	-0.04 -0.05	-0.02 0.02
	Spotted seatrout	-0.09 -0.08	• •	-0.09 -0.07	-0.03 -0.04	**0.19** **0.21**	**0.16** **0.16**	**-0.16** -0.13	• -0.01	-0.04 -0.08
Lag 2	Blue crab gill	0.14 **0.14**	• •	• •	**-0.23** **-0.18**	• •	• •	-0.06 -0.10	• •	• •
	Blue crab trawl	• •	**0.38** **0.35**	• -0.02	• **0.14**	-0.06 -0.11	• •	• -0.03	**-0.19** **-0.19**	• 0.14
	Blue crab seine	• •	• •	• •	**0.22** **0.21**	• •	• •	**-0.14** **-0.17**	• •	• •
	Red drum	-0.07 •	• •	• •	**0.24** **0.21**	• •	• •	**-0.16** -0.14	• •	• •
	Black drum	**-0.15** **-0.19**	-0.11 -0.09	• •	• -0.08	**0.20** **0.21**	• •	• •	**-0.22** **-0.22**	• •
	Spotted seatrout	**-0.16** •	-0.09 -0.10	-0.11 -0.05	0.14 •	• **0.28**	0.11 •	• •	-0.15 **-0.19**	• **-0.15**

White Shrimp Years								
	Variate	White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
Lag 0	White shrimp trawl	• •	**0.25** **0.20**	-0.16 -0.14	**-0.69** **-0.70**	-0.04 -0.03	-0.09 -0.07
	White shrimp seine	**0.37** **0.33**	• •	• •	**0.33** **0.32**	-0.03 -0.03	• •
	Southern flounder	-0.24 -0.22	• •	• •	**-0.35** -0.12	-0.03 •	**-0.32** •
Lag 1	White shrimp trawl	• 0.15	**-0.23** **-0.21**	**-0.25** -0.10	• 0.22	-0.08 •	**0.25** **0.41**
	White shrimp seine	• •	**0.19** 0.14	• -0.12	• •	**-0.21** **-0.20**	• •
	Southern flounder	• •	0.07 0.08	**0.20** **0.23**	• •	**-0.33** **-0.31**	0.14 0.12
Lag 2	White shrimp trawl	• •	• -0.10	• •	• •	0.16 •	• •
	White shrimp seine	• •	• •	• •	• •	**-0.25** **-0.19**	• •
	Southern flounder	**-0.27** **-0.25**	0.05 0.01	• •	0.10 0.12	**-0.20** **-0.21**	**0.28** **0.28**

White Shrimp Seasons

	Variate	White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
Lag 0	White shrimp trawl	• •	**0.18** **0.16**	• •	**-0.68** **-0.58**	**0.11** **0.11**	**-0.15** •
	White shrimp seine	**0.24** **0.24**	• •	• •	**0.28** **0.27**	0.08 0.10	• •
	Southern flounder	• 0.01	• •	• •	-0.15 -0.16	• •	**-0.30** **-0.28**
Lag 1	White shrimp trawl	• •	• •	**-0.16** **-0.12**	**-0.23** **-0.25**	• •	**0.28** **0.29**
	White shrimp seine	• •	0.12 **0.13**	-0.04 •	• •	-0.10 -0.10	**-0.13** •
	Southern flounder	-0.05 -0.05	• •	**0.34** **0.31**	**-0.21** **-0.19**	• •	0.07 0.07
Lag 2	White shrimp trawl	• •	-0.11 •	**-0.13** •	• •	• •	**0.22** **0.27**
	White shrimp seine	**0.22** **0.19**	• •	• •	**0.17** **0.15**	• •	• •
	Southern flounder	-0.08 -0.09	0.09 0.08	**0.13** **0.12**	**-0.23** **-0.22**	**-0.20** **-0.18**	• •

White Shrimp Months

	Variate	White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
Lag 0	White shrimp trawl	•	**0.11**	•	**-0.46**	-0.05	**-0.13**
		•	**0.10**	•	**-0.48**	-0.05	**-0.13**
	White shrimp seine	**0.12**	•	0.05	•	0.05	-0.04
		0.11	•	0.05	•	0.06	-0.04
	Southern flounder	•	0.06	•	0.02	•	-0.09
		•	0.06	•	0.01	•	-0.08
Lag 1	White shrimp trawl	**0.34**	**0.11**	•	**-0.21**	•	•
		0.33	**0.11**	•	**-0.24**	•	•
	White shrimp seine	•	**0.21**	•	•	**0.18**	•
		•	**0.20**	•	•	**0.18**	•
	Southern flounder	•	•	**0.18**	•	•	-0.08
		•	•	**0.17**	•	•	•
Lag 2	White shrimp trawl	**0.36**	**0.17**	•	**-0.24**	0.13	•
		0.35	**0.19**	•	-0.15	0.11	0.13
	White shrimp seine	•	-0.07	**-0.17**	•	**0.18**	0.08
		•	-0.04	**-0.17**	•	**0.19**	0.07
	Southern flounder	•	•	**0.24**	•	•	•
		•	•	**0.22**	•	•	•

APPENDIX B

R^2 and conditional R^2 values for the regressions for each species included in the original (top values) and updated (bottom values) blue crab and white shrimp MAR models. Values that changed by more than 0.02 are highlighted. R^2 provides a measure of the total variance in the time-series explained by a model. Conditional R^2 is a measure of how much of the change between time-steps is explained by an autoregressive model. Since the lag 0 models were not autoregressive, there are no conditional R^2 values for those models.

