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

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PURSUANT TO SENATE BILL 1 AS APPROVED BY THE 83RD 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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ABSTRACT

Natural freshwater inflow (FWI) from rivers, streams, and rainfall maintains nutrients, sediments, and salinity regimes within estuaries. These factors, together, produce a healthy and sustainable estuary for juvenile and adult finfish and invertebrates that utilize an estuary for foraging, refuge, and reproduction. Other key drivers, such as droughts and human contributed impacts have negative effects on estuaries. Reduced FWI can affect the population dynamics of commercially and ecologically important species such as blue crab, *Callinectes sapidus*, and white shrimp, *Litopenaeus setiferus*. Past studies have indicated that less FWI is reaching the Texas coast, but little work has been done to evaluate the impacts of inflow variability on focal species inhabiting Mission-Aransas and Guadalupe estuaries. This two-part report 1) reviews studies related to blue crab and white shrimp abundances in the Mission-Aransas and Guadalupe estuaries, and 2) describes a multivariate autoregressive (MAR) analysis of the long-term Texas Parks and Wildlife Department (TPWD) fisheries independent survey species abundance data done to assess the effects of FWI and other potential drivers on local abundances of blue crab and white shrimp in the Mission-Aransas and Guadalupe estuaries.

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Part I: Literature Review

The Impacts of Freshwater Inflow and Other Key Drivers on the Population Dynamics of Blue Crab and White Shrimp in the Mission-Aransas and Guadalupe Estuaries in Texas

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1.0.0 INTRODUCTION

The health and resilience of estuarine ecosystems are maintained by freshwater inflow (FWI) as well as water exchange with the coastal ocean. FWI not only provides nutrients to support primary production in coastal environments, but also helps regulate salinity and sustain appropriate habitat for local estuarine species (Longley, 1994; Kim and Montagna, 2009). In the northwestern Gulf of Mexico (GoM), Aransas, Copano, and San Antonio bays of southeastern Texas are mainly fed by four major rivers, with the first two bays (the Mission-Aransas Estuary) being supported by both Aransas and Mission rivers, and San Antonio Bay (the Guadalupe Estuary) by both Guadalupe and San Antonio rivers.

However, growing human pressures, including climate change, are having profound effects on FWI into estuaries. Humans are becoming increasingly involved in FWI management by influencing the quality, quantity, and timing of freshwater input to marine systems (Alber, 2002). Historic studies have indicated reductions in FWI have been and will be a potential threat to the sensitive coastal ecosystems of Texas (Chapman, 1966; Kalke, 1981; Kim and Montagna, 2009). Direct effects of declines in FWI may increase estuarine salinities and decrease the deliveries of nutrients, organic matter, and sediment, which in turn, potentially affect the distribution and abundance of estuarine biota.

Shrimp and blue crab (*Callinectes sapidus*), are among the top three most valuable commercial fisheries species in Texas (Hammerschmidt et al., 1998; TPWD, 2002). White shrimp, *Litopenaeus setiferus*, are the second most important shrimp fishery species in Texas (contributes 25% of total shrimp landings). However, both blue crab and white shrimp fisheries have undergone significant downward trends in catch per unit effort (CPUE) since the mid 1980s in Texas (TPWD, 2002; Ward, 2012). In Guadalupe Estuary, for example, Johns (2004) suggested that without adequate FWI from the Guadalupe River, several fishery species including blue crab, shrimp, oyster, striped mullet, and gulf menhaden would decline dramatically. The effects of FWI do not act in isolation. Additional regional pressures on blue crab and white shrimp in Texas might include fluctuations in water temperature (Baker and Minello, 2010), low dissolved oxygen (Rabalais et al., 2001; Zimmerman and Nance, 2001), habitat change or loss (Rozas et al., 2007), parasitism and disease (Messick et al., 1999), and predation pressure from red drum and whooping cranes (Scharf and Schlicht, 2000; Pugesek et al., 2013). It is suggested that multiple factors must be included to understand the mechanisms underlying the population dynamics of estuarine blue crab and white shrimp (see Part II of this report).

There are a limited number of systematic reviews available on the work that has been done concerning FWI reduction in the Mission-Aransas or Guadalupe estuaries (e.g. Johns, 2004) and its impact on blue crab and white shrimp (e.g., Ward, 2012). Here, we document changes in FWI to these two estuaries, review the literature related to blue crab and white shrimp populations in the area, and evaluate general impact points from the most recent studies (Table 1.1). FWI management is discussed in Section 6.0.0 (Environmental management implications).

Table 1.1 The number of studies on blue crab (BC), white shrimp (WS), and freshwater inflow (FWI) covered in the present review by location.

Species	Mission-Aransas Estuary	Guadalupe Estuary	Texas	Gulf of Mexico	Atlantic Ocean	Lab	General
BC	6	4	9	13	8	12	3
WS	4	1	11	13	1	2	
FWI	6	7	11	1			4

2.0.0 Changes in FWI

2.1.0 Causes

Alterations in quality, quantity, and timing of freshwater runoff are all considered as changes of FWI into estuaries (Alber, 2002). FWI varies year to year primarily due to variations in rainfall, but it is also affected by changes in other climate factors (e.g., temperature), topography, and soil characteristics (Lanning-Rush, 2000). Human influenced events occurring upstream also play a very important role in these changes. For example, dams and other large upstream water withdrawals directly modify the amount of freshwater that reaches estuaries. Dams could also affect the timing of water delivery by adjusting flooding volume and reducing seasonal variation. In addition, dams upstream tend to affect FWI quality by trapping sediments and the associated materials. This includes particle-active metals, pollution, and changes in the loading of nutrients and organic matter into estuaries. Other human-induced changes of FWI include shifts in land use, channelization of rivers, and construction of control structures (Alber, 2002).

2.2.0 Potential impacts in an estuarine system

FWI is an essential component necessary to maintain the overall health of an estuary (Castillo et al., 2014), and modifications of FWI can have structural and adverse effects on the ecosystem (Russell et al., 2006). A constant decrease in FWI will affect estuarine conditions such as sediment composition and dissolved/particulate organic matter (Longley, 1994; Alber, 2002), as well as primary and secondary production levels (Alber, 2002). It also will increase salinity and cause a decline in marsh, seagrass, and mangrove habitat (Longley, 1994). Changes in salinity are often of primary concern since it is one of the most important environmental variables influencing the distribution of macrofauna in the northwestern GoM, especially in estuarine systems, where salt tolerance plays a vital role (Montagna et al., 2002; Palmer et al., 2002). All of these impacts, in turn, affect species composition, abundance, and distribution.

3.0.0 FWI IN MISSION-ARANSAS AND GUADALUPE ESTUARIES

3.1.0 Data sources

Based on historical data, river inflow is the greatest source of freshwater into Texas estuaries. Freshwater from rivers is much greater than what direct rainfall supplies, which is always exceeded by evaporation when averaged annually. The U.S. Geological Survey (USGS) maintains daily streamflow data from more than 200 streamflow-gaging stations in Texas (http://waterdata.usgs.gov/tx/nwis/rt). From 1941-1976, FWI was calculated monthly using USGS flow-gage data and rainfall-runoff estimates measured from a water yield model that was used to determine monthly flows of ungaged watersheds (TDWR, 1980). Since 1977, flow-gage measurements have been recorded daily and surface flows from ungaged watersheds have been estimated on a daily basis using a rainfall-runoff model (TxRR) based on the curve number method (TDWR, 1981). FWI (i.e., combined FWI) can be obtained from the combined gaged and modeled ungaged runoffs, with diversions (e.g., municipal, industrial, or agricultural use) subtracted and return flows (i.e., surplus wastewater from upstream users) added (Longley, 1994). In a recent report by Tolan (2007), FWI (i.e., FWI balance) was calculated more accurately by adding and subtracting the respective precipitation and evaporation components of an estuary. The observed daily flow-gage data for Mission-Aransas and Guadalupe estuaries can be approximated from a total of eight gage stations (four per estuary) at or near each river basin's discharge point (Table 3.1). The Texas Department of Water Resources (TDWR) and Texas Water Development Board (TWDB) have also published a series of reports regarding FWI information for Mission-Aransas and Guadalupe estuaries (e.g., TDWR, 1980; 1981; 1982; Guthrie and Lu, 2010; Schoenbaechler et al., 2011).

Table 3.1 USGS gaged stations for collecting daily streamflow data at the Mission-Aransas and Guadalupe estuaries, TX (Guthrie and Lu, 2010; Schoenbaechler et al., 2011).

Estuary	Gaged Station No.	Gaged Location	Period of Record
Guadalupe	8176500	Guadalupe River at Victoria	1941-present
	8177000	Coleto Creek near Schroeder	1953-1978
	8177500	Coleto Creek near Victoria	1941-1952; 1978-present
	8188500	San Antonio River at Goliad	1941-present
Mission-Aransas	8189200	Copano Creek near Refugio	1970-present
	8189500	Mission River at Refugio	1939-present
	8189700	Aransas River near Skidmore	1964-present
	8189800	Chiltipin Creek at Sinton	1970-1991

3.2.0 General assessment of FWI rate: historic and current

There are seven estuaries along the Texas coast (Figure 3.1), with a general decrease from north to south in both FWI and rainfall (Table 3.2). Guadalupe and Mission-Aransas estuaries are among them with moderate ($2,664 \times 10^6$ m^3 y^{-1} or 2,160,000 acre-feet y^{-1}) and low (265×10^6 m^3 y^{-1} or 215,000 acre-feet y^{-1}) FWI, respectively (based on 1941-1999 averages that include the precipitation and evaporation components; Tolan, 2007). These values are similar to the values reported by Longley (1994) of 2,340,000 acre-feet y^{-1} for Guadalupe and 430,000 acre-feet y^{-1} for Mission-Aransas estuaries, however these combined FWI values are based on 1941-1987 averages and did not include precipitation or evaporation components. The most recent reports of FWI in Guadalupe and Mission-Aransas estuaries include, for accuracy, the necessary components (i.e., gaged and ungaged flows, diversions, return flow, evaporation, and precipitation) during an approximate 70-year period from 1941-2009, and were conducted by Guthrie and Lu (2010) and Schoenbaechler et al. (2011), respectively (based on TWDB hydrology dataset version #TWDB201004). FWI balance was calculated for Guadalupe and Mission-Aransas estuaries in terms of their annual average values during the ~70-year period as 2,270,000 acre-feet y^{-1} and 280,000 acre-feet y^{-1}, respectively. Although a general but steady decrease in water flow occurs from the northeastern region of Texas near the Louisiana state line due south along the coast to the Mexican border (Kim and Montagna, 2009), annual FWI to Guadalupe Estuary revealed no significant changing trend (p-value = 0.09), while Mission-Aransas Estuary exhibited a slight increase in FWI that was significant (p-value = 0.02) over the ~70-year period (Figure 3.2; Guthrie and Lu, 2010 and Schoenbaechler et al., 2011, respectively).

According to model-derived FWI rates of Guadalupe and Mission-Aransas estuaries from 1941-2009, big variations occurred monthly (Figure 3.3; only for 1941-1987; Longley, 1994) and annually (Figure 3.2) as a result of drought and flood conditions. Drought perhaps has led to the most dramatic reduction in FWI in Texas and is connected to large-scale weather patterns. In 1956, after 10 years of the worst droughts in Texas history, river discharge to the Texas coast dropped approximately 86% below average (Longley, 1994), and FWI in both Guadalupe and Mission-Aransas estuaries reached historic all-time lows (Figure 3.2). On the other hand, for example, elevated FWI to Guadalupe Estuary in 1987 (130% above average) was due to heavy precipitation following an extended wet period that saturated the soil (Longley, 1994). Some of the monthly peaks were attributed to hurricanes and tropical storms. For example, two of the three largest inflow peaks in Mission-Aransas Estuary were recorded during hurricanes.

From 1941-2009, gaged inflow in Guadalupe Estuary accounted for approximately 85% of the combined FWI, while ungaged inflow accounted for nearly 15% of the combined FWI. Gaged inflow in Mission-Aransas Estuary, however, only accounted for 29% of the combined FWI, while ungaged inflow accounted for nearly 70% of the combined FWI. Although a growing population with increasing demands for water is another cause of reduced FWI in the state of Texas, annual freshwater withdrawals (i.e., diversions) from Guadalupe Estuary from 1977-2009 declined

(Guthrie and Lu, 2010). Likewise, annual withdrawals from Guadalupe and Mission-Aransas estuaries accounted for relatively small percentages (only about 3% and 0.03%, respectively) of their combined FWIs. However, there is still uncertainty about future FWIs in these two estuaries. Johns (2004) demonstrated that Guadalupe Estuary will be significantly threatened during periods of low rainfall if all of the currently authorized surface water permits were fully used and if wastewater reuse increased to 50%. Additionally, the possibility of large-scale groundwater contributions, which is still under study, has been indicated as a potentially important component of FWI in Mission-Aransas Estuary, particularly during dry periods (Johns, 2004).

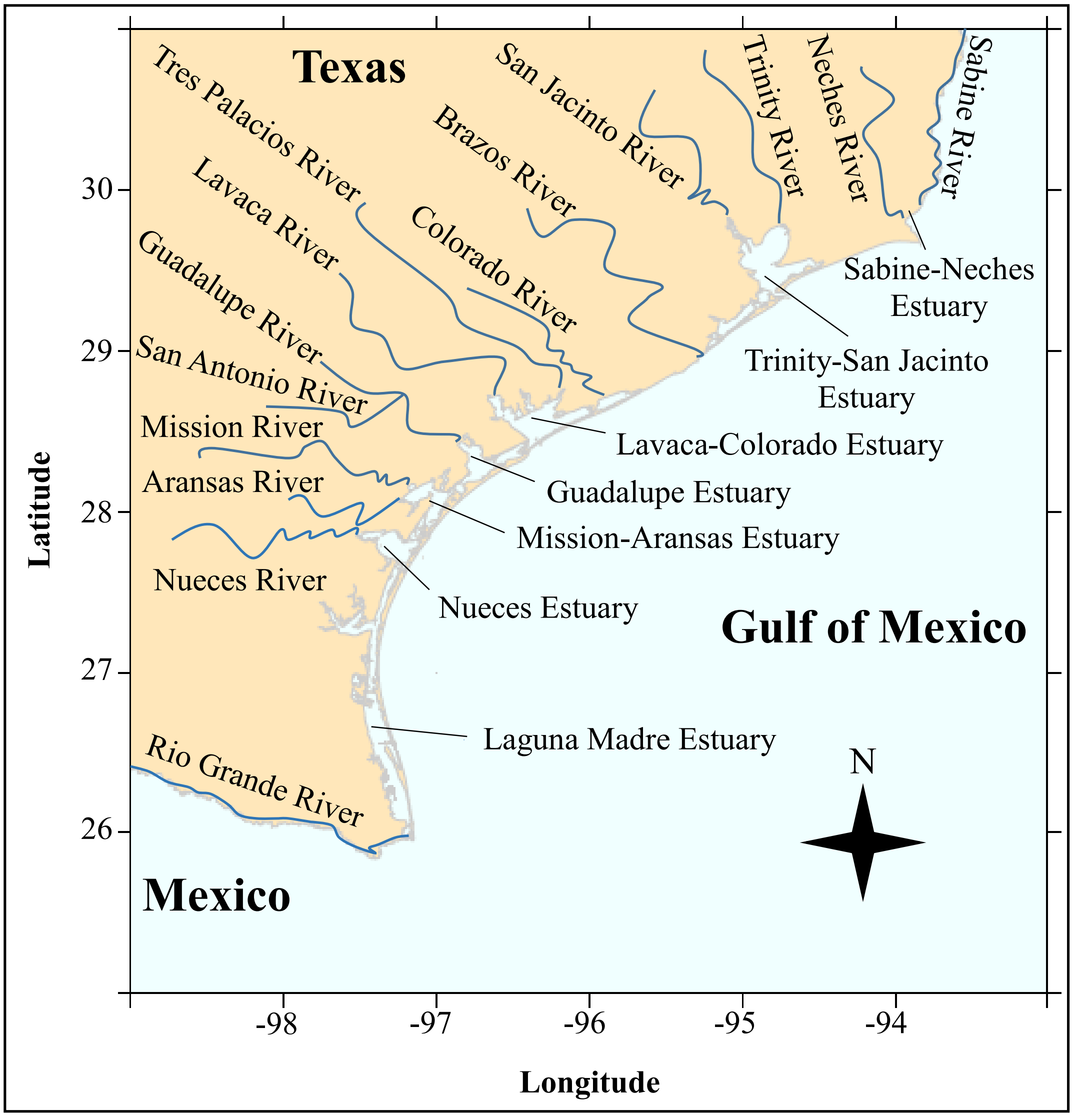

Figure 3.1 Locations of Texas estuaries. Redrawn from Longley (1994).

Table 3.2 Climatic gradients in Texas estuaries, listed north to south. Data from Tolan (2007).

Estuary	Rainfall ($cm\ y^{-1}$)	Freshwater Inflow ($10^6\ m^3\ y^{-1}$)	Salinity (psu)
Sabine-Neches	142	16897	8
Trinity-San Jacinto	112	14000	16
Lavaca-Colorado	102	3801	18
Guadalupe	91	2664	16
Mission-Aransas	81	265	19
Nueces	76	298	29
Laguna Madre	69	-893	36

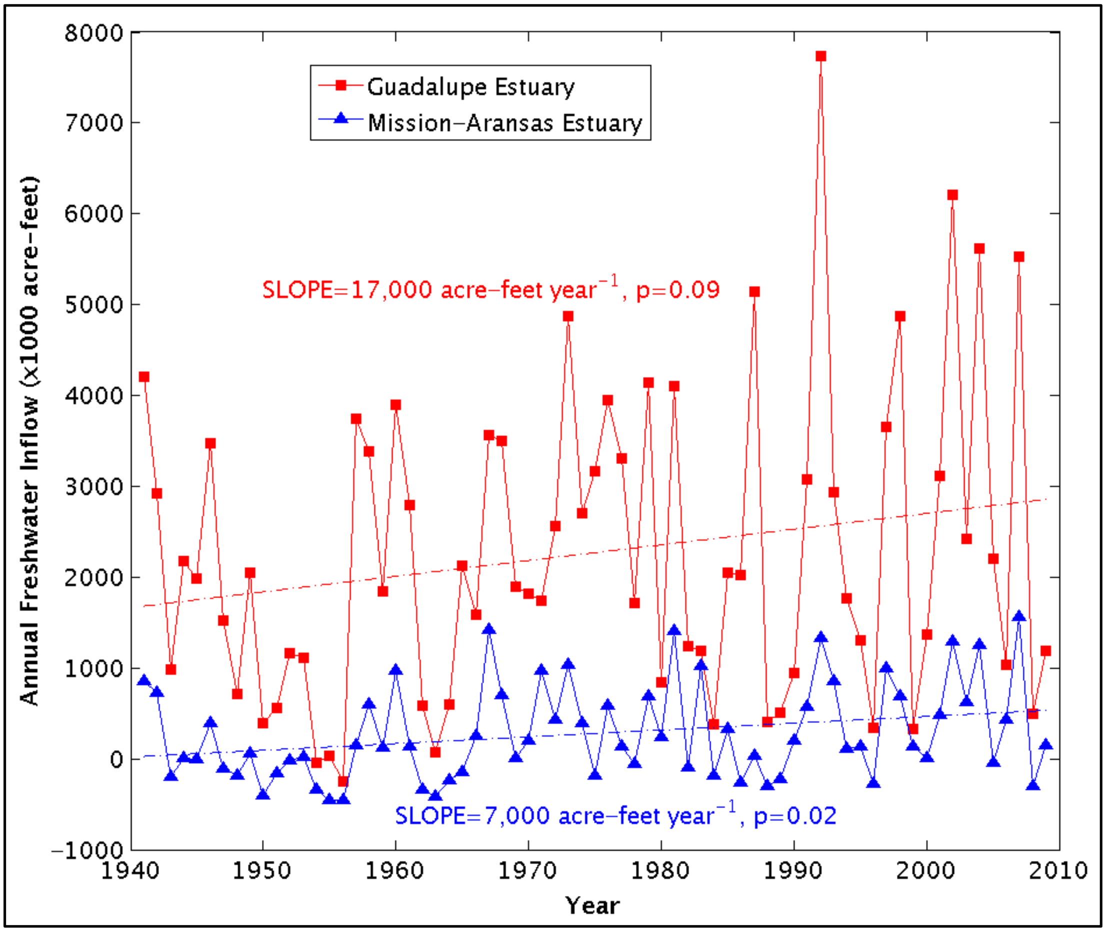

Figure 3.2 Annual FWI from 1941-2009, data for Guadalupe and Mission-Aransas estuaries are from Guthrie and Lu (2010) and Schoenbaechler et al. (2011), respectively. A significant (though small) increase in annual FWI was observed in Mission-Aransas Estuary, but not in Guadalupe Estuary over the approximate 70-year period, based on their respective *p*-values of 0.02 and 0.09.