Blue Crab

		Years		Seasons		Months	
	Variate	R^2	Cond. R^2	R^2	Cond. R^2	R^2	Cond. R^2
Lag 0	Blue crab gill	0.42 0.45	- -	0.20 0.20	- -	0.08 0.08	- -
	Blue crab trawl	0.39 0.37	- -	0.28 0.27	- -	0.10 0.10	- -
	Blue crab seine	0.26 0.24	- -	0.13 0.12	- -	0.05 0.05	- -
	Red drum	0.36 0.39	- -	0.28 0.29	- -	0.24 0.23	- -
	Black drum	0.51 0.50	- -	0.37 0.37	- -	0.25 0.24	- -
	Spotted seatrout	0.37 0.34	- -	0.25 0.23	- -	0.12 0.10	- -
Lag 1	Blue crab gill	0.32 0.28	0.44 0.44	0.17 0.17	0.47 0.47	0.11 0.12	0.40 0.40
	Blue crab trawl	0.47 0.45	0.34 0.35	0.40 0.41	0.25 0.26	0.32 0.31	0.28 0.29
	Blue crab seine	0.18 0.17	0.48 0.49	0.12 0.14	0.36 0.39	0.06 0.08	0.47 0.49
	Red drum	0.20 0.19	0.37 0.39	0.16 0.15	0.40 0.41	0.17 0.16	0.38 0.39
	Black drum	0.41 0.39	0.29 0.27	0.40 0.39	0.31 0.31	0.16 0.16	0.33 0.33
	Spotted seatrout	0.35 0.34	0.37 0.37	0.27 0.25	0.40 0.39	0.11 0.11	0.41 0.41
Lag 2	Blue crab gill	0.28 0.28	0.60 0.60	0.11 0.10	0.42 0.42	0.08 0.07	0.43 0.42
	Blue crab trawl	0.41 0.41	0.44 0.46	0.36 0.34	0.39 0.38	0.22 0.25	0.29 0.34
	Blue crab seine	0.17 0.19	0.54 0.57	0.08 0.08	0.48 0.48	0.09 0.10	0.53 0.52
	Red drum	0.13 0.15	0.52 0.54	0.17 0.17	0.35 0.38	0.10 0.07	0.37 0.39
	Black drum	0.33 0.32	0.40 0.40	0.30 0.27	0.26 0.23	0.11 0.13	0.42 0.43
	Spotted seatrout	0.36 0.28	0.55 0.50	0.25 0.24	0.39 0.38	0.10 0.13	0.43 0.45

White Shrimp

	Variate	Years R^2	Years Cond. R^2	Seasons R^2	Seasons Cond. R^2	Months R^2	Months Cond. R^2
Lag 0	White shrimp trawl	0.45 0.45	- -	0.35 0.37	- -	0.17 0.18	- -
	White shrimp seine	0.10 0.08	- -	0.07 0.07	- -	0.02 0.02	- -
	Southern flounder	0.08 0.03	- -	0.05 0.04	- -	0.01 0.01	- -
Lag 1	White shrimp trawl	0.20 0.17	0.51 0.48	0.27 0.28	0.52 0.51	0.25 0.26	0.32 0.33
	White shrimp seine	0.08 0.08	0.42 0.46	0.04 0.02	0.45 0.45	0.07 0.07	0.38 0.38
	Southern flounder	0.18 0.17	0.47 0.48	0.15 0.14	0.34 0.39	0.04 0.03	0.41 0.41
Lag 2	White shrimp trawl	0.02 0.01	0.50 0.47	0.09 0.07	0.51 0.49	0.29 0.30	0.34 0.37
	White shrimp seine	0.05 0.03	0.55 0.54	0.04 0.03	0.45 0.46	0.07 0.07	0.51 0.50
	Southern flounder	0.12 0.11	0.50 0.54	0.09 0.08	0.48 0.49	0.06 0.05	0.38 0.39

APPENDIX C

The Water Availability Model (WAM) is used by the Texas Commission on Environmental Quality to evaluate water rights applications. The model estimates the amount of water that would be in a river system based on a specific set of conditions, and output can include estimates of river discharge at specific gaging stations. It is therefore possible to incorporate WAM discharge estimate output into the focal species models from the present study to assess the effects of different flow scenarios on blue crab and white shrimp abundance trends.

Four WAM flow scenarios were selected for the example given here:

1) Natural[1]: estimated natural river flow with no surface water right use and no Edwards Aquifer use
2) Natural EA[2]: estimated natural flow with no surface water right use but with Edwards Aquifer use
3) Run 8 [2]: estimated river flow with current surface water right usage level and Edwards Aquifer use
4) Run 3 [2]: estimated river flow with maximum surface water right usage and Edwards Aquifer use

Table C-1 Summary of the 4 WAM flow scenarios run to acquire river discharge estimates

WAM flow scenario	urface water right usag level	Edwards Aquifer use
Natural	none	no
Natural EA	none	yes
Run 8	current	yes
Run 3	maximum	yes

As there are few surface water rights in the watersheds feeding into the Mission-Aransas Estuary relative to the Guadalupe Estuary, larger differences between various WAM flow scenarios were likely to be seen for the Guadalupe basin. Therefore, WAM discharge estimates were acquired for the U.S. Geological Survey gage stations that were used to approximate flows to the Guadalupe Estuary in the focal species models (08176500 Guadalupe River at Victoria and 08188500 San Antonio River at Goliad)[3].

[1] South Central Texas Regional Water Planning Group & HDR Engineering, Inc., "South Central Texas Regional Water Planning Area, 2011 Regional Water Plan, Volume 1, Executive Summary and Regional Water Plan," San Antonio River Authority, Texas Water Development Board, September 2010, p. 7-30, http://www.twdb.texas.gov/waterplanning/rwp/plans/2011/L/Region_L_2011_RWPV1.pdf?d=1560200019318.
[2] Dr. Kathy Alexander, Texas Commission on Environmental Quality, "Draft Guadalupe – San Antonio River Basin Water Availability Model Input Data Files," Personal Communication with HDR Engineering, Inc., April 11, 2019. These data files were received by "Personal Communication" and identified as "Draft" because TCEQ staff are in the midst of periodic data file updates and such updates have yet to be posted to their website https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/wam.html.
[3] HDR Engineering, Inc., "Simulated Flows at Victoria and Goliad for Four Scenarios," Personal Communication, June 6, 2019.

The WAM discharge output for the 4 flow scenarios consisted of monthly total discharge in acre-feet from Jan 1934-Dec 1989 for each gage station. Coefficients in the focal species models were estimated from discharge time-series with units of logged $ft^3\ s^{-1}$. To make the WAM discharge time-series compatible with the focal species model, they were converted to $ft^3\ s^{-1}$ by multiplying each value by 43,560 ft^3 and dividing by the number of seconds in the respective month. Values were then summed between the stations to get a total monthly flow rate approximation, averaged into the seasonal increments used in the focal species models (winter Jan-Mar, spring Apr-Jun, summer Jul-Sep, fall Oct-Dec), and log transformed (Figure C-1, Table C-2, Figure C-2).

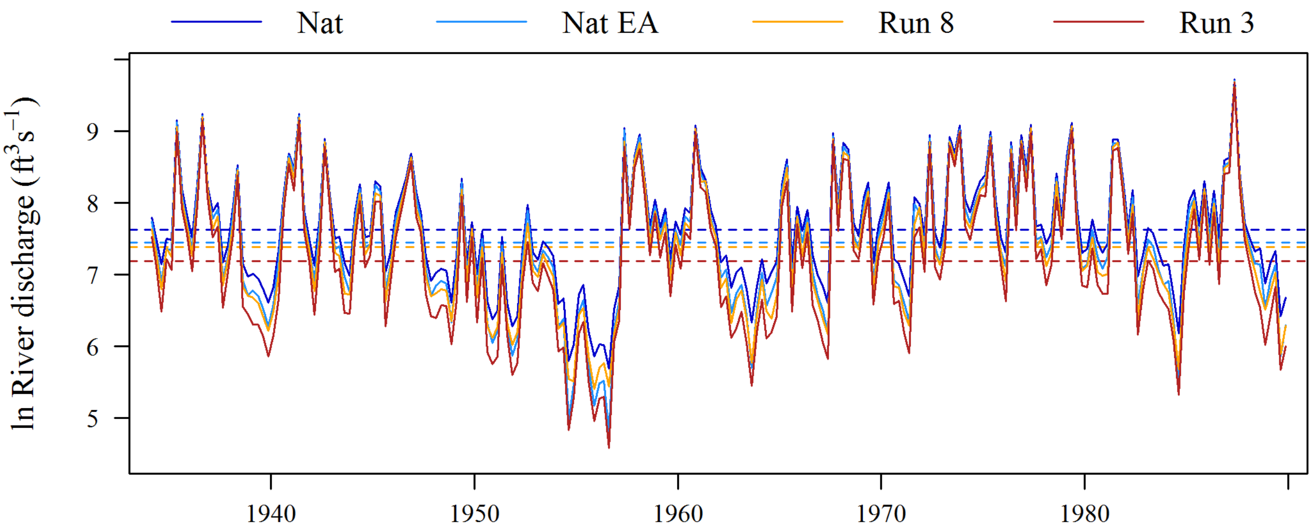

Figure C-1 Seasonal time-series of river discharge based on WAM output for each of 4 flow scenarios: Natural, Natural EA, Run 8, and Run 3 (see Table C-1). Horizontal dotted lines represent overall discharge means for each scenario.

Table C-2 Mean river discharge estimated for the 4 WAM flow scenarios and the percent discharge relative to the Natural scenario.

WAM flow scenario	Mean river discharge ($ft^3\ s^{-1}$)					% Natural discharge
	Winter	Spring	Summer	Fall	Overall	
Natural	2366	3799	2379	2429	2743	100
Natural EA	2100	3519	2098	2157	2469	90
Run 8	1887	3336	1963	2104	2322	85
Run 3	1606	3036	1722	1871	2059	75

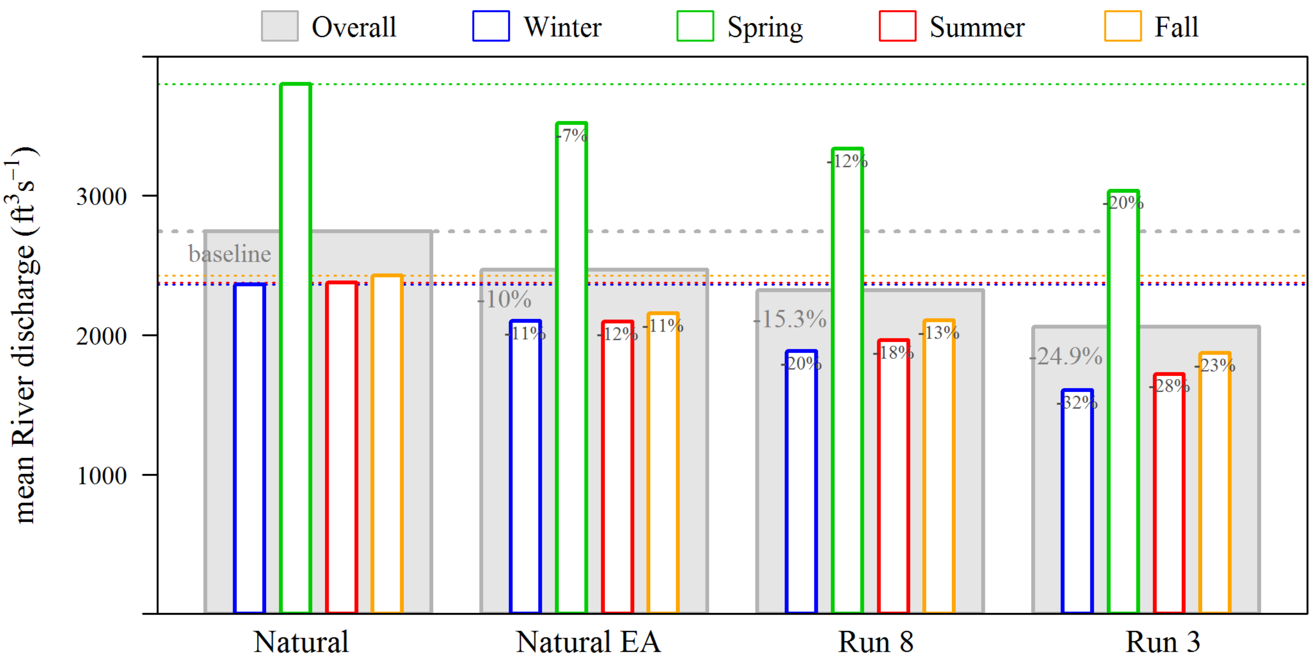

Figure C-2 Overall and seasonal river discharge means estimated for each of 4 WAM flow scenarios. Horizontal dotted lines represent mean discharge values under the Natural scenario. Percent change in discharge using the Natural scenario as a baseline is shown on each bar.

The blue crab and white shrimp models given in Tables 4-2 and 4-5, respectively, were used to estimate abundance trends for each species under each flow scenario. In these models, the water temperature time-series consisted of the seasonal means from the San Antonio Bay TPWD trawl temperature time-series repeated for each year (Table C-3). Initial values for the density dependent terms for each species (Table C-3) were taken as the seasonal means of their abundance time-series estimated with the mean water temperature time-series described here and the measured discharge time-series for the Guadalupe Estuary used in the focal species models (Section 4.3.0). New abundance time-series were calculated one time-step at a time, so that each new estimate was based off of the estimated abundance value at the previous time-step.

Table C-3 Seasonal water temperature means repeated to construct the water temperature time-series and values of blue crab and white shrimp abundance used for initial density dependent terms in the models.

Season	Water temperature (°C)	Blue crab (CPUE)	White shrimp (CPUE)
Winter	15.3	17.4	5.9
Spring	25.4	37.3	6.8
Summer	29.2	11.4	65.3
Fall	19.8	6.2	66.9

Blue crab and white shrimp abundances are both strongly seasonal (see Figure 4-9), so yearly means of the estimates are shown in Figures C-3 and C-4 to more clearly demonstrate long-term temporal trends. See Table C-4 for seasonal and overall mean abundance values for each species under each flow scenario.