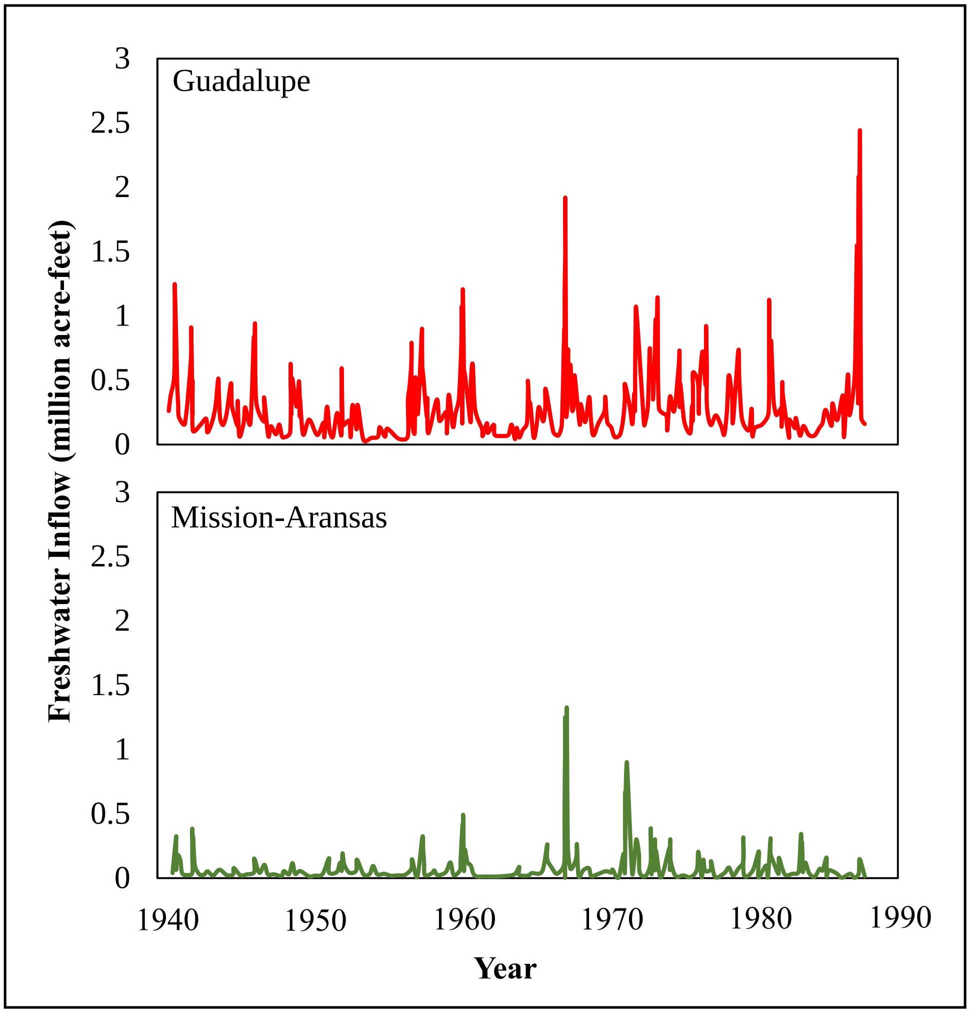

Figure 3.3 Monthly FWI hydrographs of Guadalupe (top) and Mission-Aransas (bottom) estuaries from 1941-1987. Replotted from Longley (1994).

3.3.0 Seasonal variation of FWI

With the influences of spring time precipitation, early autumn hurricanes, and tropical and coastal storms, both Guadalupe and Mission-Aransas estuaries have similar seasonal FWI patterns with two annual inflow peaks in the late spring and the early autumn (Figure 3.4; Longley, 1994). In the Guadalupe River from 1950-2009, no significant changing trend was found for the two streamflow peaks. In the San Antonio River, however, the fall inflow peak increased, possibly due to the heavier autumn hurricanes and storms (Joseph et al., 2013).

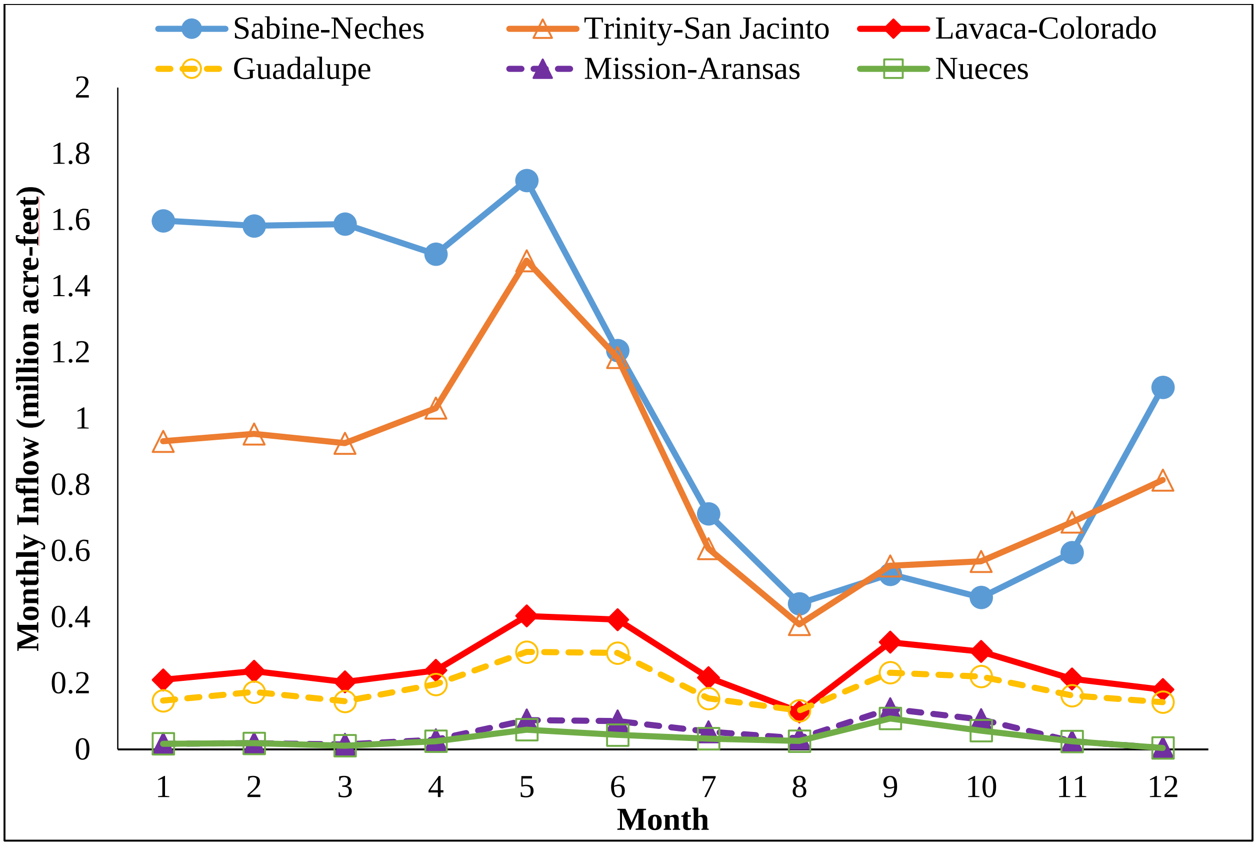

Figure 3.4 Monthly average inflows for the major Texas estuaries. Dotted lines represent Guadalupe and Mission-Aransas estuaries. Redrawn from Longley (1994); based on 1941-1987 averages.

3.4.0 Subsequent changes in salinity

Salinity in Texas estuaries is directly regulated by changes in FWI, but is also influenced by evaporation, precipitation, tidal exchange with saline GoM water, wind, and estuary volume. The estuarine salinity pattern in Texas from 1982-2004 was reported by Tolan (2007) as strongly responsive to the level of rainfall and stream discharge, with high salinities occurring during periods of low streamflow. Although average annual salinities in the Guadalupe and Mission-Aransas estuaries were similar (16 vs. 19 psu; Table 3.2), salinities within Guadalupe Estuary were highly variable, with mean values ranging between 24.14‰ in Espiritu Santo Bay and 5.64‰ near Seadrift (Figure 3.5). In comparison, most salinities recorded in Mission-Aransas Estuary ranged from 10-20‰. Seasonally, a distinct salinity minimum occurred in June in the Guadalupe Estuary while a distinct salinity peak occurred in August in the Mission-Aransas Estuary (Figure 3.5).

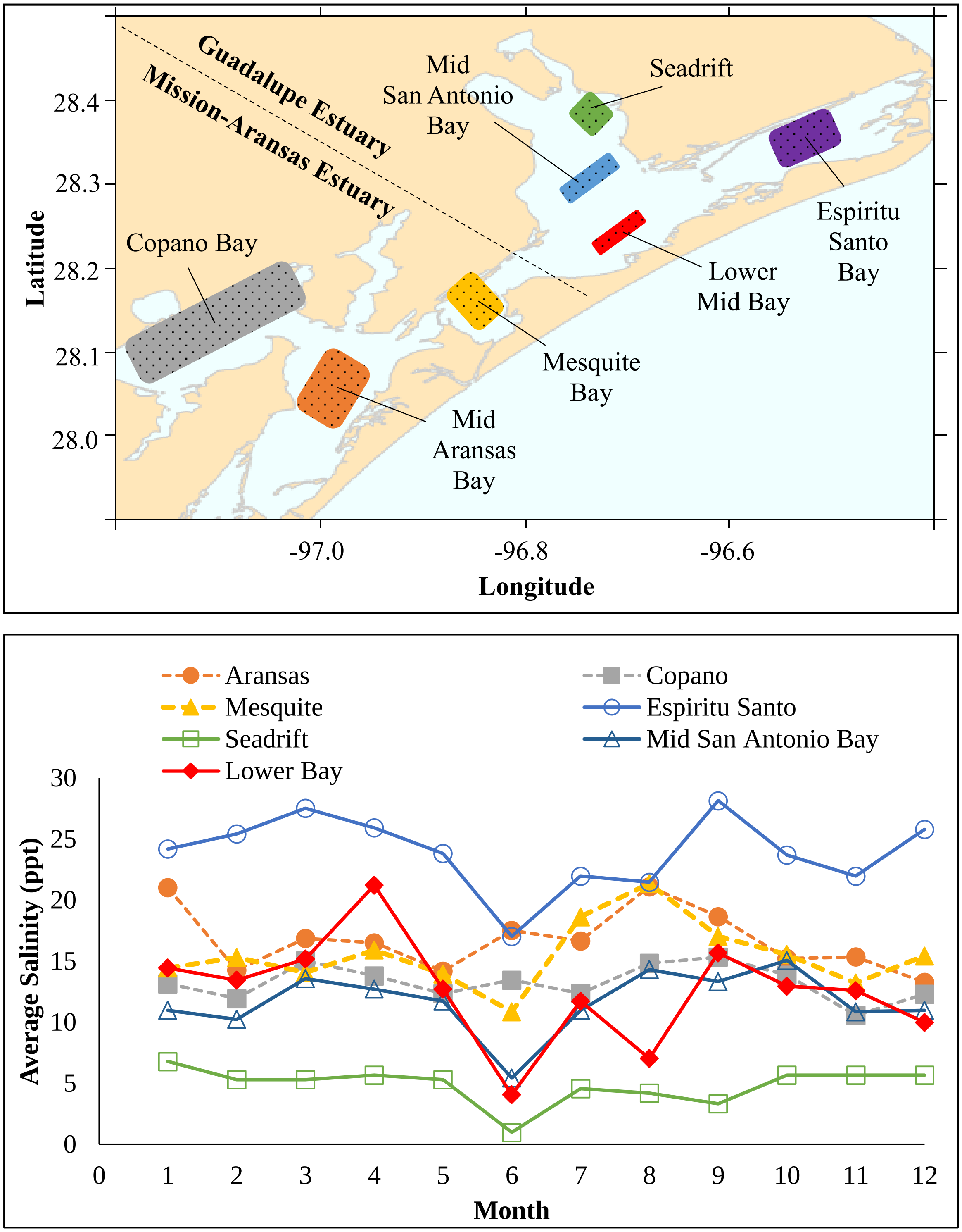

Figure 3.5 Salinity measurement sites (top) and the monthly salinity distributions at each site (bottom) within Guadalupe (solid lines) and Mission-Aransas (dotted lines) estuaries. Data from Longley (1994); based on 1941-1987 averages.

4.0.0 BLUE CRAB

The blue crab, *Callinectes sapidus,* is a commercially and ecologically important invertebrate that dominates shallow and estuarine habitats of the Atlantic and GoM coasts. Blue crab are a nektonic "free-swimming" species that possess modified appendages called swimmerets (Churchill, 1919; Rabalais et al., 1995a; Gandy et al., 2011; Ward, 2012). Blue crab grow via a series of molts and reach sexual maturity at approximately 120 mm carapace width (CW), measured from one spine tip to the other (Osborn et al., 1992). Adult and juvenile blue crab are primarily scavengers, but can also be cannibals (Churchill, 1919). They feed on small fish, crab, and other organisms.

4.1.0 Life cycle

Blue crab migrate between estuary and ocean over the course of their life cycle, and the estuary serves as a nursery for their young. In general, adult female blue crab live and spawn at the mouth of the estuary during the summer months of July and early August. The larvae hatch offshore and develop through seven zoeal stages for 31 to 49 days before they metamorphose to a postlarval or megalopal stage (Costlow and Bookout, 1959; Ward, 2012). After persisting for 6 to 20 days as nekton in nearshore waters (Costlow and Bookout, 1959), megalopae enter estuaries and settle in shallow nursery habitat (e.g., salt marsh and seagrass beds) where they undergo approximately twenty juvenile stages over a period of 1 to 3 years, depending on the conditions (Churchill, 1919; Gandy et al., 2011; Ward, 2012). Juveniles live in and at the mouth of estuaries near brackish, shallow water utilizing the high and low tidal cycle to molt, find refuge, and feed (Darnell, 1959). Juvenile blue crab populations are primarily found in estuaries that are influenced by FWI. During the late juvenile stages, males and females can be easily distinguished by the characteristic shape of their abdomen. Once mature, blue crab mate in the shallow reaches of an estuary, after which the females, with a lifetime supply of semen, begin a seaward migration and the males continue forage-meandering within the estuary. After they enter the sea, females spawn in nearshore waters. In Texas, blue crab develop to maturity in about one year, which is half the time required for individuals inhabiting colder mid-Atlantic regions (Ward, 2012).

4.2.0 Ecological interaction

FWI is a basic requirement for estuarine health. In the GoM, Wilber (1994) observed greater blue crab landings among five distinct bays of northern Florida one year following relatively high rates of FWI. Basically, increased FWI carried more nutrients and organic matter, which provided both critical and more suitable nursery habitat, especially for juvenile blue crab in the middle and lower portions of the estuary. In addition, low salinity has been associated with reduced predation mortality, more rapid growth, and greater survivorship of juvenile blue crab in southeastern U.S. estuaries (Posey et al., 2005). Recently, high blue crab abundance was also linked to high rainfall and river flow into the Louisiana and Mississippi river systems of the northcentral GoM (Sanchez-Rubio et al., 2011). In Texas, FWI may also function to signal postlarval entry into estuaries via selective tidal stream transport (STST), a process that may have serious implications for blue crab settlement and recruitment (Bittler et al., 2014). Previous work reported reduced blue crab populations in Mesquite Bay, Texas when estuarine salinities were above that of seawater (Hoese, 1960; Copeland, 1966). More recently, Georgia experienced a drastic decline in blue crab landings following a 4- to 5-year drought from 1999-2003 (Bishop et al., 2010). It is suggested that FWI is essential to the health of the blue crab population in an estuary.

Salinity plays a very important role in blue crab distribution as well as potential movements of females between estuary and coastal water. Schweitzer and Withers (2009) characterized adult blue crab according to their distribution, size, and sex ratio in correlation with season and salinity regime in Nueces Estuary, Texas. Salinities ranged from 0‰ in the upper tidal portion of the river to 30‰ or higher in the bay. Blue crab were collected in traps deployed for 24-hour periods along a range of different zones based on Venice salinity classification, including oligohaline (<5‰), β-mesohaline (5-10‰), α-mesohaline (11-18‰), lower polyhaline (19-24‰) and upper polyhaline to euhaline (>25‰). It was concluded that males dominated all salinity zones except the lower polyhaline (19-24‰). Across all zones, male mean size varied little while females were smaller in size, but varied more. Females utilize the estuary to molt, mate, and then move to more saline areas (e.g., mouth of an estuary where salinity closely resembles that of seawater) to spawn because their larvae do not adapt well to salinities below 32‰ (Costlow and Bookout, 1959). Furthermore, laboratory experiments showed that optimal hatching rates of blue crab eggs occurred at relatively high salinities of 23-28‰ (Sandoz and Rogers, 1944). To characterize the early life history stages of blue crab at different salinities, Mense and Wenner (1989) examined preferences of salinity regimes during the megalopal and juvenile stages in an estuary, near Charleston Harbor, SC. Distributions of megalopae and juveniles were determined among poly- (>18‰), meso- (5-18‰), and oligohaline (<5‰) regimes over a 16-month period. Megalopae were dominant at the polyhaline site where salinities exceeded 18‰, specifically 32‰, while juveniles preferred lower salinities at the meso- and oligoaline sites, specifically <10‰. In Guadalupe Estuary, Hamlin (2005) found that higher blue crab CPUE was associated with calculated zones of lower salinity, which shifted spatially depending on inflow regime. In a recent model study conducted in the San Antonio Guadalupe Estuarine System (SAGES) project, however, Slack et al. (2009) found that salinity (although important) was only a minor component driving blue crab abundance in the Aransas National Wildlife Refuge (located on the southwest side of San Antonio Bay), relative to other variables such as habitat type and structural complexity.

Temperature also has a significant impact on the life cycle of blue crab in terms of growth. Larval forms of blue crab require a narrow range of warm (above 25°C) and saline (above 20‰) conditions (i.e., seawater) for complete development (Ward, 2012). For postlarval blue crab, temperature is the most important factor controlling mortality followed by salinity, as noted in Figure 4.1, which shows 100% mortality at all salinities when temperature drops below 10°C (Costlow, 1967; Ward, 2012). During the juvenile stage, low temperatures lead to low molting rates and longer intermolt periods (Cadman and Weinstein, 1988). In the laboratory, the optimal temperature range for juveniles is 29-30°C (Holland et al., 1971), and the temperature range for

50% survival after 2 days is 2-36°C (Tagatz, 1969). Both juvenile and adult blue crab are less tolerant of temperature (i.e., have a smaller tolerant range) at lower salinities (Rome et al., 2005), and do not grow or molt below a minimum threshold of 9-11°C (Brylawski and Miller, 2006). Adult growth appears to be strongly affected by temperature as time required to reach maturity varies regionally (Guillory et al., 2001). Furthermore, blue crab mature at smaller sizes as temperature and salinity increase (Fisher, 1999).

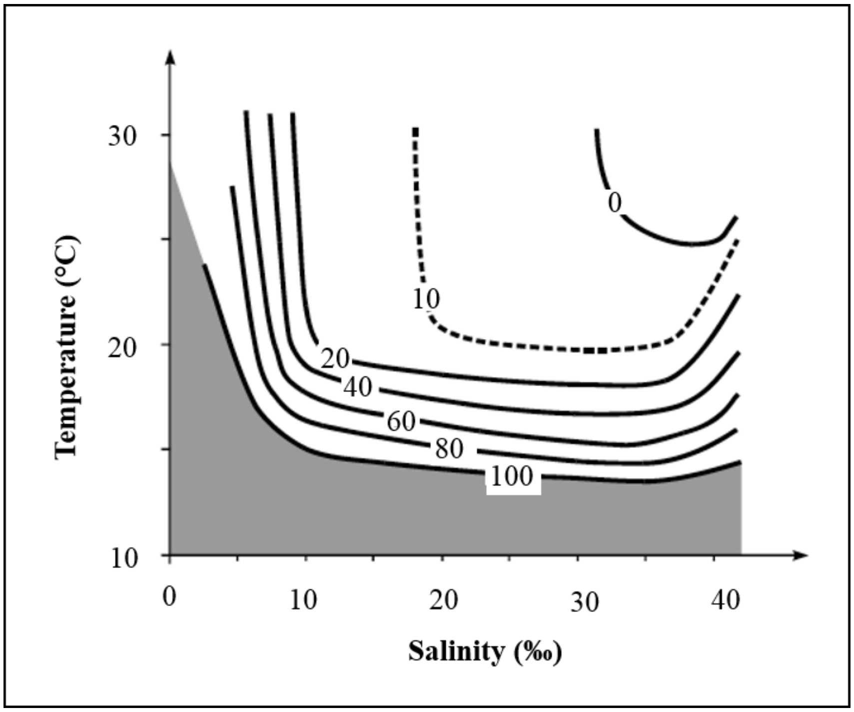

Figure 4.1 Percentage of postlarval mortality in response to temperature and salinity. Copied from Ward (2012). Data from Costlow (1967).

Blue crab recruitment and development take place in estuaries along the GoM during the respective summer and fall seasons. Thus, seasonal reductions in dissolved oxygen (DO) concentration (e.g., hypoxia) can influence onshore migration, settlement, and survival of postlarvae and newly metamorphosed juveniles (Tankersley and Wieber, 2000). In the laboratory, 100% mortality occurred following exposure to <1.2 mg l^{-1} for 6 days and 50% survival was observed after a 28-day exposure to 5.5 mg l^{-1} (Das and Stickle, 1993). In Chesapeake Bay, Pihl et al. (1991) reported that blue crab systematically migrate from hypoxic (<2 mg l^{-1}) to normoxic waters to escape mortality from July-August. Similarly, in the laboratory, Eggleston et al. (2005) observed migrations of adult blue crab during prolonged hypoxic events (i.e., weeks to months), but not during short-term episodes.

Heck and Coen (1995) reviewed factors that affect juvenile blue crab abundance among several geographical locations (Texas, Alabama, Virginia, and New Jersey) on the Gulf and Atlantic coasts. Megalopae were sampled, using passive collectors, every few days during periods of postlarval migration toward estuarine nursery habitat. Although densities of postlarvae were 1-2 magnitude higher in the GoM than the Atlantic, juvenile abundances of both regions were on the same order of magnitude. Juvenile blue crab utilize marsh and seagrass habitat for refuge and often migrate to open ocean depending on season. The similarity in abundances between locations may be a result of juveniles in one area were not able to seasonally escape predation compared to the other, and thus, predators controlled the population. It was concluded that predation pressure was an important factor and much greater in the GoM than the Atlantic.

Although blue crab utilize all salinity regimes within an estuary to complete their life cycle, habitat selection (in terms of salinity) is dependent on particular physiological requirements in each stage, and the alteration of any one of these habitats may affect the population (Guillory et al., 2001). Daud (1979) observed (in Louisiana) early juvenile stages of blue crab in shallow brackish water, then movement of later stages into fresher water. Heck et al. (2001) studied the abundances of juvenile blue crab across different habitats of Mobile Bay, Alabama and collected the greatest numbers near lower bay sites with an average salinity of 23‰. Rounsefell (1964) identified low salinity marsh habitat in the northern GoM as important nursery grounds for juveniles, suggesting an increase in salinity from reduced FWI may be harmful to blue crab populations, at least in the short term. Any disruption of the salinity gradient or any other physical alteration such as inflow effects imposed by water control structures may seriously impact blue crab populations (Guillory et al., 2001).