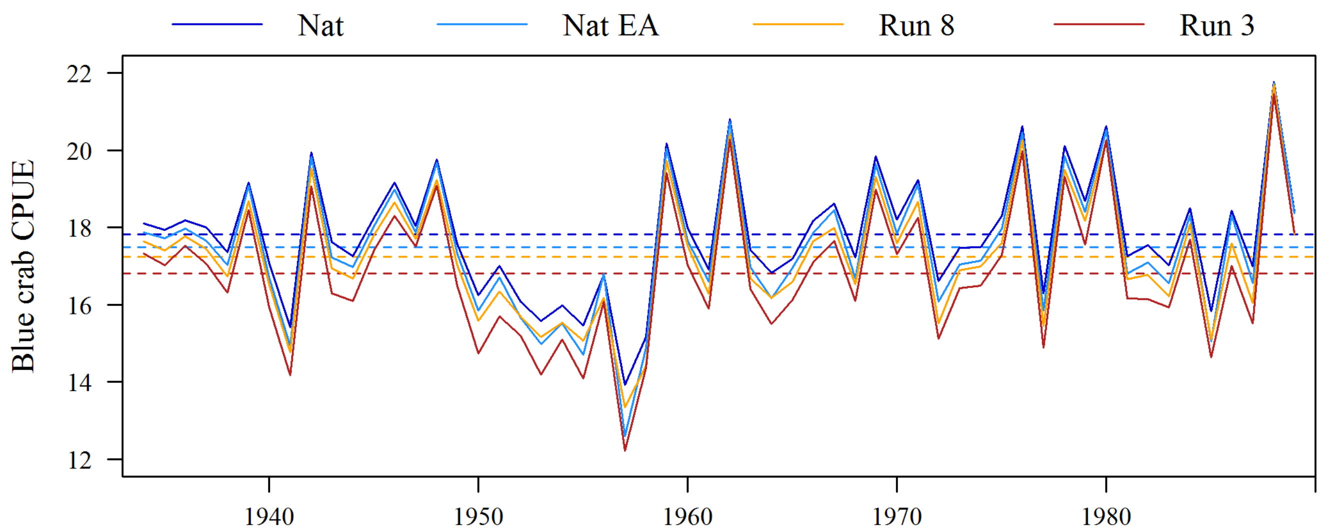

Figure C-3 Yearly time-series of blue crab abundance based on WAM discharge estimates for each of 4 flow scenarios. Horizontal dotted lines represent overall abundance means for each scenario.

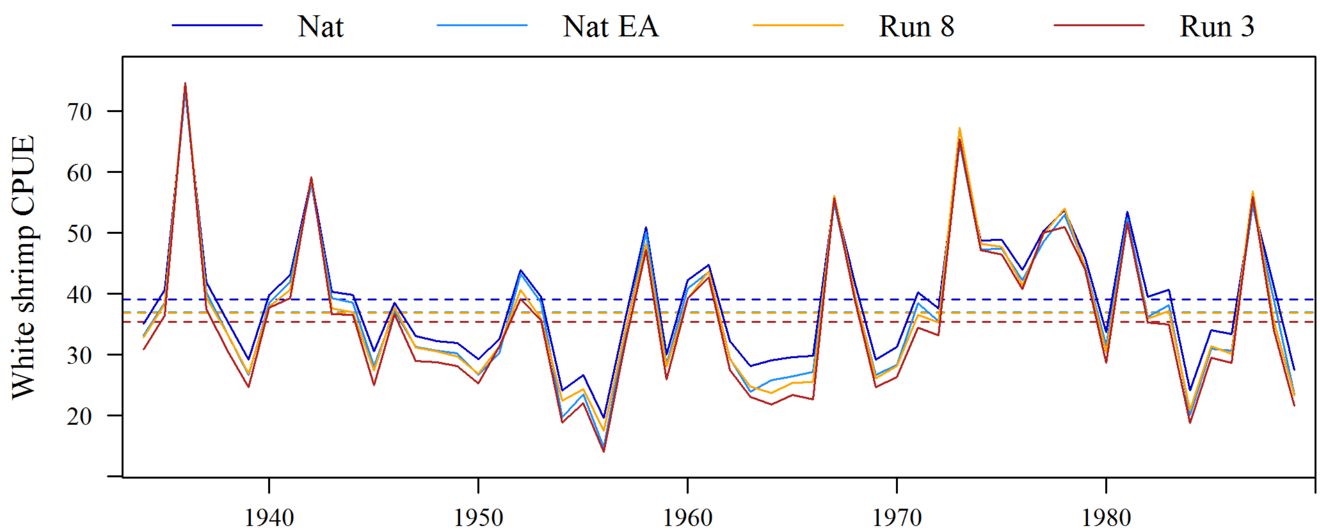

Figure C-4 Yearly time-series of white shrimp abundance based on WAM discharge estimates for each of 4 flow scenarios. Horizontal dotted lines represent overall abundance means for each scenario.

Table C-4 Mean blue crab and white shrimp abundances estimated for the 4 WAM flow scenarios and the percent overall abundance of each species relative to its abundance under the Natural scenario.

Focal species	WAM flow scenario	Mean abundance (CPUE)					% Natural abundance
		Winter	Spring	Summer	Fall	Overall	
Blue crab	Natural	16.9	36.9	11.3	6.1	17.8	100
	Natural EA	16.7	36.0	11.2	6.1	17.5	98
	Run 8	16.3	35.5	11.1	6.1	17.2	97
	Run 3	16.0	34.4	10.9	6.0	16.8	94
White shrimp	Natural	6.3	6.9	72.7	70.1	39.0	100
	Natural EA	6.1	6.7	68.5	66.7	37.0	95
	Run 8	6.0	6.6	68.7	66.0	36.8	94
	Run 3	5.8	6.3	66.0	63.3	35.3	91

Figures C-5 and C-6 depict the overall and seasonal mean abundances for blue crab and white shrimp given in Table C-4. Abundances of both species were negatively affected by decreases in discharge between scenarios, although larger decreases in abundance relative to those under the Natural scenario were seen for white shrimp than for blue crab. Also, it is interesting to note that the changes in relative abundance between flow scenarios are not parallel between the two species (Figure C-7). While blue crab abundance decreases by a fairly consistent increment (~1.9%) between each pair of scenarios, white shrimp abundance does not greatly change between the Natural EA and Run 8 scenarios (<0.5%). Since the abundance models for both species were run with identical temperature and discharge time-series, these inconsistencies can be attributed to differing importance of conditions in certain seasons for each species and differing levels of density dependence. It is possible that, due to such differences, the relatively high white shrimp abundances in the Run 8 scenario reflect positive influences of treated wastewater discharges that are not present in the other flow scenarios and tend to increase low, typically summer and fall, flows above the Natural EA levels.