4.3.0 The blue crab in Mission-Aransas and Guadalupe estuaries

4.3.1 Data sources

The investigation on blue crab in Mission-Aransas and Guadalupe estuaries started as early as the 1940s in Aransas, Mesquite, and San Antonio bays as well as in Cedar Bayou (Daugherty, 1952). Then, another major investigation on blue crab migration was conducted in Cedar Bayou in the late 1960s (King, 1971). From 1971-1974, sampling efforts were also conducted in San Antonio Bay to observe correlations of FWI with blue crab and other estuarine biota (Childress et al., 1975). These were all special-purposed studies on blue crab for limited time periods. Some of the studies discussed in this review refer to Mission-Aransas and Guadalupe estuaries as Aransas-Copano and San Antonio bays, respectively, and we feel it is noteworthy to inform the reader of this discrepancy to prevent any confusion.

To evaluate long-term, large-scale variation of fishery abundance, the Coastal Fisheries monitoring program of the Texas Parks and Wildlife Department (TPWD) began using a suite of sampling gears for its routine monthly fisheries-independent monitoring of finfish and shellfish communities in Texas estuaries in the late 1970s. Sampling gears of varying efficiency for certain species across different habitats were used at different times. Gears included: (1) bag seines for collecting small organisms near shore since 1976; (2) bay trawls for collecting benthic organisms from open bays since 1982; and (3) gill nets for collecting larger organisms near shore since 1975. Data include numbers of species captured or catch per unit effort (CPUE) and average total length (TL) or, for crab, carapace width (CW) of each species. Mission-Aransas and Guadalupe estuaries are among the eight major bay systems along the Texas coast sampled by this monitoring program (http://gulfcoast.harc.edu/CoastalResources/CoastalFisheries/TexasCoatalFisheries/tabid/2236/Default.aspx).

4.3.2 General assessment of blue crab abundance

Ward (2012) documented the average abundance of seined and trawled blue crab from 1986-2005 by major bay system in Texas (Table 4.1). Data represent blue crab biomass in grams collected by: 1) bag seine as the surface area across which the net was pulled times the average water depth and 2) otter trawl as the open area of the net times the distance towed. No clear correlation between salinity and biomass density of blue crab was found among bays. San Antonio Bay (Guadalupe Estuary), however, contained the most trawled crab while Galveston Bay was dominant in bag seine collections. Aransas-Copano (Mission-Aransas Estuary) and San Antonio bays exhibited similar numbers of seined crab, although both were lower than the average of all bays.

Table 4.1 1986-2005 average biomass density (mg m^{-3}) of seined and trawled blue crab in TPWD Coastal Fisheries collections by major bay system in Texas, modified from Ward (2012).

Estuary	**Bag Seine**	**Otter Trawl**	**Estuary**	**Bag Seine**	**Otter Trawl**
Sabine Lake	118	103	Aransas-Copano	74	101
Galveston Bay	147	66	Corpus Christi	117	43
East Matagorda	136	81	Upper Laguna	80	74
Matagorda	45	52	Lower Laguna	73	112
San Antonio	71	147	*Average of all bays*	*96*	*86*

The Texas blue crab fishery has undergone significant downward trends in both number and size since the mid-1980s (Ward, 2012). Based on TPWD data, a 70% reduction in biomass was observed from 1982-2005 (Figure 4.2a). Although the data are noisy in each bay, the declining trend in San Antonio and Aransas-Copano bays (i.e., Guadalupe and Mission-Aransas estuaries, respectively) is quite clear (Figures 4.2b and 4.2c). Similar declining trends for blue crab were also observed elsewhere in the GoM (e.g., Galveston Bay, Upper and Lower Laguna Madre) and on the Atlantic coast, indicating large-scale factors, such as overfishing, poor water quality, predation, disease and parasitism, and habitat loss, may be present everywhere (Ward, 2012).

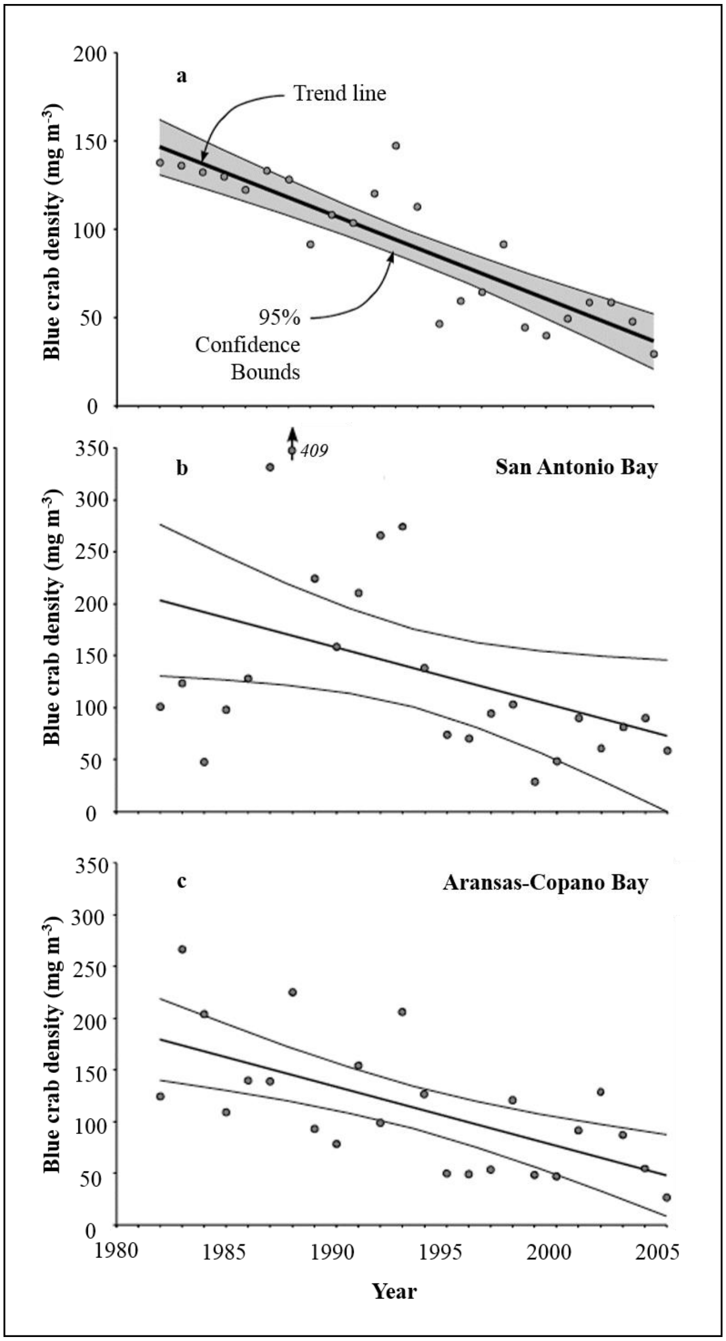

Figure 4.2 Time trends in annual trawl biomass for (a) all bays averaged; (b) San Antonio Bay (Guadalupe Estuary); and (c) Aransas-Copano Bay (Mission-Aransas Estuary), 1982-2005, with 95% confidence bounds on regression. Copied from Ward (2012).

4.3.3 Geographical and seasonal variation of blue crab

In San Antonio Bay (Guadalupe Estuary; Figure 4.3), trawled crabs were most prevalent in either the lower bay and channel areas under cooler temperatures or the channel at low salinities (Tables 9 & 10 in Ward, 2012). However, there was no clear correlation of crab density with salinity. To our knowledge, there are no published studies on the geographical distribution of blue crab in Mission-Aransas Estuary.

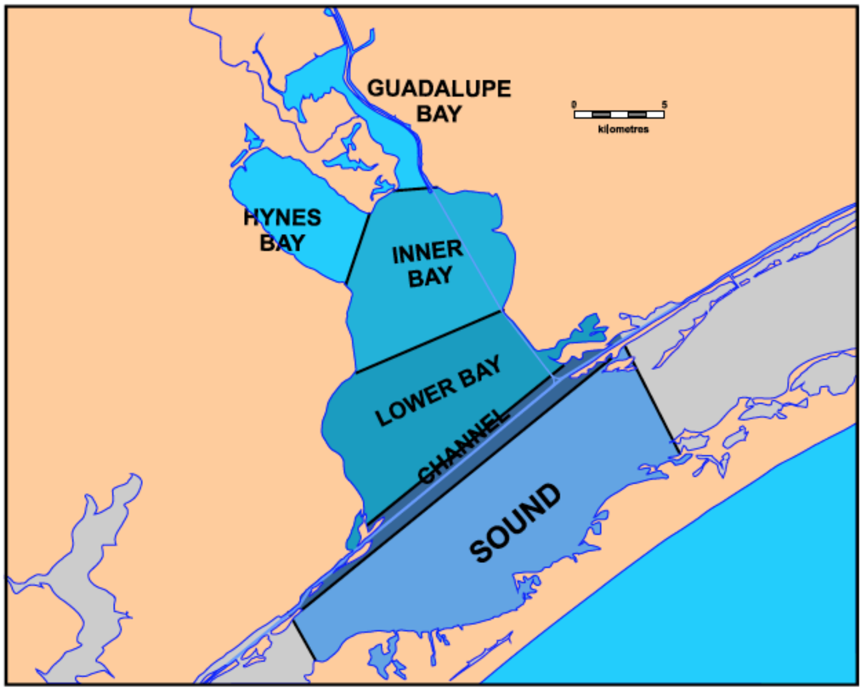

Figure 4.3 Segmentation of San Antonio Bay (Guadalupe Estuary), copied from Ward (2012).

In general, along the Texas coast, blue crab size and density varied with seasonal changes in life cycle (Figure 4.4; Ward, 2012). From December-March, size remained relatively stable at 60 mm CW (matching the size blue crab typically move from marsh to bay), while density markedly increased. From March-May, density remained stable while size increased to 90 mm CW. From May-September, size remained stable, but density declined by a factor of ten. From September-December, there was no change in density while size decreased to smallest of 50 mm CW.

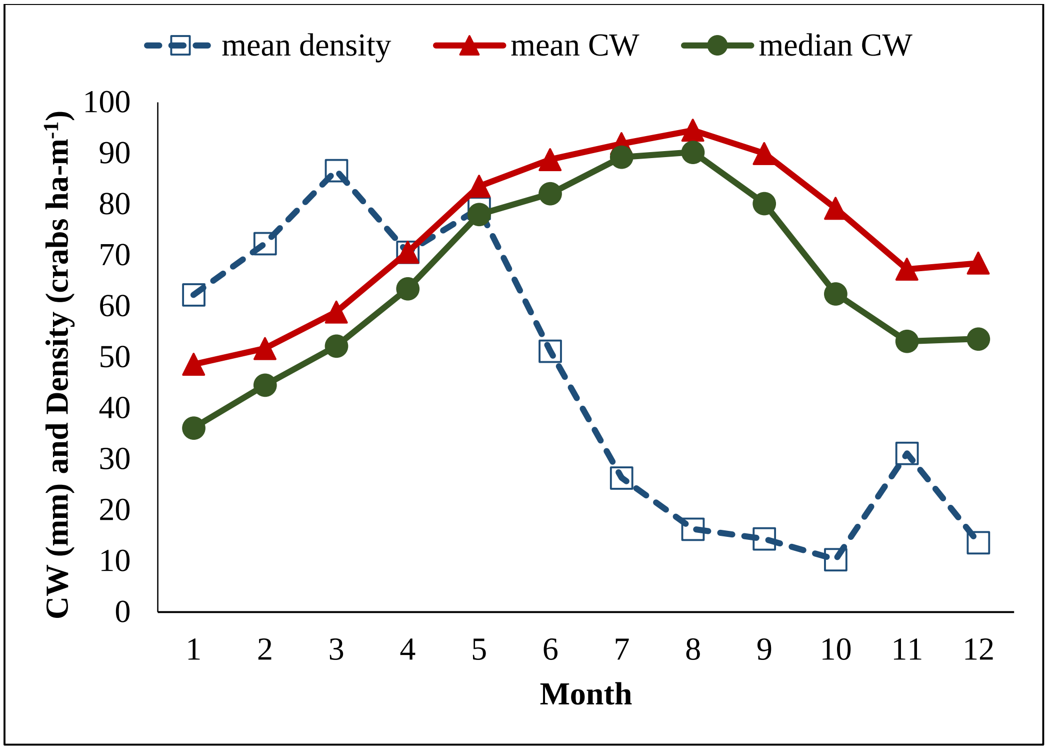

Figure 4.4 Monthly mean density (dotted line), mean carapace width (solid triangle), and median carapace width (solid circle) of blue crab along the Texas coast, from TPWD 1982-2008 trawl data, modified from Ward (2012).

4.3.4 Dependency on FWI and salinity

Short-term observations (1965-1973) of river flow and blue crab in Guadalupe Estuary indicated that the greatest commercial poundage landings occurred during years of highest river input (Childress et al., 1975). In a more recent review concerning FWI requirements in Texas, Estevez (2002) reported that juveniles exhibited a stronger relationship to inflow than adults, and the two-year antecedent average inflows explained most of the variance in blue crab landings. Also more recently, Sutton and Wagner (2007) revealed in a stock assessment study on Texas blue crab that a reduction in FWI was one of four factors responsible for the observed declines in both abundance and commercial harvest; while the remaining three consisted of overfishing, shrimp trawl bycatch, and habitat loss or degradation. Similarly, during the Texas drought in the 1950s, salinity was greatly enhanced, and the crab population declined in Mesquite Bay, northeastern Mission-Aransas Estuary (Hoese, 1960). The population rebounded to its normal level only after the drought ended and salinity levels returned to moderately low. However, poor correlations between blue crab abundance and FWI in San Antonio Bay have also been reported in many recent studies (e.g., Hamlin, 2005; Ward, 2012). Although it is suggested that FWI may influence blue crab population size, little evidence of direct effects of salinity on blue crab physiology has been observed (GSA BBEST, 2011). Moreover, the multivariate time-series modeling study in Part II of this report also implicated that direct relationships between FWI and blue crab abundances in Mission-Aransas and Guadalupe estuaries were only seen in models with lags of one to two years, indicating that FWI may positively influence blue crab populations at longer time scales.

4.3.5 Other potential drivers

The observed decline in abundance of Texas blue crab in recent years may also be due to predation (Pugesek et al., 2013; Guillory and Elliot, 2001), disease and parasitism (Messick et al., 1999), and habitat loss or degradation (Guillory et al., 2001). Guillory and Elliot (2001) identified 67 fish species as predators of blue crab of which red drum had the highest predation index, 5 times greater than that of the sea catfish. Blue crab are also the most important winter food for whooping cranes, and are critical to the survival of overwintering whooping cranes at the Aransas National Wildlife Refuge, Texas (Hunt and Slack, 1989; Pugesek et al., 2013). Both lab experiment and field analysis in Chesapeake Bay indicated that cannibalism by large adult blue crab caused 75-97% mortality of juveniles (Hines and Ruiz, 1995). However, predation on postlarvae is largely unknown due to difficulties in identifying them in the stomach contents of predators (Van Engel, 1987).

In 2002, Georgia experienced a crash in blue crab populations due to the proliferation of the parasitic dinoflagellate *Hematodinium* sp. (Lee and Frischer, 2004). That same year, drought led to increases in temperature and salinity that allowed for the proliferation of *Hematodinium*. Messick et al. (1999) studied parasitism and blue crab mortality in the laboratory and found both low water temperature and salinity reduced the prevalence of *Hematodinium* and its effect on mortality. Another common parasite in the GoM, *Loxothylacus texanus*, targets immature blue crab and disrupts the development of the abdomen causing males to "feminize" and females to appear mature (Reinhard, 1950). Earlier work on blue crab infected with *L. texanus* reported incidence rates of 1.5% in Aransas and Copano bays (Gunter, 1950) and up to 25.8% near the southwestern end of Mud Island in Aransas Bay (Daugherty, 1952). More recently, however, Wardle and Tirpak (1991) observed rates as high as 53% in Galveston Bay, one of the highest recorded to date. Microbial infections also occurred in blue crab collected at Galveston Bay, specifically the pathogenic species *Vibrio parahaemolyticus*, which is known to cause blue crab mortality, was found in 30% of the study organisms (Davis and Sizemore, 1982).

Estuarine salt marsh and seagrass beds are typically the ideal refuge and nursery habitat for early life history stages of blue crab. Rozas and Minello (1998) reported that salt marsh and seagrass habitat in Aransas National Wildlife Refuge supported significantly higher densities of most nekton, including blue crab, than non-vegetated sites, and salt marsh was preferred over seagrass for blue crab in the GoM. Orth and Van Montfrans (2002) found, from laboratory studies, that simulated seagrass reduced predation in both postlarval and first instar juvenile blue crab. However, substantial marsh habitats have been lost or altered across the estuaries of the GoM, and habitat loss has been a significant factor in determining blue crab production (Guillory et al., 2001).

5.0.0 WHITE SHRIMP

White shrimp, *Litopenaeus setiferus*, the second most important shrimp species in Texas, support a large food fishery in the shallow Gulf and upper coast bays. As an estuarine-dependent and nektonic species, the white shrimp moves between bay and offshore waters throughout its life cycle, reaching sexual maturity at a length of approximately 152 mm TL (TPWD, 2002). White shrimp are primarily omnivorous, feeding on many different plants and animals.

5.1.0 Life cycle

White shrimp complete their life cycle in one year, and have five similar life history stages (Figure 5.1; relative survival of each stage also shown), but different seasonalities compared to other shrimp species (i.e., brown and pink shrimp). In general, female white shrimp spawn a large number of eggs offshore ranging in depths of 7 to 33 m from March-September. These eggs hatch into larvae, and then develop into postlarvae (<6 mm TL) via a series of molts and stages. Simultaneously, eggs or larvae are carried into bays by currents, tides, and winds, and the influx of postlarval white shrimp to estuarine bay waters reaches its peak in summer. Within the estuary, postlarvae usually concentrate in shallow bays (<1 m), attaching to vegetation and organic debris, where they develop into juveniles, and in time, move to deeper bay waters, preferring soft mud or peat bottoms. In Mission-Aransas and Guadalupe estuaries, juveniles, which range from 6-70 mm TL, are found inland near brackish bay, bayou, and estuarine systems to utilize marsh and seagrass habitat for food, refuge, and development (Diop et al., 2007, Gunter, 1961, Weymouth et al., 1933). After a certain size (>70 mm TL), these shrimp migrate to the Gulf as sub-adults where they mature to adults (>100 mm TL). White shrimp move in and out of bays through the fall, especially in October at its peak. The following spring and summer they move offshore to spawn and start a new life cycle in the shallow Gulf and upper coast bays.

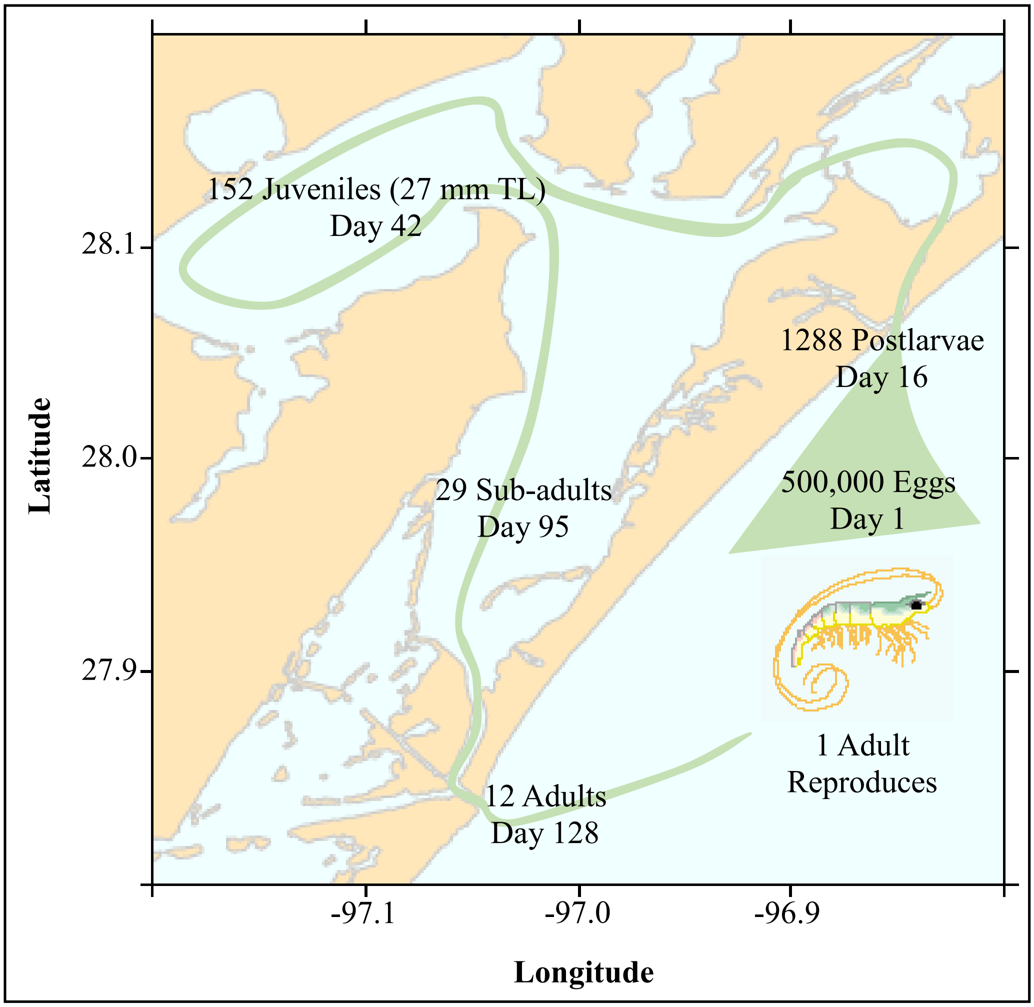

Figure 5.1 Graphical depiction of the white shrimp life cycle in Aransas and Copano bays (Mission-Aransas Estuary) of Texas, northwestern GoM. Modified from Baker et al. (2014).