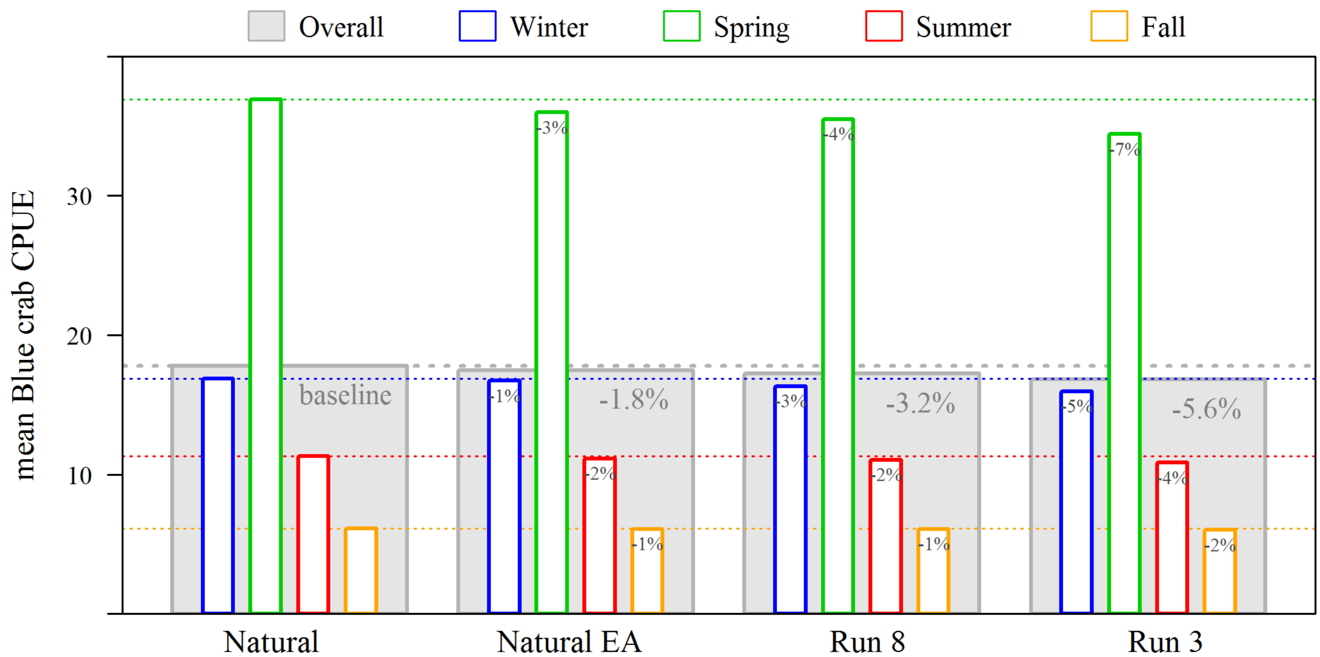

Figure C-5 Overall and seasonal blue crab abundance means estimated for each of 4 WAM flow scenarios. Horizontal dotted lines represent mean abundances under the Natural scenario. Percent change in abundance using the Natural scenario as a baseline is shown on each bar.

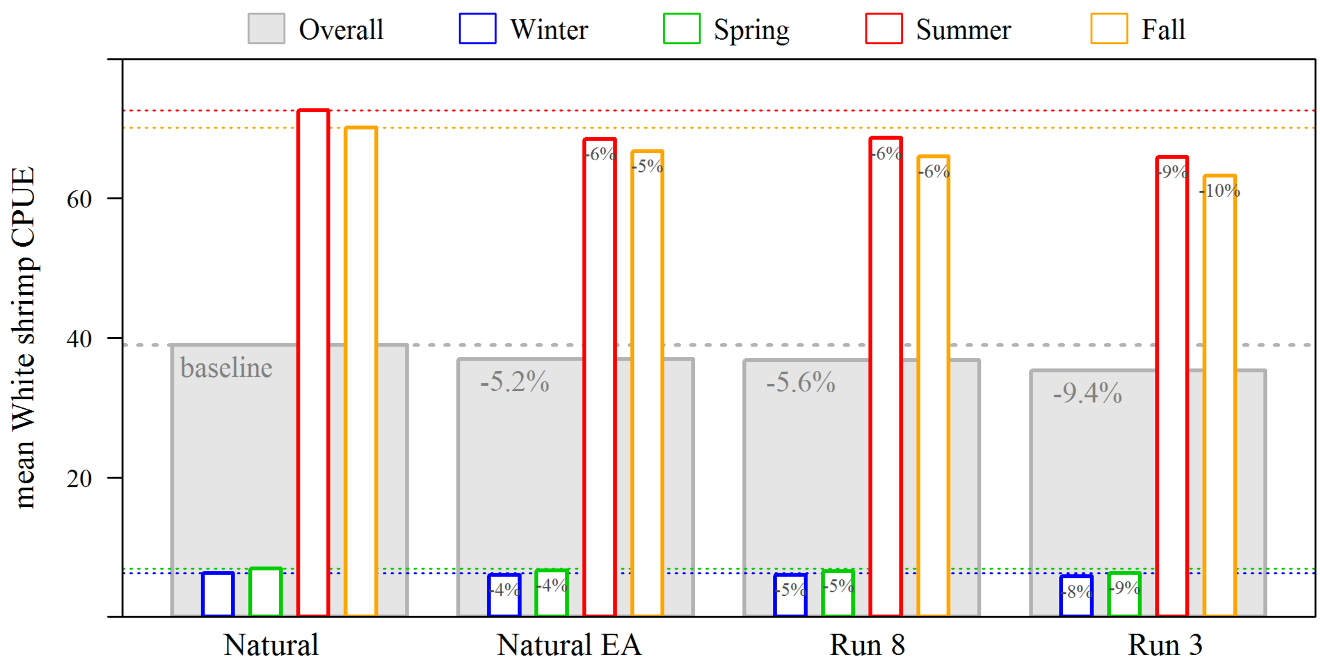

Figure C-6 Overall and seasonal white shrimp abundance means estimated for each of 4 WAM flow scenarios. Horizontal dotted lines represent mean abundances under the Natural scenario. Percent change in abundance using the Natural scenario as a baseline is shown on each bar.

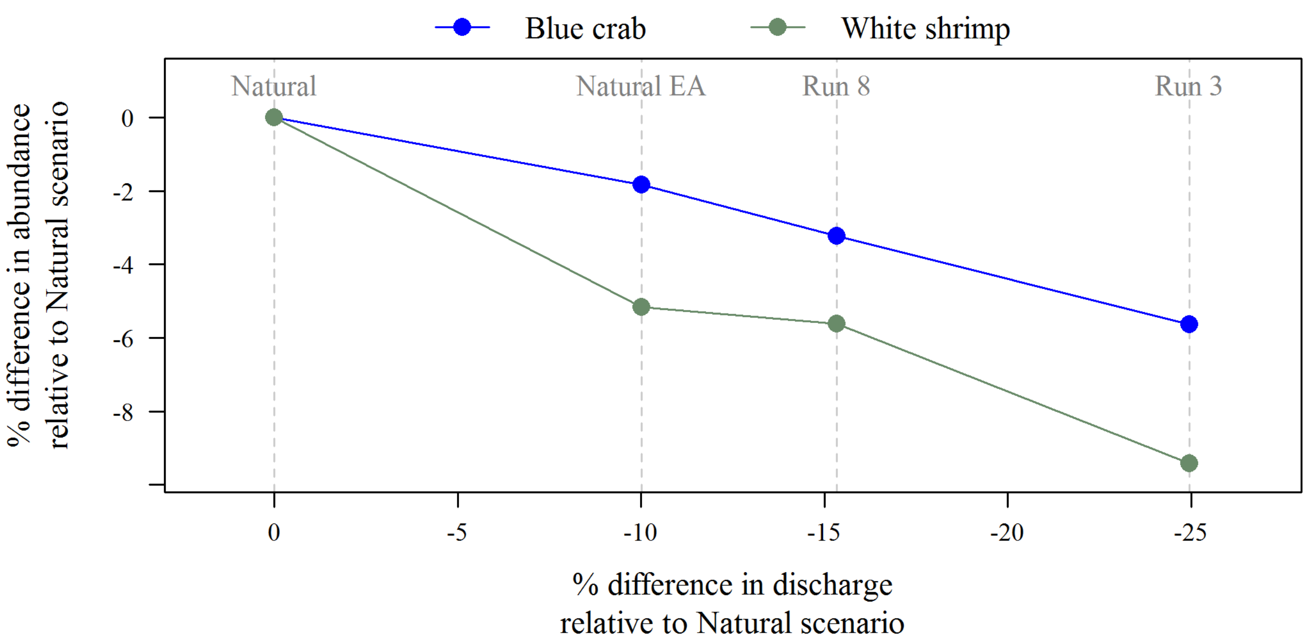

Figure C-7 Percent difference in blue crab and white shrimp abundance for each % difference in river discharge relative to conditions under the Natural flow scenario. Flow scenarios associated with each % difference are marked with vertical dotted lines and labeled in gray.

APPENDIX D

Assessing the effects of freshwater inflows and other key drivers on the population dynamics of blue crab and white shrimp using a multivariate time series modeling framework: Phase 2.

TWDB Contract #1600011966

REQUIRED CHANGES

General Draft Final Report Comments:

This study report presents an evaluation of a multivariate autoregressive (MAR) modeling approach to study the population dynamics of blue crab and white shrimp in the Guadalupe Estuary. The information yielded from this research represents the best available science with respect to estimation of blue crab and white shrimp abundance in the Guadalupe Estuary based on freshwater inflow and temperature. The report is well-organized and well-written, adequately addresses the study goals and objectives as described in the scope of work, and provides tools and insights relevant to informing the validation or refinement of freshwater inflow standards. One reviewer explicitly stated support for the author's suggestions under 'Future Directions' that modeling methods developed in this study could be applied to assess the effects of seasonal river discharge and water temperature on finfish and oyster abundances.

1. Please add the following corrections (underlined) to the statement on the cover page of the final report:
   Pursuant to <u>House Bill 1</u> as approved by the <u>84th</u> Texas Legislature, this study report was funded for the purpose of studying environmental flow needs for Texas rivers and estuaries as part of the adaptive management phase of the Senate Bill 3 process for environmental flows established by the 80th Texas Legislature. The views and conclusions expressed herein are those of the author(s) and do not necessarily reflect the views of the Texas Water Development Board. - Corrections made

2. Please discuss the implications of gear selectivity for the focal species (*i.e.*, how well the selected gears capture shrimp and crab) on interpretation of model results. Please refer also to comment #7 under the next section labeled 'Specific Draft Final Report Comments.' This discussion can be included in a section of the report determined by the author.
   - Details on the spatial and size selectivity of the gear types was added to Section 3.4.2. Sections 4.4.1 and 4.4.2 contain discussion on how selection for larger/older and potentially migratory individuals affects interpretation of model results

3. Please minimize the use of acronyms so that readers aren't required to search the document for the significance of the acronym upon each encounter.
   - The 5 acronyms that are used multiple times throughout the paper have been re-defined more frequently

Specific Draft Final Report Comments:

1. Section 1.0.0, Project Overview, Page 1: Please add an executive summary of results to the project overview.
   - Summary of results was added to overview

2. Section 2.3.0, Background, Phase 1 summary, Page 4: Please clearly define the focal and predator species in the text and refer to Table 2-1.
   - Text was updated

3. Section 3.1.0, Methods, Data acquisition and preparation, Page 6:
   a. Please provide a brief rationale for excluding samples taken from small, shallow bays and lakes. Likewise, Espiritu Santo Bay was dropped later because it was “not well aligned” with others. Please define “not well aligned” and discuss relevant implications or additional insight into the flow ecology of these bay systems, given that Espiritu Santo Bay is an exception.
      - More detail added and flow ecology mentioned
   b. Please describe why the more proximate gaging station at Tivoli was not used to estimate discharge into the Guadalupe Estuary (*e.g.*, short period of record).
      - A mention of the short temporal overlap of the Tivoli station time-series with the species abundance time-series was added to the text
   c. The TWDB estimated surface inflow data are presented in Figure 4-4 on Page 16, but there is no description of this dataset. Please add a description of the TWDB estimated surface inflow in the Methods section or remove Figure 4-4 if these data were not used in the analysis
      - Mention of the TWDB surface inflow estimates was removed from the report since these data were not used in any of the final model