5.2.0 Ecological interaction

River flow, rainfall, and salinity are primary environmental factors that impact white shrimp distributions and populations in Texas. In the 1950s, a drought caused a significant decrease in white shrimp along the Texas coast (Copeland, 1966). In a review on white shrimp in Texas, Zein-Eldin and Renaud (1986) reported that juveniles were more frequent and grew faster at low salinities, and that postlarval survival rates decreased at 35‰ compared to 25‰. More details about the ecological interaction of white shrimp with changes in river flow, rainfall, and salinity are discussed in Section 5.3.4. (Dependency on FWI and salinity).

Several other factors may also affect the health of white shrimp populations in Texas. Recently, Baker et al. (2014) reported white shrimp stock size was significantly affected by juvenile growth and survival, and thus, factors affecting juvenile success were most critical. Elevated water temperature, for example, might have inhibited the growth of juvenile white shrimp during summer in Galveston Bay, Texas (Baker and Minello, 2010). Although white shrimp were more tolerant to low dissolved oxygen concentration than brown shrimp, juveniles were seldom found in bottom water <1.5 mg l^{-1} (Renaud, 1986; Zimmerman and Nance, 2001). In addition, salt marsh habitat plays a very important role in white shrimp growth and mortality (Webb and Kneib, 2002). In a model study, Rozas et al. (2007) documented large areas of up to 61% wetlands and 70% marsh edge were lost in Galveston Bay from 1982-1995. Populations of white shrimp, brown shrimp, and blue crab declined as a result, however, they rebounded in 1999, following a marsh restoration project. Also, predators like red drum may affect populations during fall, when juveniles seek refuge in estuarine nursery habitat (Scharf and Schlicht, 2000).

5.3.0 The white shrimp in Mission-Aransas and Guadalupe estuaries

To our knowledge, ecological interaction studies on white shrimp in Mission-Aransas or Guadalupe estuaries are quite limited (Table 1.1). Thus, we are collecting reviews in this section, not only from these two estuaries, but also from the surrounding area, such as Galveston Bay, along the Texas coast.

5.3.1 Data sources

Data sources utilized to assess white shrimp populations in Mission-Aransas and Guadalupe estuaries were similar to those used for the blue crab assessment. The TPWD utilized several sampling gears, including bag seines and bay or gulf trawls, for its monthly fisheries-independent monitoring of white shrimp along the Texas coast, northwestern GoM (http://gulfcoast.harc.edu/CoastalResources/CoastalFisheries/TexasCoatalFisheries/tabid/2236/Default.aspx).

5.3.2 General assessment of white shrimp abundance

The temporal fishery-independent data for white shrimp abundance were collected in Texas coastwide by TPWD using either bag seine (1977-2000) or bay trawl (1982-2000), and both exhibited significant decreases in CPUE (i.e., catch rate) during these sampling periods, although variations occurred among bays (TPWD, 2002). A significant increase in CPUE, however, was observed in white shrimp collected by gulf trawl coastwide from 1986-2000. Specifically, for bag seines, average catch rate decreased from highest of 3000 $acre^{-1}$ in 1982 to lowest of less than 500 $acre^{-1}$ in 2000. For bay trawls, this value decreased from highest of 46 hr^{-1} in 1996 to less than 15 hr^{-1} in 2000. And for gulf trawls, catch rate also decreased initially from highest of 24 hr^{-1} in 1986 to lowest of 10 hr^{-1} in 1990 and 1994. However, this rate rebounded after 1995, and returned to 24 hr^{-1} in 1999. There were no significant changing trends for white shrimp abundance in Mission-Aransas or Guadalupe estuaries over these two decades. However, white shrimp CPUE by bay trawl displayed a significant increase after 2000, especially from 2007-2008 (over 200 hr^{-1}) in Mission-Aransas Estuary (Xue et al., unpublished technical report; also see Part II Figure 4.1).

The annual average TL of white shrimp significantly decreased in both bag seine and bay trawl collections in Texas coastwide during these sampling periods. However, an increase in size was observed in Mission-Aransas and Guadalupe estuaries, where the annual average TL of bag seine collections increased during the same sampling periods. Similarly, white shrimp sampled coastwide by gulf trawl also displayed a significant increase in size.

5.3.3 Geographical and seasonal variation of white shrimp

White shrimp collected in Texas by TPWD (2002) during the approximate 20-year period using the three distinct sampling gears can be broadly divided into three size-dependent life stage groups: 1) juveniles (51-76 mm TL); 2) sub-adults (>76-102 mm TL); and 3) adults (>102-127 mm TL). The geographical variability of white shrimp is correlated with changes in life cycle since the size range associated with each gear varied among the three different types of sampling sites: 1) bay shoreline via bag seine; 2) open bay via otter trawl; and 3) nearshore GoM via otter trawl. Hence, in Texas, juveniles were found along shallow shorelines of bays and estuaries (<1 m) where vegetation did or did not exist, while sub-adults inhabited deeper bay and channel waters (>1 m) characterized by soft muddy sediments, and adults resided in nearshore coastal waters (7-33 m) with sandy peat bottoms.

The seasonal variability of white shrimp along the Texas coast was also reported by TPWD (2002), based on the size and density of samples collected. Juvenile size ranged from smallest in June to largest in August with the greatest density observed in October. Sub-adult size was smallest from December-January and largest in May with peak densities observed from July-December. And adult size was smallest in December and largest in June while densities peaked from November-January.

5.3.4 Dependency on FWI and salinity

White shrimp change their feeding behaviors and preferred habitat at various times during their life cycle, therefore, different life stages need to be considered to look at the effects of FWI (i.e., reduced salinity) on white shrimp. For example, the transport of eggs, larvae, and postlarvae is predominantly dependent on currents, wind direction, and tidal height. However, FWI may indirectly affect transport through passes and channels via changes in salinity (e.g., Bittler et al., 2014). Juveniles, which are confined to estuaries, are also directly affected by FWI. A significant positive correlation (R=0.85) was observed between reductions in salinity due to FWI from May-June and commercial landings of white shrimp in San Antonio Bay (Guadalupe Estuary), from 1959-1975 (Williamson, 1977; Longley, 1994). Mueller and Matthews (1987) also reported significant correlations between river flows of critical flow months (March, April, June, and October) and white shrimp harvests in Matagorda Bay (northeastern border of Guadalupe Estuary) from 1960-1982. Elevated spring flows reduced salinity, while loading nutrients and organic matter into the system, which may have benefited newly arrived postlarvae. Similar to its findings for blue crab, the multivariate time-series modeling study in part II of this report also indicated that FWI might influence white shrimp abundances at longer time scales.

Rainfall is an important source of freshwater to the Texas land-surface system. In the past, a strong statistical correlation was found between annual white shrimp catch and average rainfall for Texas (Gunter and Hildebrand, 1954; Copeland, 1966). Specifically, an increase or decrease in rainfall was always followed by similar fluctuations in annual shrimp catch with a two-year lag from 1927-1964 (Figure 5.2). The 1950s drought ranked among the most severe over the past 400 years in Texas and was responsible for a sharp decline in white shrimp landed during that decade. Following the drought, recovery was slow relative to the frequency of rainfall, which can be explained by the high affinity of dry land to readily absorb water.

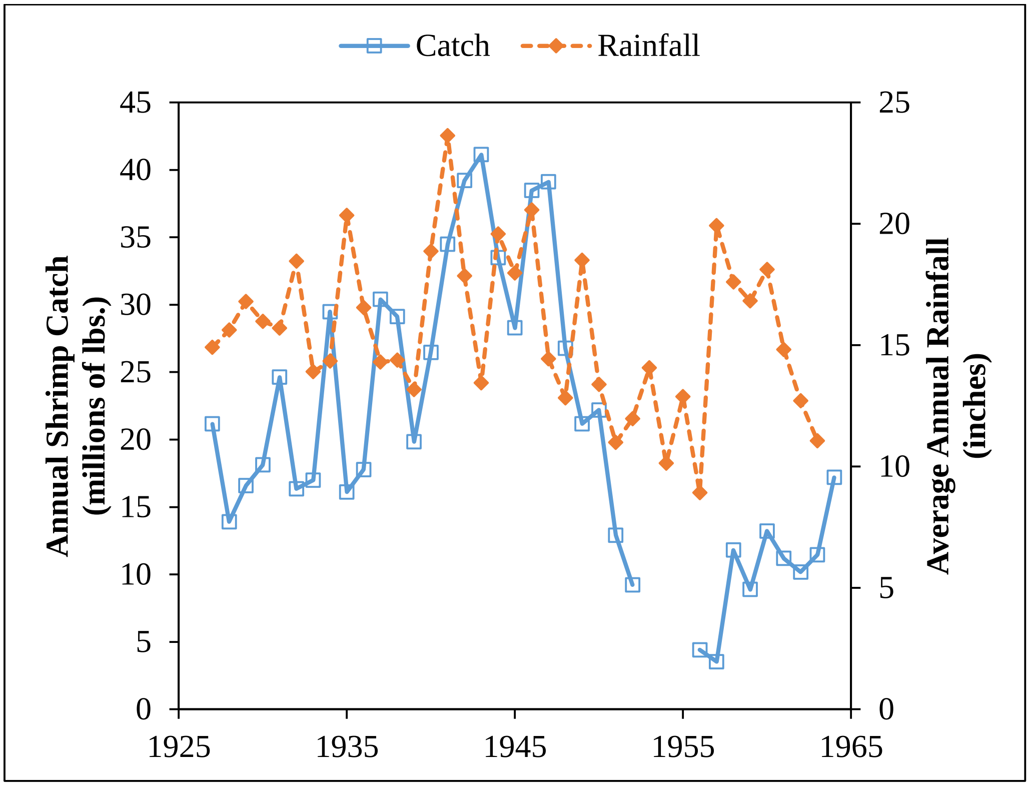

Figure 5.2 Annual white shrimp catch and average rainfall for Texas, 1927-1964. Modified from Copeland (1966). Dotted line = average annual rainfall for Texas, 1927-1964; solid line = annual white shrimp catch in Texas waters, 1927-1952 & 1956-1964.

In order to take advantage of highly productive estuaries, white shrimp tolerate a wide range of salinities, though lower-range conditions are preferred. In general, white shrimp are found in salinities that range from 0-38‰ (Copeland and Bechtel, 1974), yet they are most abundant at salinities below 22‰ (Longley, 1994), while young prefer less than 10‰ (Gunter et al., 1964). With the decline of FWI in Texas from 1949-1951, salinity levels increased and a sharp decline in young white shrimp was observed in Mission-Aransas Estuary, specifically Aransas Bay (Parker, 1955). Furthermore, in the northern GoM during the 1950s and 1960s, observed increases in salinity caused a shift in the dominant species from white shrimp to brown shrimp (Christmas and Etzold, 1977).

5.3.5 Other potential drivers

In addition to FWI and salinity impacts, the decline of white shrimp in Texas estuaries may also be driven by fluctuations in water temperature, low dissolved oxygen, habitat change, and pressure from predators such as red drum. Whitaker (1983) showed that low temperatures (following cold fronts) in the Atlantic Ocean (southeastern U.S.) can lead to high levels of mortality in white shrimp, especially less-tolerant adults. In a review, Zein-Eldin and Renaud (1986) reported white shrimp in Texas can survive temperatures ranging from 5.2-38°C, however, growth may be affected at either extreme. For example, in the laboratory, growth rates of postlarval white shrimp increased with temperature up to 32°C (Zein-Eldin and Griffith, 1969). Baker and Minello (2010), moreover, suggested high summer temperatures in Galveston Bay, Texas may have inhibited the growth of juveniles, which had higher growth rates during the fall at lower temperatures. Zein-Eldin and Renaud (1986) also suggested the interaction of temperature and salinity might have more pronounced effects than either factor acting alone, and the combination of low temperature and low salinity has more adverse effects on white shrimp than any other combination. Therefore, FWI during late spring and summer would provide low salinity conditions together with warm water temperature, and thus, benefit the population.

Elevated summer temperatures combined with the effects of common environmental stressors such as eutrophication from human activity can also lead to reductions in dissolved oxygen (Rabalais et al., 1995b). Hypoxia, defined as dissolved oxygen <2 mg l^{-1}, has been observed in large areas of the northwestern GoM (up to 20,000 km^2), including coastal Texas, and has led to the loss of habitat available to nekton and demersal “bottom-dwelling” species (Rabalais et al., 2001). In the 1950s and 1960s, Rabalais et al. (2001) suggested hypoxia was responsible for the reduction in numbers of adult white shrimp caught commercially along the continental shelf from the Mississippi Delta westward to the upper Texas coast. Furthermore, observations from laboratory experiments concluded juvenile white shrimp detected and avoided hypoxic levels ≤ 1.5 mg l^{-1} (Renaud, 1986).

Habitat loss is a major source of environmental change along the Texas coast. Earlier work suggested a lack of affinity for marsh vegetation by white shrimp (Zimmerman and Minello, 1984; Minello and Zimmerman, 1985), but more recent and comprehensive studies indicate white shrimp show a strong affinity to marsh edge vegetation (Rozas et al., 2007; Shervette et al., 2011). In a model study by Rozas et al. (2007), white shrimp experienced a significant and corresponding decline in Galveston Bay, Texas as a consequence of habitat loss (61% wetlands and 70% marsh edge) from 1982-1995. Kinney et al. (2014) indicated the absence of white shrimp during a 2010 drought in the Lower Neches Wildlife Management Area, located on the eastern border of Sabine Lake, Texas, was attributed to nearly a 100% reduction in submerged aquatic vegetation (SAV).

White shrimp are a common prey item for many estuarine fish species, especially red drum. In a study by Scharf and Schlicht (2000), the stomach contents of red drum captured in Galveston Bay, Texas during fall 1997 revealed the presence of white shrimp to be the most abundant prey item in terms of percent frequency of occurrence, percent number, and percent wet weight. Sizes of prey found matched closely to the sizes of individuals caught in bag seines, indicating red drum utilize nursery areas such as seagrass beds and salt marsh as feeding grounds. White shrimp, however, were absent in red drum stomachs during spring 1998, suggesting predation from red drum is seasonal and young had not yet reached juvenile size.

6.0.0 Environmental management implications

Historically, management of fisheries has functioned primarily to implement and enforce "preventative" regulations on species rather than the environment. With heightened awareness and concern surrounding the impacts of human activity, however, focus has shifted to the environmental conditions and availability of habitat. Both blue crab and white shrimp spend their earliest life stages (i.e., eggs and larvae) in the GoM, and are largely controlled by factors outside the estuary. Once settled within the estuary, however, local environmental conditions take precedence and become the controlling factors that affect growth and survival of these two important fishery species.

Copeland and Bechtel (1974) stated in a review that there are two objectives to properly managing estuarine systems. First, to control environmental conditions to within the tolerance range of all the inhabitants in a system. And second, to provide conditions for optimal survival of species with commercial and/or ecological value. Thus, they acquired catch data of several important species, including blue crab and white shrimp, within four single limiting environmental factors (i.e., temperature, salinity, season, and location), from studies conducted in the GoM and on the Atlantic coast to ascertain ranges of each factor for each species. According to the literature and data sources used by Copeland and Bechtel (1974), blue crab were found in: 1) temperatures of 0-40℃ (optimum: 10-35℃); 2) salinities of 0-40‰ (optimum: 0-27‰); 3) seasons throughout the year (optimum: spring and fall); and 4) locations throughout the estuary (optimum: primary rivers, secondary streams, marsh, and tertiary bays). Similarly, white shrimp were found in: 1) temperatures of 10-40℃ (optimum: 20-38℃); 2) salinities of 0-38‰ (optimum: entire range); 3) seasons throughout the year (optimum: July-December); and 4) locations throughout the estuary (optimum: secondary streams, marsh, and primary, secondary, and tertiary bays).

For estuarine blue crab and white shrimp, moreover, the tolerant and optimum ranges of environmental factors differ at each stage of their life cycle (e.g., Zein-Eldin and Renaud, 1986). Similarly, Zein-Eldin and Renaud (1986) compiled an overview of environmental conditions (i.e., temperature, salinity, rainfall, and their interactions), relative ecological factors (e.g., location, vegetation, and predation), and the resulting biological responses (e.g., growth, migration, and abundance) of white shrimp during the postlarval, juvenile, and adult stages of their life cycle in coastal waters, particularly of Texas. Here, we construct Tables 6.1 (for blue crab) and 6.2 (for white shrimp) in a similar fashion. The specific responses of blue crab and white shrimp to changes in the environment during the postlarval, juvenile, and adult stages provide insight for environmental management, and therefore, must be considered.

Table 6.1 The major environmental factors affecting blue crab in each of three growing stages: postlarval, juvenile, and adult.

Major Factors	Postlarval (6-20 d)	Juvenile (~2-80 mm CW)	Adult (>80 mm CW)	General Comments
Habitat (life cycle)	Enter estuaries and settle in shallow nursery habitat. In Aransas National Wildlife Refuge, Texas, greater densities were observed in vegetated relative to unvegetated areas (Rozas and Minello, 1998). In the laboratory, simulated seagrass reduced predation (Orth and Van Montfrans, 2002).	Migrate upstream for refuge, food, and ecdysis (molting). In Texas, early stages begin in brackish waters and move into fresher waters with each molt, utilizing vegetation for protection (Guillory et al., 2001; Daud, 1979).	Disperse throughout the estuary from upper to lower regions. In Nueces Estuary, Texas, males dominated all areas except the lower estuary, where females prevailed (Schweitzer and Withers, 2009).	Habitat selection (in terms of salinity) is dependent on particular physiological requirements in each life stage, and alterations of any one of these may affect the population (Gandy et al., 2011).
FWI	May be a necessary component for recruitment into Texas estuaries through selective tidal stream transport (STST; Bittler et al., 2014).	Provides nutrients and organic matter that can cause similar increases in growth rate and survivorship (Posey et al., 2005).	In San Antonio Bay, Texas, the greatest commercial poundage landings occurred during years of greatest inflow (Childress et al., 1975). However, poor correlations between blue crab abundance and FWI in San Antonio Bay have also been reported in many recent studies (e.g., Hamlin, 2005; Ward, 2012). The multivariate time-series modeling study in Part II indicated that FWI might influence blue crab at longer time scales.	Historically, in Texas, changes in abundance and commercial harvest have closely resembled that of FWI (Sutton and Wagner, 2007).
Salinity	Near Charleston, South Carolina, megalopae were most numerous at >18‰, specifically 32‰ (Mense and Wenner, 1989). In the laboratory, a range of 23-28‰ was optimal for larvae to hatch (Sandoz and Rogers, 1944).	In Mobile Bay, Alabama, the greatest abundances were found at an average 23‰ in lower bay regions (Heck et al., 2001).	In Nueces Estuary, Texas, males were dominant in all zones except the polyhaline (19-24‰), where spawning occurred due to larval intolerance of low salinities (Costlow and Bookout, 1959; Schweitzer and Withers, 2009).	In Mesquite Bay, Texas, salinities above that of seawater caused a decline in the population (Copeland, 1966). In Guadalupe Estuary, higher blue crab CPUE was associated with calculated zones of lower salinity (Hamlin, 2005).

Temperature	Ward (2012) reported the lower limit threshold for survival was approximately 10°C and survival increased with temperature to an optimal range of 25-30°C.	Holland et al. (1971) reported an optimal range of 29-30°C. Tagatz (1969) observed 50% survival after 2 days exposure to 2-36°C. Cadman and Weinstein (1988) concluded low temperatures lead to reduced molting rates.	Growth appears to be strongly affected by temperature as time required to reach maturity varies regionally (Guillory et al., 2001).	Rome et al. (2005) indicated blue crab were less tolerant of temperature at lower salinities. Molting was inhibited below a minimum threshold of 9-11°C (Brylawski and Miller, 2006).
DO	Tankersley and Wieber (2000) suggested megalopal recruitment and settlement may be limited and regulated by reduced levels of dissolved oxygen.	In the laboratory, Das and Stickle (1993) found 100% mortality after exposure to <1.2 mg l^{-1} for 6 days and 50% survival following exposure to 5.5 mg l^{-1} for 28 days.	Eggleston et al. (2005) observed systematic migrations to shallow water occurred during prolonged rather than episodic hypoxia (i.e., weeks to months).	In Chesapeake Bay, from July-August, Pihl et al. (1991) observed blue crab migration from hypoxic to normoxic conditions to escape mortality.
Predators	Largely unknown because the remains are difficult to identify in the stomach contents of fish and other predators (Van Engel, 1987).	Red drum had the highest predation index of 67 fish species (Guillory and Elliot, 2001). Most important food source for overwintering whooping cranes in the Aransas National Wildlife Refuge (Hunt and Slack, 1989).		Predation pressure was much greater in the GoM compared to the Atlantic (Heck and Coen, 1995). Cannibalism accounted for 75-97% of juvenile mortality (Hines and Ruiz, 1995).

Table 6.2 The major environmental factors affecting white shrimp in each of three growing stages: postlarval, juvenile, and adult.

Major Factors	Postlarval (< 6 mm TL)	Juvenile (6-70 mm TL)	Adult (> 100 mm TL)	General Comments
Habitat (life cycle)	Carried via offshore currents to shallow estuarine areas. In Galveston Bay, postlarvae exhibited a strong affinity for marsh edge vegetation (Rozas et al., 2007).	Descend from shallow shoreline vegetation to deeper mud bottoms of bays (TPWD, 2002).	Migrate offshore as sub-adults (>70-100 mm TL) and develop into adults, preferring sandy sediments at depths of 7-33 m (TPWD, 2002).	In Galveston Bay, from 1982-1995, the loss of 61% wetlands and 70% marsh edge resulted in a corresponding decline (Rozas et al., 2007). In Lower Neches Wildlife Management Area, a 100% reduction in SAV led to the species' absence (Kinney et al., 2014).