4. Section 3.2.0, Methods, Re-run original MAR models, last paragraph, Page 7: Please provide a description of bootstrapping and justification for using 500 iterations, as bootstraps typically use a larger number of iterations.
   - Text was updated to indicate that this number of iterations is often used in ecological MAR analyses

5. Section 3.3.0, Methods, Reformat data into seasonal increments, second paragraph, Page 7: Please provide an expanded description of the cubic smoothing spline method including justification, purpose, caveats and assumptions for the selection of this interpolation method for seasonal trends. The use of this interpolation method assumes a pattern in the months between gill net samples. Please discuss how the interpolated pattern created for the gill nets match the monthly patterns for the gears which have year-round data. As well, in the results section, clearly label which sections of analysis are

based on the seasonal interpolated data. If feasible, please provide fit statistics for the interpretation within the results section. If the cubic smoothing spline method was not used to develop the final models and is not relevant to the final study results, please clearly indicate this or remove the discussion entirely.
- Text was altered to clarify that these interpolated time-series were not ultimately used in the models and are not relevant to the results

6. Section 3.3.0, Methods, Reformat data into seasonal increments, Pages 7–8: Please include in an appendix, in graphical or tabular form, the raw data of the monthly estimated values of CPUE alongside the sample CPUE for each variable to allow for complete reproduction of the analysis by other researchers.
   - Text was altered to clarify that these interpolated time-series were not ultimately used in the models and are not relevant to the results

7. Section 3.4.2, Methods, Revised methods, second paragraph, Page 9: Please include a discussion about the degree to which patterns match between the otter trawl data series and the omitted gill net and bag seine data series. The use of trawl-only data makes an assumption that this data set is truly representative of abundance patterns for these species, but the degree to which this may or may not be the case has implications for interpreting results from the simplified model structure. This discussion could also be included in Section 4 where model results for the simplified model are discussed.
   - Section 3.4.2 was updated with more detail on why the trawl data were used and the gill and seine data were omitted

8. Section 3.4.2, Methods, Revised methods, Pages 9–10:
   a. In the description of the revised modeling methodology, it is stated that several of the predictor values such as salinity and predator species abundances were removed because they were affected by freshwater inflows, and if estimated as a function of freshwater inflows would introduce increased error and cross-correlations into the final models. Please describe the calculated potential error from cross-correlation effects between freshwater inflows and water temperature in the revised modeling methodology (*e.g.*, visual inspection of some of the graphs such as Figure 4-3 and 4-4 seem to indicate a strong inverse relationship between these parameters).
      - These 2 variables do seem correlated, but correlations are actually small and not significant. This statement was added to section 3.4.2
   b. In the description of the revised modeling methodology, it is stated that white shrimp abundance for lags of greater than 1 year were not included because the white shrimp life span only lasts for one year and that lags of greater than 2 years were not included for blue crabs because this was the extent of the blue crab life span. Please describe how the inherent seasonal bias of trawl sampling for migratory species is accounted for in the model (*i.e.,* pre-juvenile life stages and

reproducing females of the focal species are unlikely to be counted with this methodology during significant portions of the winter and spring sampling seasons).

- The seasonal bias of trawl sampling was not accounted for in the models, which was the likely cause of poor model fits for certain seasons. This is stated in the first paragraphs of sections 4.4.1 and 4.4.2

9. Section 3.4.2, Methods, Revised methods, last paragraph, Page 11: As a reminder, please submit the data and annotated R code used to compile the final models to the TWDB with the final report.

Figures and Tables Comments:

1. Figure 3-1, Page 8: Please label the x-axis with “Month.”
   - This figure was deleted

2. Figure 4-1, Page 14; Figure 4-2 and 4-3, Page 15; Figure 4-4, Page 16: Please ensure consistent, uniform axis labels throughout the report. The orientation of the year (*e.g.*, 1985) on the x-axis in these figures is inconsistent with others, such as Figure 4-9, Page 22; and Figure 4-10, Page 23.
   - Where space constraints required year labels to be rotated, the figures were edited so the orientation of the labels is consistent

3. Figure 4-4, Page 16: Aransas Bay and Espiritu Santo Bay are represented in the legend, but the data are not included in the figure. Please make the appropriate correction.
   - Figure legend was corrected

4. Figure 4-9, Page 22: Figure 4-9, Page 22: Please add a space between “springsummer” in the x-axis label.
   - No species abundance estimations were used in the final seasonal models. The text was clarified and the spacing was fixed

5. Table 3-1, Page 11: Please add a dash “-“ or other symbol if there are no values and mention this in the figure caption.
   - Dashes were added to the table

6. Table 4-2, Page 24 and Table 4-5, Page 27: Please explicitly state what the green and red colored values represent.
   - Table captions were edited to include this information

7. APPENDIX A, Page 39: Please add a dash “-“ or other symbol if there are no values and mention this in the text.
   - Symbols were added where no values were estimated

SUGGESTED CHANGES

Specific Draft Final Report Comments:

1. Section 2.1.0, Background, Page 3: Where applicable, please clarify whether the author intends to mean “density” or “CPUE” when stating “abundance” which refers to counts of individuals or relative abundances.
   - Text was edited to clarify that, when referring to the TPWD data, “abundance” refers to “CPUE”

2. Section 2.2.0, Previous studies, Page 3:
   a. Please define “calculated salinity zones” and describe the association between white shrimp and the salinity gradient, including whether the association is positive or negative.
      - A brief description of salinity zones was added, and the word “positive” was added to describe the association between white shrimp and freshwater inflows
   b. Please define “habitat structure” and provide a citation for the suggestion that the apparent relationship between shrimp abundance and salinity is due to an underlying correlation between salinity and habitat structure.
      - An example of habitat structure and an example reference were added
   c. Please give a few examples of the additional factors that covary with salinity that affect the distribution of white shrimp.