FWI	In Matagorda Bay, Texas, from 1960-1982, annual harvests were correlated with FWI, which delivered nutrients and detritus during months of postlarval arrival (March, April, June; Mueller and Matthews, 1987).	In San Antonio Bay, Texas, FWI during months of juvenile development (May-June) were strongly correlated with catch rates and commercial landings (Williamson, 1977; Longley, 1994).	In Texas, the 1950s drought led to increased salinities and a significant decline in the population (Copeland, 1966). In Aransas Bay, Texas, from 1949-1951, increased salinities from reduced water flow caused a decline (Parker, 1955). The multivariate time-series modeling study in Part II indicated that FWI might influence white shrimp abundances at longer time scales.	In Texas, from 1927-1964, a strong statistical correlation was observed between average rainfall and annual catch with a 2-yr lag, suggesting dry land readily absorbed water following a drought (Copeland, 1966).
Salinity	In general, survival decreased at 35‰ compared to 25‰ (Zein-Eldin and Renaud, 1986).	Historically, growth and abundance increased at lower salinities (Zein-Eldin and Renaud, 1986).	In Texas bays, adults ranged from 0-38‰ (Copeland and Bechtel, 1974) and were most abundant at <22‰ (Longley, 1994).	In the GoM, the observed increases in salinity over recent decades have caused a shift in dominant species from white shrimp to brown shrimp (Christmas and Etzold, 1977).
Temperature	In the laboratory, growth increased with temperature up to 32°C (Zein-Eldin and Griffith, 1969).	In Galveston Bay, Texas, temperatures >35°C may have inhibited growth during summer relative to fall, when growth rates were higher (Baker and Minello, 2010).	In Texas, white shrimp generally occurred from 5.2-38°C and survival was reduced at either extreme (Zein-Eldin and Renaud, 1986).	In southeastern U.S. coastal waters, Whitaker (1983) reported the effects of winter cold fronts included mass mortality.
DO	In general, hypoxia has reduced the amount of habitat available to less-mobile nekton and bottom-dwelling species (Rabalais et al., 2001).	In the laboratory, juveniles detected and avoided levels <1.5 mg l^{-1} (Renaud, 1986; Zimmerman and Nance, 2001).	In the GoM, in the 1950s and 1960s, reductions in the numbers of adults landed in trawl nets were attributed to hypoxia (Rabalais et al., 2001).	Historically, hypoxia has been observed in large areas (up to 20,000 km^2) of the northwestern GoM, especially during summer (Rabalais et al., 2001).
Predators		Most abundant prey item found in the stomach contents of red drum during fall in Galveston Bay, Texas (Scharf and Schlicht, 2000).		

In Texas, the decline of blue crab and white shrimp in the past may be due to a number of factors acting either in isolation or synergistically (Tables 6.1 and 6.2). For estuarine-dependent species, FWI is a key component in terms of ecological stability of the system and may influence a multitude of factors that together can have a significant impact on a population. For example, water management that influences salinity and temperature (two major factors) is expected to affect the dominant species and overall community structure in an estuary (Baltz and Jones, 2003). Because the delicate early life history stages of commercially and ecologically important species utilize estuaries as nursery habitat, the amount and timing of FWI becomes paramount in our understanding of how population productivity is affected. During periods of peak recruitment, for example, FWI that reduces estuarine salinities over large areas of available habitat may inhibit growth and productivity in the affected areas (Rozas and Minello, 2011). On the other hand, in the absence of FWI during such periods, estuarine habitat may be reduced and experience high salinities, which can also adversely affect the survival of young. Inclusion of additional factors such as low dissolved oxygen and predation may exacerbate the effects on a population. For example, moderate to severe dissolved oxygen depletion (<5 mg l^{-1}), a currently used indicator of aquatic system impairment (Bricker et al., 1999), has been linked to the eutrophication and water column stratification of estuaries, which may be attributed to FWI and high summer temperatures (Rabalais et al., 1995b). Furthermore, estuarine ecosystems support communities with complex food webs, and in the absence of available habitat, as a result of reduced FWI, ecologically important species may be exposed to enhanced predation (Guillory and Elliot, 2001). Thus, FWI, although a critical element of estuarine health, could be planned in a manner that yields minimal interaction with the major factors listed in Tables 6.1 and 6.2. For example, Zein-Eldin and Renaud (1986) stated, "simultaneously providing marsh areas with sufficient covering water for the young while lowering salinities (<20-25‰) during hotter summer months when young white shrimp are most numerous in the estuarine areas" would provide optimal conditions for survival.

In 1975, Texas state agencies began addressing the coastwide FWI problem, and then published a series of reports exploring influences of FWI on the major estuaries, providing recommendations for adequate long-term studies and monitoring. The State of Texas Bays and Estuaries FWI Research Program (consisting of the TWDB and TPWD) helped to identify the optimal amounts (i.e., quantity) and seasonal patterns (i.e., timing and magnitude) of FWI necessary to sustain the historic biodiversity and biological productivity in Texas. First, monthly, seasonal, and annual amounts of FWI were calculated using gaged river flows, modeled runoff, diversions, and return flows from ungaged areas, with optimization modeling techniques adopted from Longley (1994) and Powell et al. (2002). As indicated in Figure 3.4, Texas estuaries are typically characterized by a large inflow peak in late spring from May-June caused by atmospheric frontal zones and a slightly smaller secondary peak from September-October caused by tropical storms. Because stream flows in Texas bays and estuaries are typically episodic, it was suggested the median inflow be used as the central tendency value of the upper bound, while the 10th percentile of inflow be used as the lower bound. Therefore, the FWI zone between the 10th and 50th percentiles was considered most effective in protecting estuaries (Powell et al., 2002). Second, the Texas Estuarine Mathematical Programming (TxEMP) model (i.e., a resource-based method; Adams, 2014), first developed by Matsumoto et al. (1994), was used by TPWD to model salinity-inflow and inflow-fishery harvest relationships, providing a range of optimized solutions from minimum required to maximum allowable annual inflows (MinQ and MaxQ) as well as maximum harvest FWI (MaxH), based on the fundamental ecological information about inflows, salinities, nutrients, and biological productions. Subsequent work was performed by TPWD to develop a FWI recommendation and implementation plan to ensure estuaries receive the freshwater necessary for sustainable health. The FWI recommendations for Guadalupe and Mission-Aransas estuaries using the TxEMP model were provided and discussed by Pulich Jr. et al. (1998) and Chen (2010), respectively. TPWD recommended target inflows between MinQ and MaxH for an estuarine system. In Guadalupe Estuary, the targeted MinQ was computed to be 1,030,000 acre-feet y^{-1}, and MaxH 1,150,000 acre-feet y^{-1}. In Mission-Aransas Estuary, it was suggested the 25th percentile of historic inflows (1941-1996) be used as the lower bound of monthly inflow since the 10th percentile inflow was too low to obtain a biologically feasible solution, and the predicted MinQ and MaxH values were 58,000 acre-feet y^{-1} and 86,000 acre-feet y^{-1}, respectively. The targeted MaxH values of both estuaries were much lower than most of the observed annual FWI rates from 1941-2009 in Figure 3.2.

More recently, the Texas Legislature recognized the need to establish environmental flow standards and incorporate nutrients and sediment into the legislative charge. The Senate Bill 3 (SB3) Environmental Flows Process was established in 2007 under the Texas Legislature to characterize a balance between human water needs and the health of the environment. The law created a public process by which State authorities would solicit input from scientists and stakeholders before establishing legal FWI standards for estuaries. Through the Senate Bill 3 process, the state was divided into eleven different regions. Each of these regions appointed their own Basin and Bay Expert Science Team (BBEST) and Basin and Bay Area Stakeholders Committee (BBASC). The BBESTs are made up of scientists and technical experts with knowledge of region-specific issues and/or experience in developing flow recommendations. They developed flow regime recommendations based on best-available science and provided their findings to the BBASCs. The BBASCs are composed of members reflecting various stakeholder groups (e.g., agriculture, recreational water use, municipalities, commercial fishing, regional water planning, etc.). Each stakeholder committee was tasked with considering the BBEST recommendations in conjunction with water policy information and incorporating their own recommendations into a Work Plan for Adaptive Management to be submitted to the Texas Commission on Environmental Quality (TCEQ) for consideration in the establishment of legal minimum flow standards. Within their adaptive management plans, the BBASCs also identified several social, climatic, physical, and biological areas of research that are essential for improving FWI recommendations.

In 2011, the FWI recommendations for Guadalupe and Mission-Aransas estuaries were determined using the Hydrology-based Environmental Flow Regime (HEFR) methodology and reported by the Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Expert Science Team (GSA BBEST) (GSA BBEST, 2011). These environmental flow regime recommendations include not only seasonal schedules of FWI quantities, but also descriptions of guiding principles for how these flow quantities are to be applied in different environmental contexts, such as low- to high-flow situations. The consideration and direct translation of the FWI recommendations by TCEQ is generally expected by GSA BBEST to ensure that such recommendations will support a sound ecological environment in both Guadalupe and Mission-Aransas estuaries.

Since the FWI recommendations in each estuary are implemented by TCEQ, plans of managing inflows to a particular estuary based on monthly optimal requirements may not include effects of long-term interactions with adjacent estuaries or the resulting biological consequences (Tolan, 2007). In addition, large-scale climate variability, such as El Niño, has cumulative effects on basin-wide stream discharge, and dominates FWI to Texas estuaries at interannual times, but to our knowledge, has not been recognized. Thus, water management decisions should also consider the interannual changes by large-scale global climate influences (Longley, 1994; Tolan, 2007). Overall, an improved understanding of FWI and its role in an estuary, we hope, will enable more effective management of limited water supplies in the future.

In addition to water resource management, habitat preservation and restoration are also very important for protecting fishery species in Texas estuaries. Generally, land use and development (e.g., levee and canal construction, dredge and fill activities, pipeline construction, and land reclamation) are consistent with a growing coastal population and can influence the quantity and quality of habitat. Moreover, estuaries may experience impaired water quality in the presence of pollutants from agricultural runoff and industrial discharge. From 1982-1996, Rozas et al. (2007) reported 61% of the wetlands was converted to open bay and marsh edge was reduced by 70% in Carancahua Cove, Galveston Bay Estuary, during which blue crab and white shrimp populations declined dramatically. However, these fishery species rebounded in 1999 after replenishing portions of open bay with marsh in a marsh-terracing project. Thus, it was suggested the loss of essential nursery habitat, such as tidal creeks, salt marsh, and seagrass beds, has the potential to reduce blue crab and white shrimp production by hindering recruitment and survival of nekton (Guillory et al., 2001; Rozas et al., 2007). Land use decisions that alter or impede access of blue crab and white shrimp to nursery habitat could be prevented in future assessments of environmental management.

7.0.0 SUMMARY

The purpose of this report is to provide a systematic review of the population dynamics of blue crab and white shrimp in Texas, specifically Mission-Aransas and Guadalupe estuaries, and to seek their relationships with variations in FWI and several other key environmental variables, including salinity, temperature, dissolved oxygen, and habitat.

1. In the GoM, both blue crab and white shrimp exhibit similar life cycles: 1) spawn at the mouth of an estuary during warm months (i.e., July-August for blue crab and March-September for white shrimp); 2) enter an estuary as postlarvae and settle in shallow nursery habitat to complete juvenile development; and 3) migrate to the GoM once mature (except for male blue crab which remain in the estuary).
2. In Texas, the blue crab fishery experienced significant downward trends in abundance and size from 1982-2005 coastwide, as well as in Mission-Aransas and Guadalupe estuaries. Similarly, white shrimp displayed a significant decline in CPUE and size via bag seine and bay trawl coastwide from 1982-2000. However, in Mission-Aransas and Guadalupe estuaries, white shrimp displayed no significant changing trend in CPUE via bag seine or bay trawl, but did show an increase in size via bag seine (i.e., juveniles) only.
3. Along the Texas coast, FWI varies year to year, primarily due to variations in precipitation, but is also affected by climate change. From 1941-2009, annual FWI to Guadalupe Estuary showed no significant change (p-value = 0.09), while Mission-Aransas Estuary exhibited a slightly positive and significant effect in FWI (p-value = 0.02) over that ~70-year period. However, with a growing population, annual water demands are expected to increase from the current levels of 3% and 0.03% of the respective combined FWIs that reach Guadalupe and Mission-Aransas estuaries.
4. In Guadalupe Estuary, the largest blue crab commercial landings occurred during years of greatest river inflow from 1965-1975. Similarly, white shrimp catch and commercial landings were also significantly correlated with spring (May-June) FWI from 1959-1975. Elevated spring flows reduced salinity and loaded nutrients and organic matter into the system, which may have benefited newly arrived postlarvae. However, poor correlations between blue crab abundance and FWI in Guadalupe Estuary have also been reported in many recent studies since 2005, and the multivariate time-series modeling study in Part II of this report indicated that FWI might influence blue crab and white shrimp populations at longer time scales.
5. FWI is critical to the ecological stability of an estuary, but it also may influence a multitude of additional environmental factors that together can have a significant positive or negative impact on blue crab and white shrimp populations. For example, FWI that is released in subtle pulses (i.e., intermittent delivery) during months of peak recruitment may be sufficient to sustain salinity gradients, deliver nutrients and sediments, and cover nursery

habitat necessary for the well-being of young recruits. In contrast, FWI that is fully pressed (i.e., continuous delivery) may cause abrupt changes in salinity and dissolved oxygen, for example, over extensive areas, which can cause negative effects on the undeveloped young (e.g., physiological impairment). Water resource management should consider not only the quantity of FWI, but also the timing and magnitude necessary to maintain healthy environmental parameters suitable for all inhabitants.

6. Monthly optimal FWI requirements can be calculated using historic FWI data and the TxEMP model, combining factors such as salinity regime, nutrient input, and biological production information. These FWI recommendations, which are implemented by TCEQ, will support a sound ecological environment in both Guadalupe and Mission-Aransas estuaries.

7. Any shortage in FWI due to human activity may reduce essential habitat and disrupt the salinity gradient necessary for blue crab and white shrimp to find refuge and escape predation. Habitat loss can also decrease carrying capacity and limit production. Habitat preservation and restoration, therefore, are key components for protecting fishery species, and land use decisions that alter or impede access of young to nursery habitat could be prevented in future assessments of environmental management.

8.0.0 FUTURE ISSUES

Future challenges for the management of blue crab and white shrimp in Mission-Aransas and Guadalupe estuaries include:

1. Determining FWI requirements (i.e., amount and timing) that provide optimal environmental conditions to species of commercial and ecological value, including blue crab and white shrimp, and coincide with periods of peak recruitment.
2. Identifying the specific sources of blue crab and white shrimp mortality, particularly during the postlarval and juvenile stages, which are influenced by post-settlement biotic processes and can limit production.
3. Implementing policies that not only prevent the loss, alteration, and/or degradation of wetlands and nursery habitat, including highly productive and sensitive tidal creeks, seagrass beds, and salt marsh, but also improve the quantity and quality of essential habitat through preservation and restoration efforts.

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Mission-Aransas Estuary	Guadalupe Estuary	Texas

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PART II: DATA ANALYSIS

Assessing the Effects of Freshwater Inflow and Other Key Drivers on the Population Dynamics of Blue Crab and White Shrimp Using a Multivariate Time-series Modeling Framework

Lindsay P. Scheef and Edward J. Buskey

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1.0.0 OVERVIEW

Efforts to find relationships between the abundances of white shrimp and blue crab and freshwater inflows are complicated by the fact that there are numerous potentially interacting variables that may be affecting the abundance and distribution of those species (Guillory et al. 2001). Environmental conditions (salinity, temperature, dissolved oxygen, turbidity, freshwater input, etc.), biological factors (e.g., predation by fish and conspecifics), and anthropogenic activities (fishing and trapping efforts) may all potentially simultaneously influence focal species abundances. Additionally, these factors may be acting at different spatial and temporal scales. These challenges make it very difficult to identify the important drivers of species abundance trends using basic univariate and time-series analyses (Ward 2012).

Multivariate autoregressive (MAR) modeling has proven to be a useful tool for the analysis of systems in which there are many potentially interacting variables that may have lagged, confounding effects (Hampton et al. 2013). This type of time-series analysis estimates the directions and strengths of species interactions based on lagged correlations in existing species abundance time-series (Ives et al. 2003). The inclusion of environmental factors in the model also allows for the estimation of the effects of those drivers on species within the community. The MAR model can be thought of as a series of regression equations in which the abundance of each species at each time step is dependent on how it was influenced at the previous time step by its own abundance (density dependence), by interactions with other species (variates), and by environmental factors (covariates).

A limitation in the use of MAR modeling to assess community dynamics is the availability of time-series that are appropriate for model application. While studies that collect monitoring data over the course of a few months or years are relatively common, MAR analysis works best with long species abundance time-series (>10 years) of high temporal resolution (~monthly sampling), which are more rare. Along the Texas coast, however, several state and federal long-term monitoring programs maintain time-series that fit these criteria. The availability of these multi-decadal time-series make it possible to use MAR modeling as a tool to simultaneously assess the impacts of both species interactions and environmental drivers on the abundances of estuarine species.

The goal of this project was to analyze the Texas Parks and Wildlife Department Coastal Fisheries monitoring program species abundance time-series along with long-term data from other sources using a MAR modeling framework to 1) assess the effects of environmental drivers on blue crab and white shrimp abundances in the Mission-Aransas and Guadalupe estuaries, 2) identify possible interactions between these two focal species and potentially influential predator species, and 3) evaluate the effects of drivers at different temporal scales and lags.

2.0.0 BACKGROUND

2.1.0 Texas Parks and Wildlife Department coastal monitoring data

The Texas Parks and Wildlife Department's (TPWD) Coastal Fisheries monitoring program maintains a long-term record of the abundances of many species inhabiting the bays along the Texas coast. Otter trawl, bag seine, and gillnet sample data for blue crab and white shrimp in Copano, Aransas, San Antonio, and Espiritu Santo bays are available starting in the late 70s and early 80s. For blue crab and white shrimp, the trawl data have been considered particularly useful for examining long-term trends because this gear type samples a calculable volume of water at stations throughout the bays rather than only near shore (e.g., Ward 2012).

2.2.0 Previous studies

Temporal trends in the TPWD time-series suggest a strong connection between white shrimp abundance and freshwater inflows. TPWD also found strong spatial relationships between white shrimp abundance and calculated salinity zones in San Antonio Bay (TPWD 1998) and Copano and Aransas bays (TPWD 2010) using this 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. 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 (SAGES) 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 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 Potential drivers of abundance

The above efforts to find relationships between the abundances of white shrimp and blue crab and freshwater inflows are complicated by the fact that there are numerous potentially interacting variables that may be affecting the abundance and distribution of those species (Guillory et al. 2001). Additionally, these factors may be acting at different spatial and temporal scales.

In addition to freshwater input and salinity, water conditions such as depth, temperature, dissolved oxygen, and turbidity may influence the abundances of motile species at very short temporal scales. Weather events such as hurricanes and front passages may have immediate impacts on estuarine populations by abruptly altering water levels, temperatures, salinities, and habitat availability. If these drivers affect fecundity, recruitment, or early life stages, lagged effects on adult species abundances may also manifest. On larger spatial scales, climatic cycles are known to affect regional precipitation and temperature patterns (e.g., Piechota and Dracup 1996) and freshwater inflow and salinity conditions in Texas estuaries (Tolan 2007), but they may also influence offshore current patterns, which in turn may influence white shrimp and blue crab larval development and recruitment back into estuaries as well as the movement of adult white shrimp along the coast.

Biotic drivers are also believed to play an important role in the population dynamics of white shrimp and blue crab. Fish predation rates on white shrimp and blue crab can be high (Heck and Coen 1995, Primavera 1997). Numerous types of fish consume white shrimp and blue crab, and, in particular, red drum are known to be an important predator of both of these species (Scharf and Schlight 2000). Interspecific predation of adult crab on juveniles may also be an important factor affecting blue crab populations (Hines and Ruiz 1995).

Fishing and trapping activities can also impact shrimp and crab populations, but it is possible that the abundances of these species may have reciprocating effects on fishing effort. For example, as the abundance of a fished species decreases, fishing effort might decrease due to poor catch rates or management implementations such as license buyback programs.

2.4.0 Assessment of community drivers with MAR models

A majority of the work using MAR modeling in the past has been done using freshwater plankton since these organisms allow for easy data collection and processing (in a timely fashion) due to their short-lived generation times (Scheef et al. 2012). However, there have been a number of marine fisheries studies with MAR modeling dating back to as early as the 90s from different locations across the globe. These include assessments of: anchovy and sardine populations in the Mediterranean Sea (Stergiou 1991, Stergiou and Christou 1996); the effects of climate and catch pricing on fishing effort for albacore tuna, Chinook salmon, sablefish, and squid in Monterey Bay, California (Dalton 2001); the ecosystem linkages that affect the carite, croaker, and honey shrimp fisheries in the Gulf of Paria, Trinidad (Dhoray and Teelucksingh 2007); the fish declines in San Francisco Bay Estuary (Mac Nally et al. 2010); the portfolio effect in coral fishes (Thibaut et al. 2012); and the effects of fishing pressure and environmental fluctuations on dynamics of commercially important cod (*Clupea harengus*) in the Black Sea with additional explorations of alternative management scenarios (Lindegren et al. 2009).

3.0.0 METHODS

3.1.0 Data acquisition

The table in Appendix A lists the sources, stations, and acquired temporal ranges of the datasets that were considered for inclusion in the MAR analyses. Estuarine species abundance time-series along with commercial fishing data for blue crab and white shrimp were acquired through direct contact with the Texas Parks and Wildlife Department (TPWD). All other datasets that were evaluated for use in this project were freely available for download from online databases. Sources, organizations, programs, acquisition/download dates, temporal and spatial coverage, and other attributes associated with each dataset were recorded as they were acquired. These logs along with the datasets used to generate the final MAR models were submitted with this report.

3.2.0 Data assessment

A small meeting with local stakeholders (17) that are familiar with the species and datasets of interest was held at The University of Texas Marine Science Institute (UTMSI), Port Aransas, TX, on November 13, 2014. Topics discussed included sources of monitoring data, the ecology of the focal species, what temporal divisions to model, what temporal lags to consider, and which predators and environmental drivers to include in the models.

It was suggested that both modeled inflow data and raw discharge data be considered for inclusion in the models in addition to salinity values, since freshwater inputs may have impacts on focal species abundances that are not correlated with salinity. There was a consensus that temporal divisions and lags should be matched to the life history and migration patterns of the focal species and that potential predators with clear increasing trends in abundance in the time-series should be given special consideration for inclusion in the models. For dividing the TPWD survey data spatially, it was recommended that the data be averaged over large bay areas with smaller bays and lakes excluded and that possible mismatches between near-shore and open bay samples be considered.

3.3.0 Data preparation

3.3.1 Variable selection

Variables to include in preliminary models were selected based on the length of the time-series, the quality/consistency of the time-series, prior beliefs about their potential impact on the focal species, and the strengths of their direct and lagged correlations with the focal species abundance time-series. Results from these preliminary models were then used to select variables to include in final models for each focal species (see Section 4.3.0).

For the focal species, the TPWD survey time-series for blue crab abundances in gill, trawl, and seine samples and white shrimp abundances in trawl and seine samples were included in the preliminary models. Predator species to include in the preliminary models were selected from the gill sample datasets. Abundance values across all bays for every gill sample species were averaged into time-series of monthly and yearly increments, and the correlations between each species and the focal species at lags of 0, 1, and 2 were determined for each time-series (Figure 3.1). From these results, species with the largest negative correlation coefficients that are known to prey on the focal species were chosen to be included in preliminary models. For the blue crab models, predator species included red drum, black drum, spotted seatrout, sheepshead, ladyfish, and gafftopsail catfish. For the white shrimp models, predator species included spotted seatrout, hardhead catfish, gafftopsail catfish, and southern flounder.

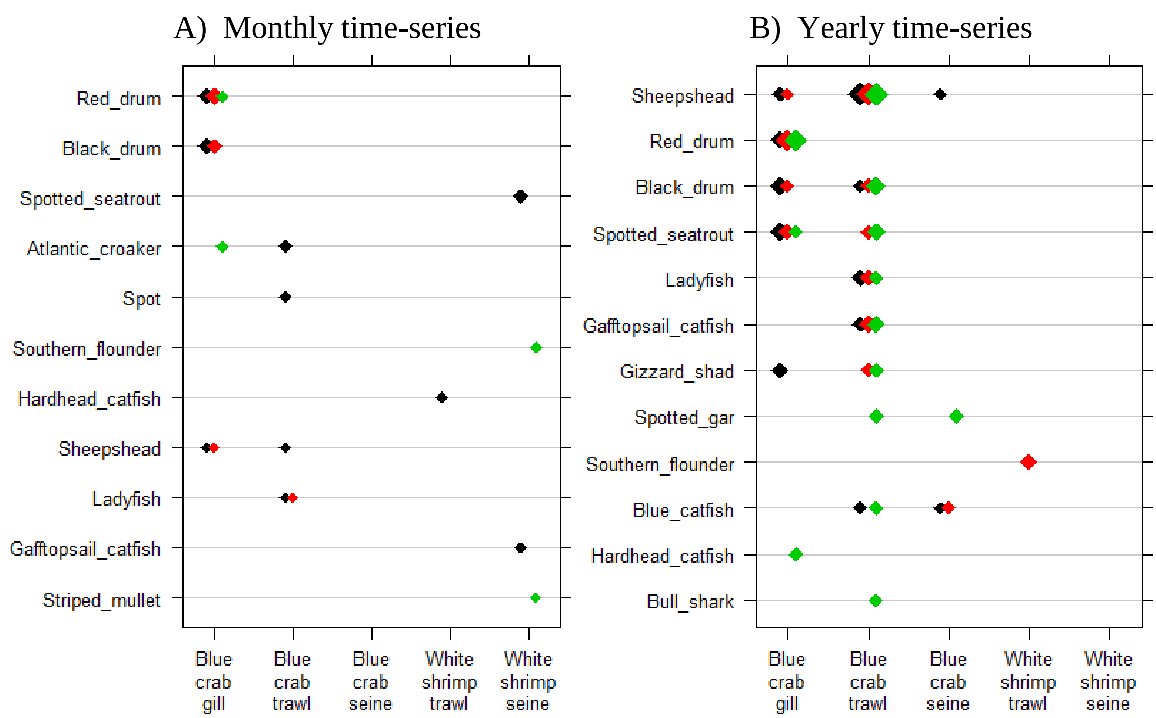

Figure 3.1 Presence of negative correlations between focal species abundances and the abundances of species captured in TPWD survey gillnets in time-series averaged by A) monthly and B) yearly increments. The size of each point represents the strength of the negative correlation between the respective species at lags of 0 (black), 1 (red), and 2 (green). Species representing >0.5% of the total gillnet species abundance that had correlations of <−0.25 for the monthly time-series and <−0.4 for the yearly time-series are shown.

Commercial landing data for blue crab are available from TPWD for the period of 1975-2014. For white shrimp, however, the National Marine Fisheries Service maintained commercial landing records for the period from 1990-2007, so the TPWD landing data for white shrimp spans 1975-1989 and 2008-2014. Both these time-series were included in preliminary models to assess whether harvest or bycatch affected the abundances of focal species or predator species in the models.

Water quality data for the Mission-Aransas and Guadalupe estuaries are available from the Mission-Aransas National Estuarine Research Reserve (NERR) System-Wide Monitoring Program and the Texas Coastal Ocean Observation Network (TCOON) database. However, the longest of these time-series only dates back to 1993. Therefore, the data for water quality included in the preliminary models were the measurements collected with each TPWD trawl sample. The trawl sample water quality data were selected over the gill net or seine data since the trawl samples covered the whole area of the bays rather than only nearshore areas.

Potential variables to include in the model as approximations of freshwater input to the estuaries included freshwater inflow estimates from the Texas Water Development Board and river discharge data from the US Geological Survey's flow-gage stations. Of these two datasets, the river discharge time-series covered the entire temporal range of the focal species trawl abundance time-series (1982-2013), while the inflow estimate values were only available for download through 2009, leaving a coverage gap of 4 years at the end of the species abundance time-series. The inflow estimate data were available through 2014 upon request, but since the discharge data and the inflow estimate data were very highly temporally correlated (0.93 Pearson's product-moment correlation, $p<0.001$) and the time-series were going to be transformed such that the magnitude of the values would not matter, the river discharge time-series was selected to approximate freshwater inputs to the bays in the MAR models.

Time-series of longshore current patterns for two Texas Automated Buoy System (TABS) stations off the coast of Texas were acquired, but only extend back to 1995. The current patterns in these time-series along with current patterns within the Mission-Aransas Estuary (Scheef unpublished data) are closely correlated with wind direction. Winds blowing from the Northeast move water Southwest along the coast and within the estuary, while winds blowing from the South move water Northeast along the coast and within the estuary. Wind direction data included in meteorological datasets can therefore be used as a proxy for longshore current patterns.

Sources of meteorological data considered for this study included the Mission-Aransas NERR System-Wide Monitoring Program, the TCOON database, the NOAA National Data Buoy Center, and the NOAA National Climatic Data Center. Of the station time-series maintained by these programs, only the Corpus Christi International Airport dataset from the NOAA National Climatic Data Center spanned the entire range of the TPWD species abundance data. Wind data from this station were divided into Northeast and Southwest directions along the 135/315° line, and the proportion of time the wind was blowing from the Northeast was included in preliminary models as an approximation for current direction, with higher values indicating more water moving from North to South along the coast.

The El Niño-Southern Oscillation (ENSO), Southern Oscillation Index (SOI), and Pacific Decadal Oscillation (PDO) have been shown to be correlated with estuarine conditions along the Texas coast (Tolan 2007) and are available through the NOAA Climate Prediction Center. Since these indices would indirectly affect the focal species abundances by influencing environmental conditions, they were included in a separate set of models to assess their effects on water quality, river discharge, and wind patterns.

3.3.2 Spatial divisions

In the TPWD species abundance dataset acquired for this study, sampling stations are categorized by major bay and then by minor bay. The major bays are the two estuaries of focus: the Mission-Aransas Estuary and the Guadalupe Estuary. The largest minor bays within each of these estuaries are Copano and Aransas bays and San Antonio and Espiritu Santo bays, respectively. Examination of the data revealed that dividing the data by the smaller minor bays or making further divisions within the four large bays would result in gaps in the time-series and high variability when the data were averaged over different temporal divisions. Therefore, the smallest divisions selected for preliminary models were Copano, Aransas, San Antonio (including Hynes Bay), and Espiritu Santo bays.

Rather than averaging values over regions larger than these four bays to build models for each estuary and for the overall system, the time-series for multiple bays in each region of interest were strung together and modeled concurrently. This method extracts the average interactions between the time-series without altering their original structures, which could potentially obscure interactions that are not perfectly synchronized between them. This was therefore more effective than averaging the time-series for separate bays together before applying the models.

3.3.3 Temporal divisions

Temporal divisions selected for preliminary models included monthly and yearly means. Seasonal divisions were also considered, but because the TPWD gill net samples are only taken during spring (April, May, and June) and fall (September, October, and November), this spring-fall scheme was the only seasonal division included in the MAR models. Because blue crab and white shrimp complete a life cycle within 1-2 years, temporal response lags of 0, 1, and 2 were considered in preliminary models.

3.3.4 Transformations

All species abundance time-series were log-transformed to account for non-linear relationships and standardized with a Z-score so model results could be directly compared between species (Hampton et al. 2006). The values of the other factors that were selected also were Z-scored and included in the models as covariates. For the yearly time-series, the Z-scored values for each variable were calculated by subtracting the variable's overall mean across all years from its mean for each year, then dividing by its overall standard deviation across all years. This method results in all variables having a mean of 0 and a standard deviation of 1.

For the monthly temporal divisions, the Z-scored values were calculated as each monthly mean value minus the overall mean for that particular month across all years, divided by the overall standard deviation for that particular month across all years. This method effectively removes seasonal signals from the time-series and thereby prevents seasonal successions from being interpreted as interactions within the MAR models. The Z-scored values for the spring-fall temporal division were also calculated with this de-seasoning method.

3.4.0 MAR model formulation

The MAR model described by Ives et al. (2003) can be thought of as a series of regression equations in which the abundance of each species at each increment in a time-series is dependent on how its abundance at the previous time step was influenced by interactions with other species (variates) and by environmental factors (covariates). In the matrix formulation, for p interacting species (variates) and q environmental factors (covariates), $\mathbf{X}_t$ is a $p \times 1$ vector of the species' abundance values at time t, $\mathbf{A}$ is a $p \times 1$ vector of intrinsic productivities, $\mathbf{B}$ is a $p \times p$ matrix of interaction coefficients, $\mathbf{X}_{t\text{-}1}$ is a $p \times 1$ vector of the abundance values for each species at time t-1, $\mathbf{C}$ is a $p \times q$ matrix of effects of covariates on variates, $\mathbf{U}_{t\text{-}1}$ is a $q \times 1$ vector of covariate values at time t-1, and $\mathbf{E}$ is a $p \times 1$ vector of process errors with mean 0 and variance-covariance matrix $\mathbf{Q}$. The coefficients in $\mathbf{B}$ and $\mathbf{C}$ represent the influence of each species and environmental factor, respectively, on species abundances. The diagonal elements of $\mathbf{B}$ contain the density-dependent interaction terms for each variate; the off-diagonal elements are the effects of the species on one another.

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

The MAR models were run in R using modifications of the functions included in the MAR1 package (Scheef 2013). The function to run the model in the MAR1 package employs a lag of 1 by default, so it was necessary to alter the code to assess potential lag 0 and lag 2 interactions between the model variables.

The best-fit models produced by the analysis were refined by eliminating coefficients that were not significantly different from zero as determined through bootstrapping. To bootstrap a best-fit model, coefficient values were re-estimated multiple times (n=500) using datasets reconstructed from the original time-series by sampling it with replacement. The upper and lower 95% confidence bounds for each coefficient were determined from its respective set of re-estimated values, and coefficients with confidence bounds overlapping zero were eliminated to produce a final, bootstrapped version of the model.

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

4.0.0 Analysis and Results

4.1.0 Trends

The direction and significance of the overall temporal trend for each variable included in the preliminary models was determined by applying linear regressions to the Z-scored yearly time-series (Table 4.1). Because the Z-scored values were used in this analysis, the regression coefficients can be used to directly compare trends between different variables. The variables exhibiting the strongest declines over the period examined were blue crab trawl abundances, commercial blue crab catch, and commercial white shrimp catch. The strongest increasing trends were seen for black drum and ladyfish.

Temporal abundance trends for blue crab in the gill, trawl, and seine samples and for white shrimp in the trawl and seine samples are shown in Figure 4.1. Significant declines in blue crab abundance were seen in the gill and trawl samples, but no significant temporal trends were detected for this species in the seine samples (Table 4.1). No significant increasing or decreasing temporal trends were detected for white shrimp in the trawl or seine samples.

Table 4.1 Coefficients and *p*-values from linear regressions of each variable's Z-scored yearly abundance values over time. Coefficients with *p*-values <0.01 are in bold.

Variable	Coef	*p*-value		Coef	*p*-value
Focal species					
Blue crab gill	**-0.05**	<0.001	White shrimp trawl	0.004	0.66
Blue crab trawl	**-0.07**	<0.001	White shrimp seine	-0.02	0.09
Blue crab seine	-0.02	0.11			
Predators (gill)					
Red drum	**0.04**	<0.001	Gafftopsail catfish	**0.04**	<0.001
Black drum	**0.07**	<0.001	Hardhead catfish	0.02	0.05
Spotted seatrout	**0.04**	<0.001	Ladyfish	**0.08**	<0.001
Sheepshead	**0.05**	<0.001	Southern flounder	**-0.04**	<0.001
Commercial catch					
Crab catch	**-0.07**	<0.001	Shrimp catch	**-0.07**	<0.001
Water quality					
Salinity	0.01	0.21	Dissolved oxygen	**-0.06**	<0.001
Temperature	**0.04**	<0.001	Turbidity	**-0.04**	0.001
Climate					
ENSO	-0.03	0.16	River discharge	-0.004	0.79
SOI	**0.05**	0.01	North winds	-0.03	0.12
PDO	**-0.06**	<0.001			

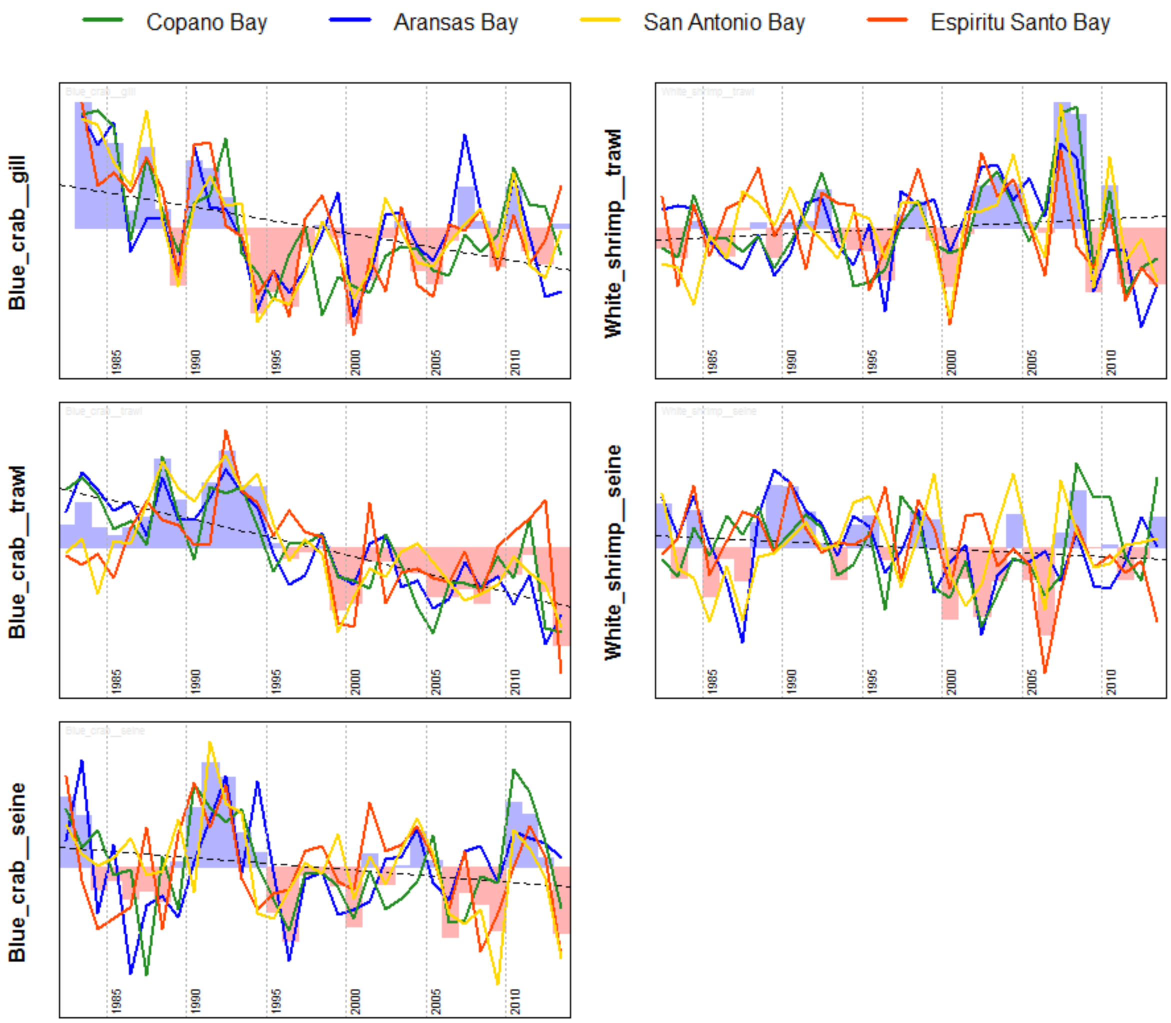

Figure 4.1 Focal species abundance trends (Z-scored yearly means) for blue crab gill, trawl, and seine samples and white shrimp trawl and seine samples. Lines represent mean abundances for Copano (green), Aransas (blue), San Antonio (yellow), and Espiritu Santo (red) bays. Yearly means across all four 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.

Significant increasing abundance trends were seen for all of the selected predators, with the exception of southern flounder, which demonstrated a significant decreasing trend, and hardhead catfish, which demonstrated a weaker increasing trend (Figure 4.2, Table 4.1). Increasing trends in red drum and spotted seatrout may be in part due to stocking programs started in 1985 and 1992, respectively, which release fingerling and fry fish into the bays. The commercial sale of red drum and spotted seatrout has also been prohibited since 1981, when these species were designated as game fish. Stricter fishing regulations put into place during the late 1980s and a ban on the use of all trammel nets and drag seines in Texas bays in 1988 may also have contributed to increases in some of these predator species.

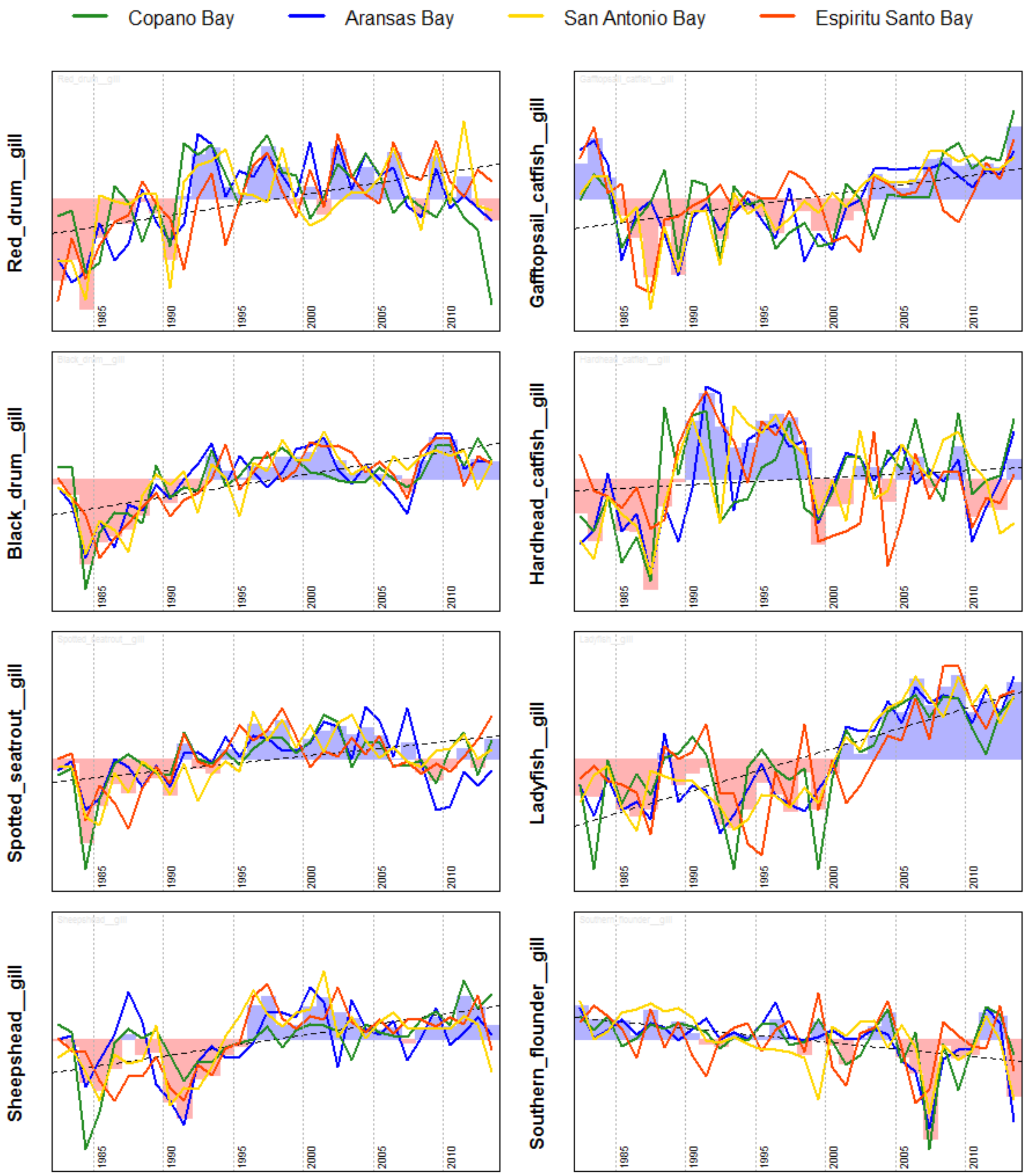

Figure 4.2 Abundance trends (Z-scored yearly means) for predator species included in preliminary MAR models. Lines represent mean abundances for Copano (green), Aransas (blue), San Antonio (yellow), and Espiritu Santo (red) bays. Yearly means across all four bays are represented by bars colored to indicate 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.