3. Section 2.3.0, Background, Page 5, regarding model variables: Please consider providing both the scientific and common names for these species. Then, defer to using common names throughout the report.
   - Scientific names were added

4. Sections 3.0.0 and 4.0.0, Methods, Analysis and Results: Discussion at the Guadalupe-San Antonio Basin and Bay Area Stakeholder Committee meeting on March 25, 2019 resulted in a suggestion to utilize WAM output for inflow scenario assessment, and relevant time series of scenario flows (*i.e.*, Natural, Natural with Edwards Aquifer Habitat Conservation Plan (EAHCP), Run8, & Run3) have been provided by HDR in cooperation with TCEQ. While not a requirement in the scope of work, if there is sufficient time please consider adding a brief section in the report or appendix comparing simulated differences in focal species abundance for hydrologic scenarios ranging from natural to fully permitted surface water use. Also, please modify the first paragraph in Section 6.0.0, Future Directions (Page 37) in accordance with this information.
   - This analysis was added as Appendix C and the text was updated

5. Section 3.1.0, Methods, Data acquisition and preparation, Page 6:

a. Please consider the possibility that the Tivoli gage is a more accurate representation of inflow to the bay. Consider conducting a comparison between the streamflow at Tivoli (*e.g.*, 2000 – 2015) and the sum of streamflow at Guadalupe River-Victoria and San Antonio River-Goliad (*e.g.*, 2000–2015). It would be helpful to know how the well the sum discharge corresponds with the Tivoli discharge, especially if there are certain aspects of the flow regime (*e.g.*, low flows, some smaller flow pulses) that are evident at Guadalupe at Victoria and San Antonio at Goliad but not at Tivoli.
- A more detailed discussion of the discharge differences between gages was added

6. Section 3.2.0, Methods, Re-run original MAR models, Page 6, first paragraph of this section: Consider adding a sentence to explain the need for log-transformation of raw data (*e.g.*, to address non-normal, skewed distributions).
- Explanation was added

7. Section 4.0.0., Analysis and Results, throughout: The authors have used Coefficient of Determination (R^2) as the statistical index to determine variability in the data and MAR models but there are several other indices that demonstrate correlation between observed and modelled data. Please provide a justification including some reference for using this index.

8. Section 4.2.0, Analysis and Results, Updated MAR models, Page 17: Please consider expanding this section to include a discussion on the relevancy and value of updating original MAR models with two additional years of data. A lot of information is provided to show correspondence between MAR analyses with updated data and original models, but the added value of this exercise is not clear.
- A brief statement describing why the patterns detected in the original models were verified before proceeding with the seasonal modeling exercise was added to the Overview

9. Section 4.3.0, Analysis and Results, Seasonal time-series, Page 21: This section includes several graphs with linear trend lines, but please consider deleting non-significant trend lines, providing a table with P-values for each trend line, or adding P-values for the slope to each graph. By convention, trend lines are not used unless the trend (slope) is different from zero.
- The line types of the trend lines were re-formatted to indicate p-values

10. Section 4.4.1, Analysis and Results, Blue Crab, Page 26, last paragraph of this section: Consider adding a sentence noting that the R^2 of 0.52 for step-wise blue crab abundance estimates exceeds the R^2 of 0.45 for blue crab harvest estimates used in the cited 1998 TPWD/TWDB Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas.

- This comparison was not added, in part because the harvest estimate R2 value referenced in this suggestion was not included in the 1998 TPWD/TWDB report or in the 2011 Region L Water Plan. There is therefore no published citation for this value

11. Section 4.4.2, Analysis and Results, White Shrimp, Page 28, last paragraph of this section: Consider adding a sentence noting that the R^2 of 0.64 for step-wise white shrimp abundance estimates exceeds the R^2 of 0.54 for white shrimp harvest estimates used in the cited 1998 TPWD/TWDB Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas.
    - This comparison was not added, in part because the harvest estimate R2 value referenced in this suggestion was not included in the 1998 TPWD/TWDB report or in the 2011 Region L Water Plan. There is therefore no published citation for this value

12. Section 4.5.1, Analysis and Results, Blue Crab, second paragraph, Page 31: Consider deleting Appendix C and the corresponding sentence, "For details on how these altered flows relate to the base and subsistence flow standards set by TCEQ for the flow gage stations included in this analysis, see Appendix C." Potential comparisons using information presented in Appendix C can easily be misleading without supplemental information. For example, the seasonal "base" flows in the TCEQ standards for the Guadalupe River gage are adjusted "base" flows for <u>wet</u> hydrologic conditions while the base flows for the San Antonio and Mission Rivers are for <u>average</u> hydrologic conditions. Furthermore, seasonal subsistence flows for the Guadalupe River are statistically-calculated values (*i.e.*, medians of the lowest 10% of seasonal base flows), while the subsistence flow for the San Antonio River is based on temperature and dissolved oxygen modeling (and is the same for all seasons) and the subsistence flow for the Mission River is the Q95 value for three seasons.
    - Appendix C was replaced with the WAM discharge time-series analysis results and references to the appendix were edited accordingly

13. Section 4.5.2, Analysis and Results, White Shrimp, second paragraph, Page 34: Consider deleting Appendix C and the corresponding sentence, "For details on how these altered flows relate to the base and subsistence flow standards set by TCEQ for the flow gage stations included in this analysis, see Appendix C." See comment 12 immediately above for explanation.
    - Appendix C was replaced with the WAM discharge time-series analysis results and references to the appendix were edited accordingly

14. Section 5.0.0, Conclusions, first paragraph, Page 36:
    a. Consider adding a sentence highlighting the finding (described on Page 10) that omission of salinity and predator species as predictor variables avoids introduction of cross-correlations and increased error with very limited reductions in model fits (*i.e.*, decreases in R^2 values by less than 0.05). This is an important

conclusion that might otherwise be overlooked.
- Statement was added

b. Please add quantitative ranges to descriptions such as “high summer water temperatures” (*e.g.*, > XX°C) and “decreases in discharge” (*e.g.*, < X amount of discharge in cubic feet per second) to clarify for the reader what exact values are being referred to. Please also consider adding the percent of time these summer time temperatures were exceeded during the period of data collection.
- It is more the directions of the relationships than exact values that are being discussed here. Increases in temperature or decreases in discharge of any amount will have the described effects on focal species abundances

c. Please consider synthesizing these findings in relation to similar studies/scientific literature and to the life history of white shrimp (*e.g.*, highlighting mechanistic relationships between temperature and life history strategies).

15. Section 6.0.0, Future Directions, Page 37: Please consider sharing your vision on the application of the models as a tool for validating the environmental flow standards. Reducing inflow by 25% was done as a proof of concept to illustrate that the models for white shrimp could be modified for different hypothetical freshwater inflow conditions. Please consider highlighting or expanding the discussion on this point. While reducing discharge by 25% doesn’t necessarily address the validation of the TCEQ standards, it does demonstrate the concept. Consider discussing specific details on how these models can be used for different scenarios related to TCEQ standards (*e.g.*, removing two per season flow events) and mention how the model would need to be revised/changed to address this scenario.
- A reference to Appendix C where the species abundance models were run with TCEQ WAM flow scenarios and a statement of how this type of analysis can be used to assess the effects of changes to the TCEQ flow standards were added to this section

Figures and Tables Comments:

1. All figures: Please consider increasing the font size of axis labels for easier visualization.
- The font size of axis labels was increased where space allowed