Commercial catch for both blue crab and white shrimp significantly decreased from 1982-2013 (Table 4.1, Figure 4.3). Blue crab catch decrease is correlated with the decreasing abundance of blue crabs in the system (see Correlations). The decrease in shrimp catch is related to the shrimp vessel license buyback program enacted in 1995 by the Texas Legislature, which has effectively reduced shrimping efforts in the bays.

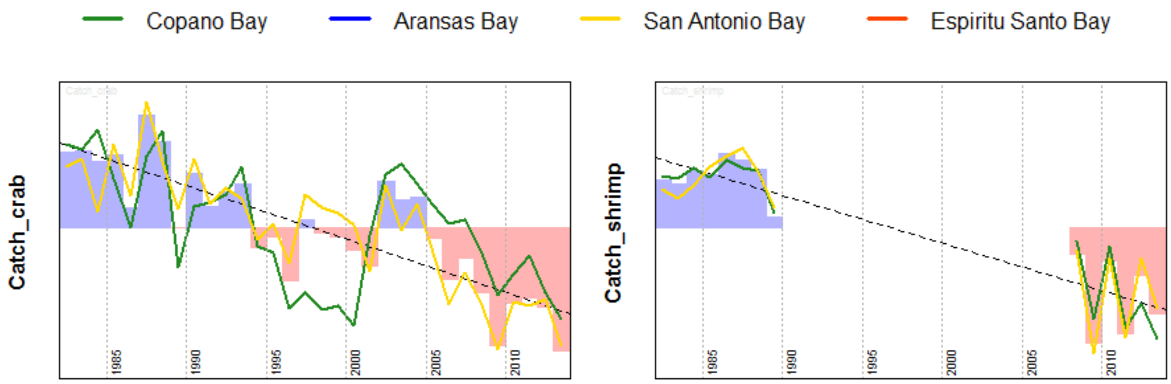

Figure 4.3 Temporal trends (Z-scored yearly means) for blue crab and white shrimp commercial catch time-series included in preliminary MAR models. Lines represent means for Copano (green) and San Antonio (yellow) bays. Yearly means across both bays are represented by bars colored to indicate whether 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.

Water temperature significantly increased over the sample period, while dissolved oxygen levels and turbidity significantly decreased (Figure 4.4, Table 4.1). No significant decreasing or increasing temporal trends were detected for salinity, river discharge, or wind patterns. All of the climate indices demonstrate clear cyclical trends on an approximate 2-4 year time scale (Figure 4.5). Within the 32-year time period examined, there was a significant increase in the SOI and a significant decrease in the PDO (Table 4.1).

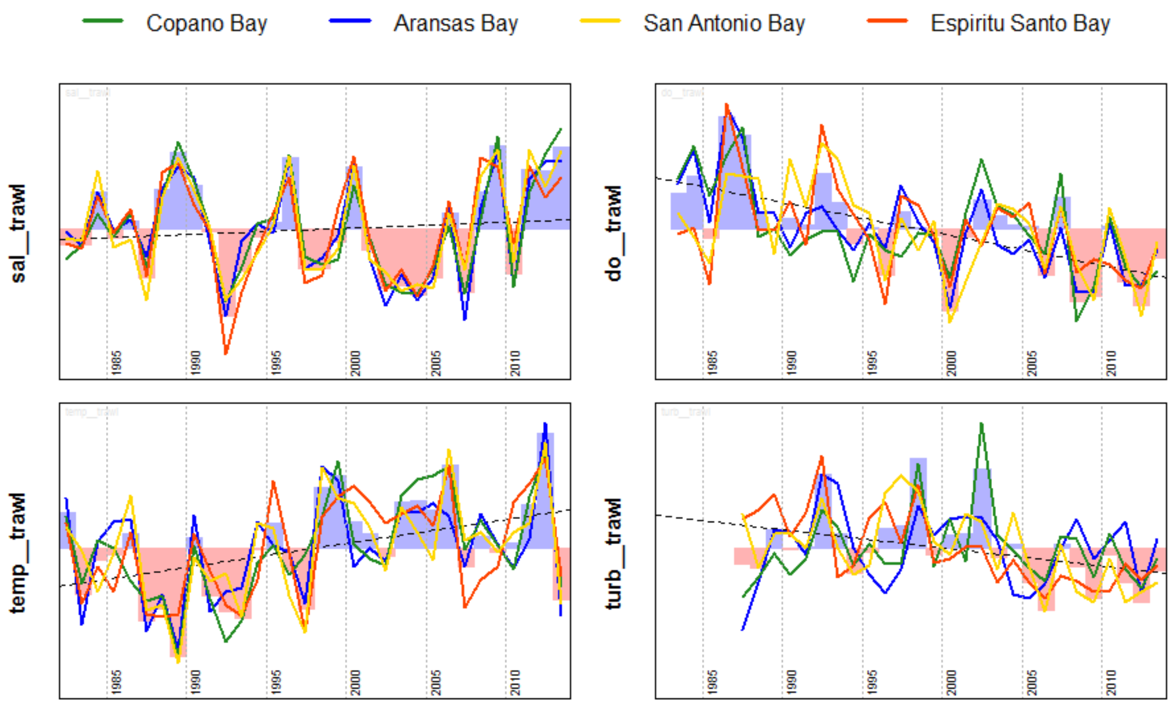

Figure 4.4 Temporal trends (Z-scored yearly means) for TPWD trawl sample water quality parameters included in preliminary MAR models. Lines represent means for Copano (green), Aransas (blue), San Antonio (yellow), and Espiritu Santo (red) bays. Yearly means across all four bays are represented by bars 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.

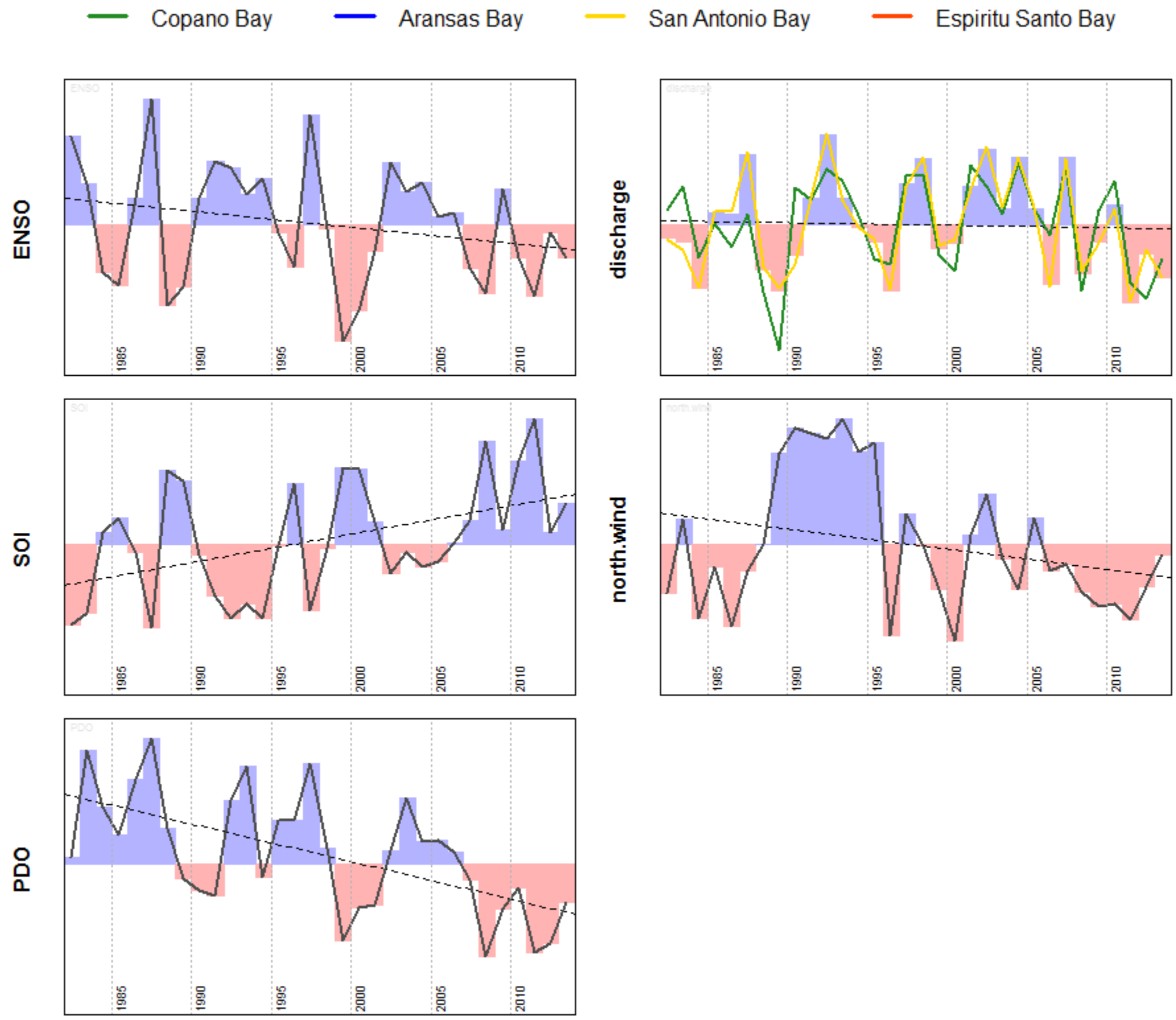

Figure 4.5 Temporal trends (Z-scored yearly means) for climate indices, river discharge, and wind patterns included in preliminary MAR models. Lines represent means for Copano Bay (green), San Antonio Bay (yellow), and the general region (gray). Overall yearly means for each variable are represented 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 Correlations

Correlation patterns between the yearly means of all selected variables are shown in Figure 4.6. In general, blue crab abundance was negatively correlated with the abundances of all predators, with the exception of southern flounder. Blue crab were negatively correlated with salinity, temperature, and the SOI and were positively correlated with dissolved oxygen, turbidity, river discharge, north wind prevalence, ENSO, and PDO. White shrimp had weak negative correlations with red drum and southern flounder, but a strong negative correlation with salinity and a strong positive correlation with river discharge. White shrimp abundance was also positively associated with dissolved oxygen and turbidity.

With the exception of southern flounder, there were positive correlations between nearly all of the predator species. Correlations between red drum, black drum, spotted seatrout, and sheepshead and between gafftopsail catfish and ladyfish were particularly strong. Generally, predator abundances were negatively correlated with dissolved oxygen and strongly negatively correlated with commercial shrimp catch.

Commercial blue crab catch was positively correlated with blue crab abundance and, as with shrimp catch, negatively correlated with predator abundances. Shrimp catch was also positively correlated with blue crab abundance, and in turn strongly positively correlated with crab catch. Both crab and shrimp catch had strong positive correlations with dissolved oxygen and were also both positively correlated with river discharge.

Dissolved oxygen and turbidity were both negatively related to salinity and temperature. The expected negative correlation between river discharge and salinity was evident, and discharge was positively correlated with dissolved oxygen and turbidity. Higher prevalence of north winds was associated with lower salinity and temperature and higher dissolved oxygen, turbidity, and discharge.

Correlations between the ENSO, SOI, and PDO climate indices and the species abundances varied. However, in general, blue crab were positively associated with ENSO and PDO values and negatively associated with SOI values, and predator species were negatively associated with PDO values and positively associated with SOI values. Between the climate indices and environmental variables, PDO was negatively correlated with water temperature, and both ENSO and PDO were negatively correlated with salinity and positively correlated with dissolved oxygen, river discharge, and north wind prevalence. Conversely, SOI was positively correlated with salinity and negatively correlated with dissolved oxygen, river discharge, and north winds.

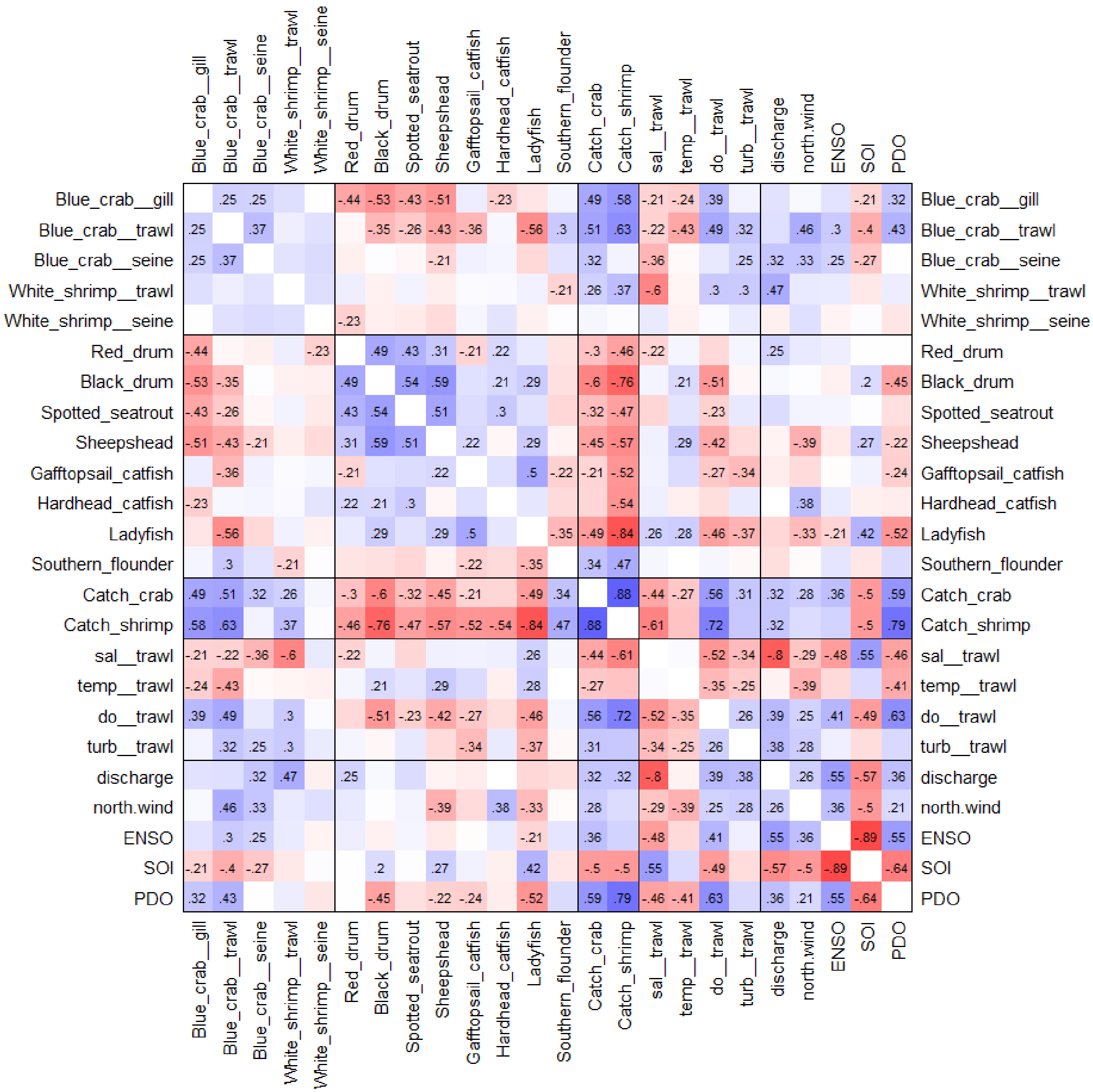

Figure 4.6 Correlations between each pair of variables included in preliminary MAR models. Cells are colored according to whether correlations were positive (blue) or negative (red). Pearson's product moment coefficients are shown for correlations with *p*-values <0.01.

4.3.0 Models

Three sets of MAR models were run: one set to determine the interactions among the environmental variables and the climate indices (Environmental models), one set to assess the drivers of blue crab abundance (Blue crab models), and one set to assess the drivers of white shrimp abundance (White shrimp models). Within each set, models for all combinations of each temporal division (year, season, and month), each spatial division (bay, estuary, and system), and each temporal lag (0, 1, and 2) were run, resulting in 63 preliminary models per set for the blue crab and white shrimp sets and 42 preliminary models for the environmental set, for which only the year and season temporal divisions were used.

A final model configuration was selected for each temporal division subset by examining the preliminary models for the various spatial division and temporal lag combinations within that subset. Variables exhibiting weak or implausible interactions or strong correlations with other driver variables were individually removed from the model structure until a simplified, predominantly ecologically feasible version was reached. Table 4.2 shows the variables that were included either as variates or covariates in the final models for each temporal division within each set.

Table 4.2 Variables included in preliminary and final blue crab, white shrimp, and environmental MAR models. Yearly (Y), seasonal (S), and monthly (M) temporal divisions used within each model set are indicated. Variables included in each model set as variates (v) or covariates (c) are indicated. Variables included in preliminary models but excluded from final models are shown in gray.

	Blue crab			White shrimp			Environmental	
	Y	S	M	Y	S	M	Y	S
Focal Species								
Blue crab gill	v	v	v					
Blue crab trawl	v	v	v					
Blue crab seine	v	v	v					
White shrimp trawl				v	v	v		
White shrimp seine				v	v	v		
Predators (gill)								
Red drum	v	v	v					
Black drum	v	v	v					
Spotted seatrout	v	v	v	v	v	v		
Sheepshead	v	v	v					
Gafftopsail catfish	v	v	v	v	v	v		
Hardhead_catfish				v	v	v		
Ladyfish	v	v	v					
Southern flounder				v	v	v		
Commercial catch								
Crab catch	v	v	v					
Shrimp catch				v	v	v		
Water quality								
Salinity	c	c	c	c	c	c	v	v
Temperature	c	c	c	c	c	c	v	v
Dissolved oxygen	c	c	c	c	c	c	v	v
Turbidity	c	c	c	c	c	c	v	v
Climate								
River discharge	c	c	c	c	c	c	v	v
North winds	c	c	c	c	c	c	v	v
ENSO							c	c
SOI							c	c
PDO							c	c

4.3.1 Environmental models

The climate oscillation indices included in the environmental set of models manifest at relatively large temporal scales, therefore only the yearly and seasonal temporal divisions were applied to the data for this set of models. Although ENSO conditions can affect Texas estuarine conditions within a lag of 6 months (Tolan 2007), no significant effects of ENSO were detected at a seasonal lag. Models run with the yearly temporal division yielded more interaction coefficients significantly different from zero and are discussed here.

Figure 4.7 is a plot of the final set of environmental MAR models for the yearly temporal division (see Appendix B for tables of the model coefficient values). For each temporal lag (0, 1, and 2 years), the coefficients of the B matrices (boxes outlined in blue) and C matrices (boxes outlined in red) are plotted for each of three regions (overall system: gray/top; Mission-Aransas Estuary: blue/middle; Guadalupe Estuary: red/bottom). The value of each coefficient is represented by a bar extending from the center of each box, and the length and direction of the bar indicate the strength and direction (positive or negative) of the effect of the column variable on the row variable. For example, in the lag 0 plot, PDO would be read as having a negative influence on temperature for all three regions and a positive effect on dissolved oxygen in the models for the overall region and the Mission-Aransas Estuary. Since the lag on this particular model is 0, these relationships are really more accurately described as correlations rather than interactions, but for any model with a lag >0, such inferences about cause and effect can be made. Hatched bars in the plots represent interactions that were not significantly different from zero as determined by bootstrapping, and red dots represent coefficients that were manually restricted to zero. All interactions in the B matrices of the lag 1 and 2 model subsets were restricted to zero since direct interactions between water quality parameters across more than 1 year were unlikely. The B matrices for those models are therefore not pictured.

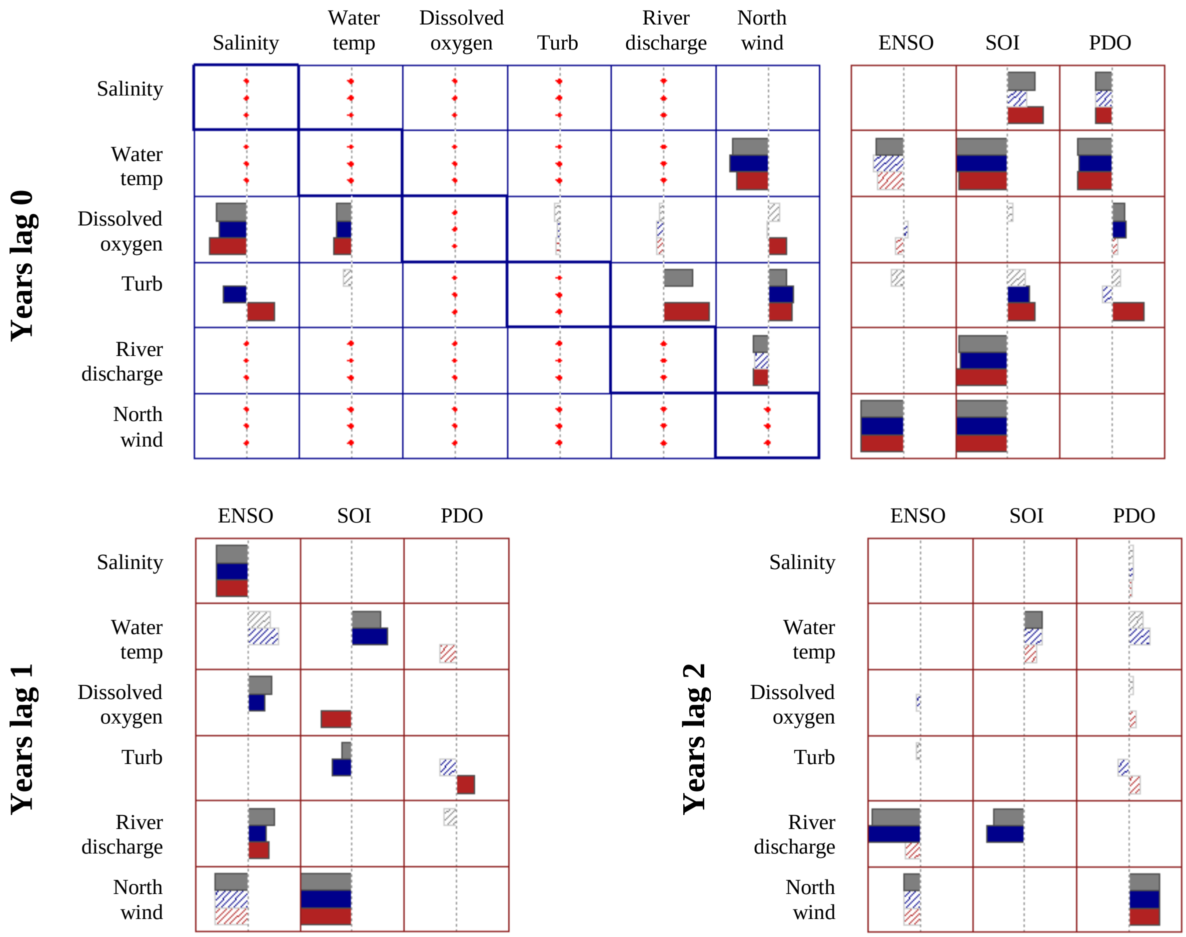

Figure 4.7 Interaction coefficient plots for environmental MAR models run at different lags. Each bar represents the direction and strength of the effect of a column variable on a row variable, such that bars extending to the right and left of the center dotted lines represent positive and negative interactions, respectively (horizontal axis limits are ±0.85). Model results for all bays (gray bars), the Mission-Aransas Estuary (blue bars), and the Guadalupe Estuary (red bars) are shown. Hatched bars represent values with 95% confidence intervals that overlap 0. Dots in place of bars represent interactions restricted to 0.

For the climate indices (i.e., the covariates in the models), ENSO was negatively related to water temperature and north wind prevalence at a lag of 0 years. At a lag of 1 year, ENSO was detected as negatively affecting salinity and north winds, and positively affecting dissolved oxygen and river discharge. SOI was associated with high salinity, cooler than average water temperature, high turbidity, less river discharge, and lower north wind prevalence at a lag of 0 years. At a lag of 1 year, higher water temperatures and lower turbidity and north winds were associated with SOI, and an additional negative influence on river discharge was detected at a lag of 2 years. PDO was related to lower salinities and temperatures at a lag of 0, and had a positive effect on north wind prevalence at a lag of 2 years.

Several relationships were detected between the variates included in the lag 0 models. Low dissolved oxygen was associated with high salinities and high water temperatures, and turbidity was most strongly related to higher river discharge, particularly in the Guadalupe Estuary. Greater north wind prevalence was linked to lower water temperatures, higher turbidity, and lower river discharge. These relationships aided in refining the preliminary models in the blue crab and white shrimp model sets.

4.3.2 Blue crab models

Model refinement

Preliminary models for blue crab generally indicated positive relationships between blue crab abundances and higher prevalence of north winds. Positive correlations between blue crab abundance and lower salinities and lower temperatures were also evident. Since the directions of the interactions for north wind, salinity, and temperature were consistent with the north wind correlations seen in the environmental model set, the north wind variable was removed from the preliminary models to reduce the number of correlated drivers.

Relationships between crab abundance and turbidity and dissolved oxygen tended to be inconsistent in strength and direction between models with different temporal and spatial divisions. This observation, along with dissolved oxygen's correlation to other environmental variables and the turbidity time-series being five years shorter than the species abundance time-series due to a change in measurement units, led to those variables being excluded from preliminary models as well.

Although salinity and river discharge are very strongly negatively correlated, both parameters were retained in the final models due to the potential for the effects of each to differ between different crab sizes (juvenile vs. adult) and vary at different time scales (e.g., shorter term effects from salinity variability vs. longer term system effects from freshwater discharge events).

Commercial catch was strongly positively related to the abundance of blue crab at lags of up to one season. Since no direct effects of catch on blue crab abundance could be detected in the preliminary models, this potential driver was also excluded. An interesting note, though, was that catch was often more strongly negatively related to predator species abundances included in the models (red drum, black drum, and gafftopsail catfish) than the three blue crab abundance variables were.

Blue crab abundances were negatively related to the abundances of all predator species included in the models at a lag of 0, and the degree to which negative predator effects were seen at other lags varied according to which additional parameters were included in the models. Since red drum, black drum, and spotted seatrout were the three most abundant of the predator species in the gill net samples, these three species were the ones retained in the final blue crab models.

Final models

Final blue crab models for the temporal response lags of 0, 1, and 2 are plotted in Figures 4.8, 4.9, and 4.10, respectively. The yearly, seasonal, and monthly temporal divisions are each represented by a separate plot in each figure, and the coefficients of models for the overall system, the Mission-Aransas Estuary, and the Guadalupe Estuary are represented in each plot by gray, blue, and red bars, respectively (see Appendix B for coefficient values and Appendix C for R^2 and conditional R^2 values).

The lag 0 blue crab models for yearly, seasonal, and monthly temporal divisions are very similar to one another (Figure 4.8), and reflect the same relationships seen in the direct correlations that were done between each pair of variables (Figure 4.6). Although the models for the three different temporal divisions generally include the same interactions, the coefficient estimates tend to be larger and more variable with increasing temporal division size, with the yearly time-series models having many large interactions that were removed through bootstrapping that were smaller and in many cases significant in the seasonal and monthly time-series models. This variability is likely to be the result of the yearly averaged time-series having fewer time steps than the seasonal and monthly time-series.

In the lag 1 blue crab models for the monthly temporal division (Figure 4.9), many of the relationships seen in the corresponding lag 0 models are lumped into the density dependent terms for each species along the diagonal of the B-matrix. This phenomenon implies that time lags of one month are not long enough for the model to be able to pick up the effects of drivers on blue crab abundance that are better predictors than their own abundance at the last time step. In other words, strong autocorrelation of the blue crab abundance time-series at a lag of 1 month obscures other potential interactions. This is not surprising given that the life cycle of the blue crab is much longer than this temporal increment.

This same lumping of interactions into density dependent terms is seen in the season lag 1 models (Figure 4.9). However, unlike with the month models, positive effects of river discharge on blue crab abundance that were not evident in the lag 0 models were detected at a lag of 1. The same is true for the year lag 1 models. However, in addition to positive effects of river discharge on crab abundance, the negative effects of salinity on crab abundance seen in the lag 0 models start to shift towards positive.

The month lag 2 models (Figure 4.10) are similar to the month lag 1 models, with the exceptions that negative effects of temperature on the predator species are consistently detected and that significant negative effects of red drum abundance on blue crab gill abundance are detected across all bays and both estuaries. For the season lag 2 models, since a lag of 2 six-month seasons is essentially the same as a lag of 1 year, it is not surprising that these models reflect the same relationships seen in the year lag 1 models, with the main difference being that more of the coefficients in the season models tend to be significant due to the seasonal time-series containing more time steps than the yearly time-series. The year lag 2 models contained the positive effects of both salinity and river discharge on blue crab that were observed in the year lag 1 and season lag 2 models, but effects of salinity were larger and more consistent between estuaries. This switching of salinity effects from negative to positive with larger time lags can be explained by the cyclic nature of salinity patterns in the estuary. If salinity at a certain time is low, lags of increasing value from that point are increasingly likely to fall in a high salinity period of the cycle and give the opposite sign of the true effect.

Overall, negative effects of predators, particularly red drum and black drum, were seen on both the gill and trawl blue crab abundances across all spatial divisions, temporal divisions, and temporal lags. Negative effects of water temperature on blue crab abundances were also detected in all models and were strongest for blue crab in trawl samples. Negative effects of salinity on the gill, trawl, and seine blue crab were seen in all models at lag 0 and in the month time-series models at lags of 1 and 2. Positive effects of river discharge were detected in the season and year lag 1 and 2 models, and positive effects of salinity were detected in the season lag 2 and year lag 1 and 2 models. The year lag 2 model was the configuration that most effectively accounted for changes in blue crab abundances in the system over time (see Appendix C for R^2 and conditional R^2 values).

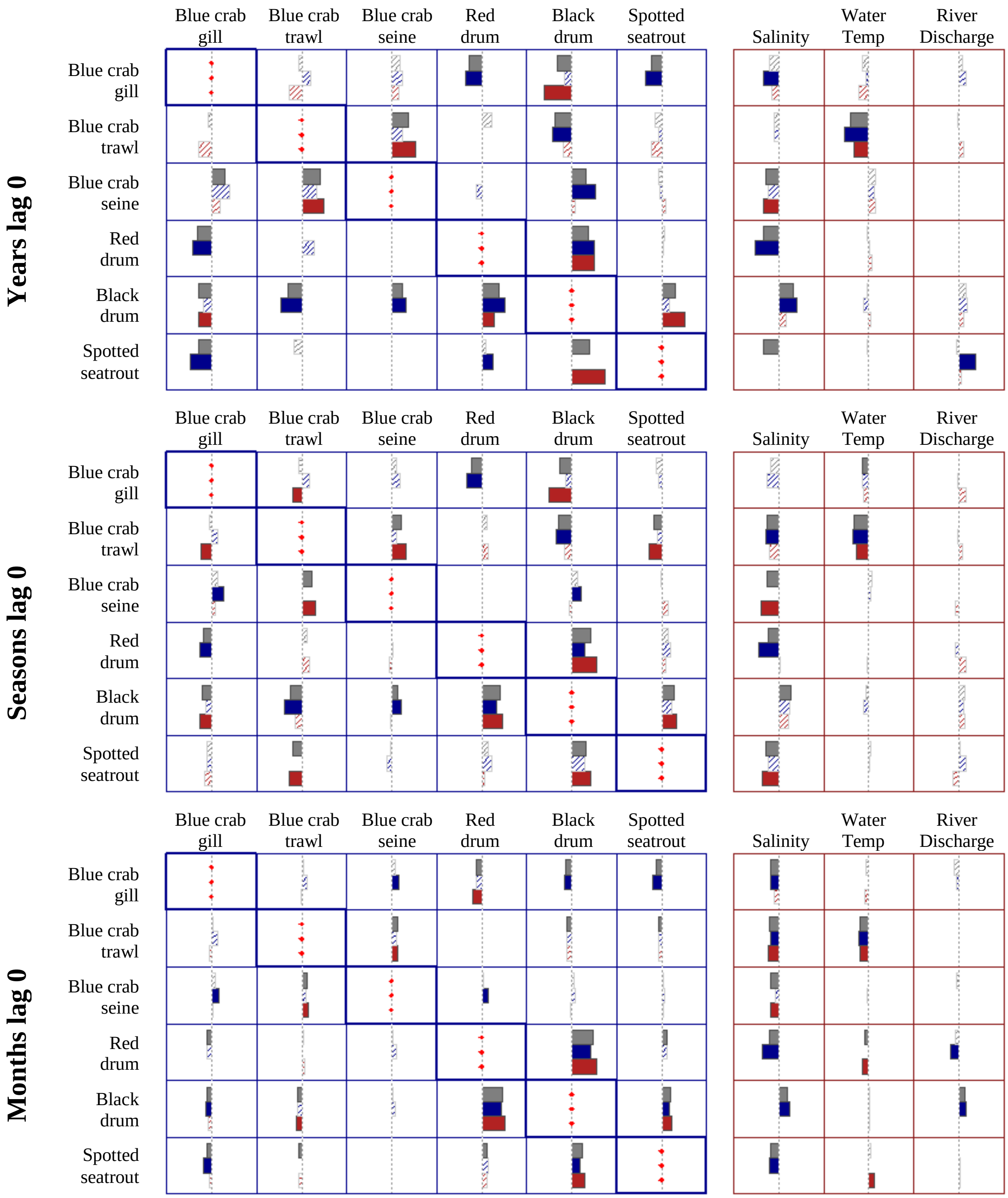

Figure 4.8 Interaction coefficient plots for lag 0 blue crab MAR models run on time-series averaged by yearly, seasonal, and monthly temporal divisions. Each bar represents the direction and strength of the effect of a column variable on a row variable, such that bars extending to the right and left of the center dotted lines represent positive and negative interactions, respectively (horizontal axis limits are ±0.85). Model results for all bays (gray bars), the Mission-Aransas Estuary (blue bars), and the Guadalupe Estuary (red bars) are shown. Hatched bars represent values with 95% confidence intervals that overlap 0. Dots in place of bars represent interactions restricted to 0.

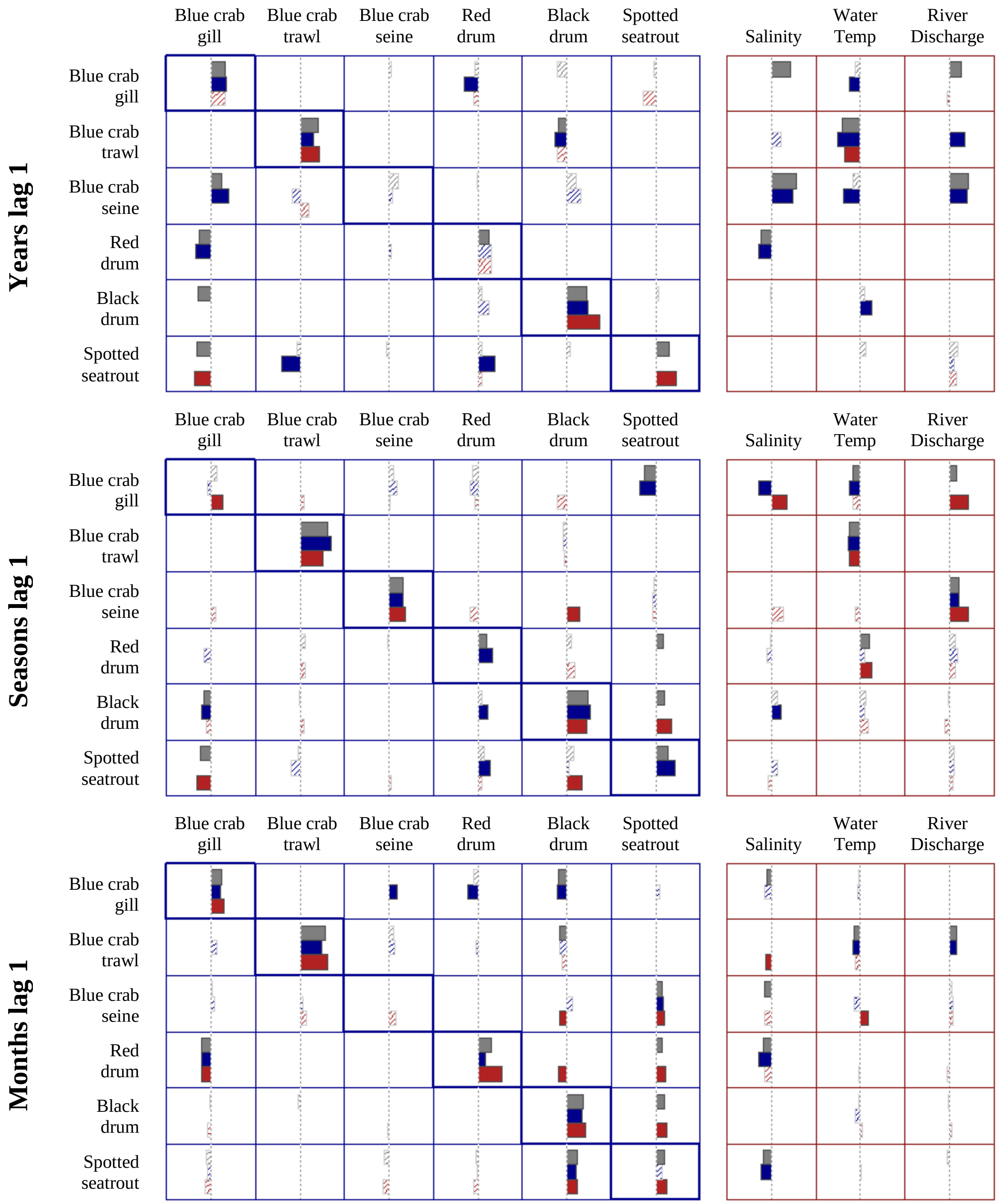

Figure 4.9 Interaction coefficient plots for lag 1 blue crab MAR models run on time-series averaged by yearly, seasonal, and monthly temporal divisions. Each bar represents the direction and strength of the effect of a column variable on a row variable, such that bars extending to the right and left of the center dotted lines represent positive and negative interactions, respectively (horizontal axis limits are ±0.85). Model results for all bays (gray bars), the Mission-Aransas Estuary (blue bars), and the Guadalupe Estuary (red bars) are shown. Hatched bars represent values with 95% confidence intervals that overlap 0.

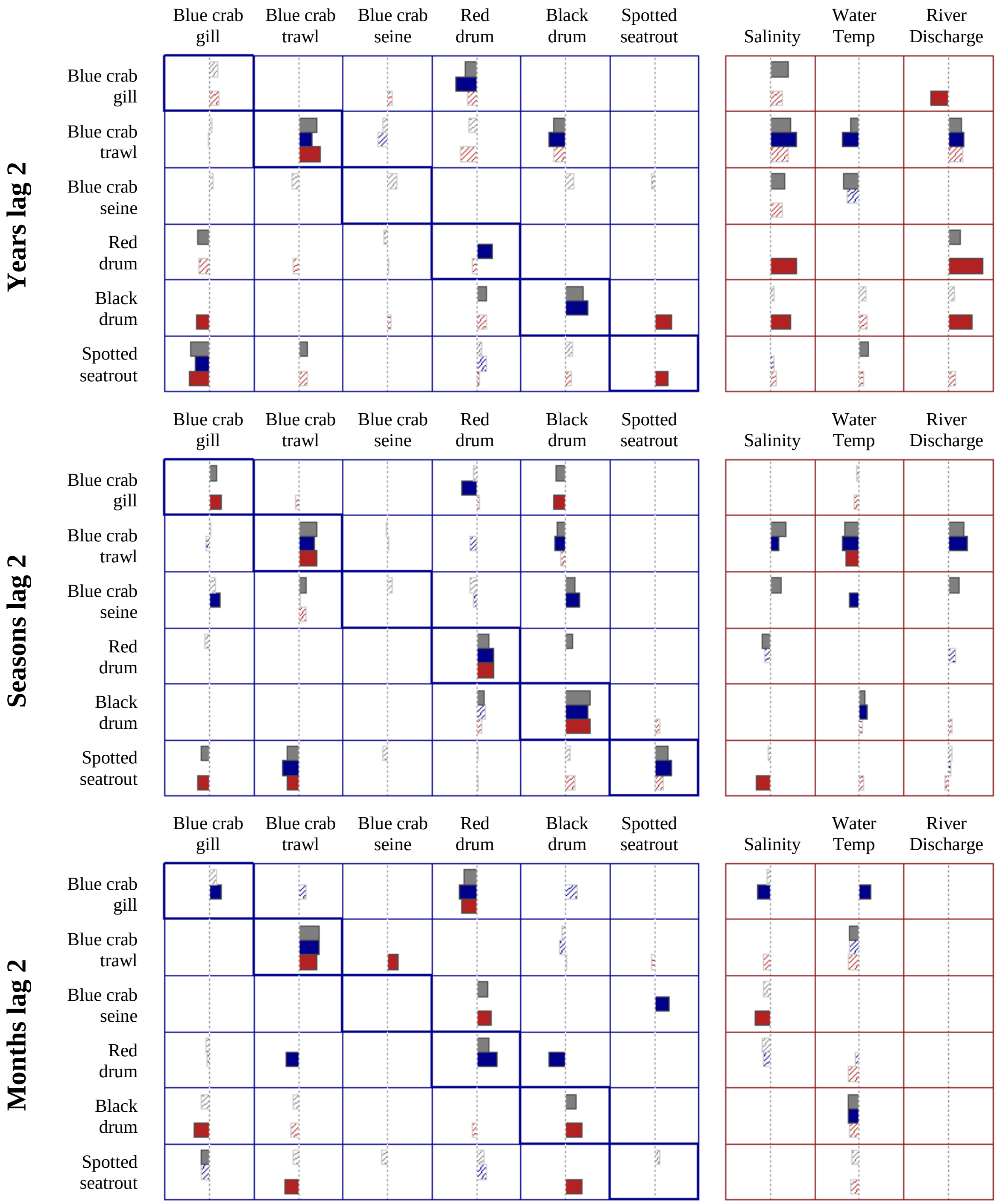

Figure 4.10 Interaction coefficient plots for lag 2 blue crab MAR models run on time-series averaged by yearly, seasonal, and monthly temporal divisions. Each bar represents the direction and strength of the effect of a column variable on a row variable, such that bars extending to the right and left of the center dotted lines represent positive and negative interactions, respectively (horizontal axis limits are ±0.85). Model results for all bays (gray bars), the Mission-Aransas Estuary (blue bars), and the Guadalupe Estuary (red bars) are shown. Hatched bars represent values with 95% confidence intervals that overlap 0.

4.3.3 White shrimp models

Model refinement

Environmental covariates retained for the final white shrimp models were selected using the same rationality that was used to select the environmental covariates for the blue crab models. The north winds variable was dropped from the models to reduce the number of correlated drivers. Turbidity was dropped from the models due to inconsistent interactions with the variates and its shorter time-series. Dissolved oxygen was also removed from preliminary models due to inconsistent and weak interactions. Salinity and river discharge were both retained in the final models despite being strongly correlated to account for potentially different effects at varying time scales.

Similar to the blue crab model set, because commercial shrimp catch was strongly related to white shrimp abundance, including this variable in the models obscured most other interactions in the model output. Commercial catch was therefore excluded as a variable in the preliminary models.

The only predator that had consistent effects on white shrimp in preliminary models was southern flounder. This was therefore the only additional species included in the final models as a variate with the white shrimp seine and trawl abundances.

Final models

Final white shrimp models for the temporal response lags of 0, 1, and 2 are plotted in Figures 4.11, 4.12, and 4.13, respectively. The yearly, seasonal, and monthly temporal divisions are each represented by a separate plot in each figure, and the coefficients of models for the overall system, the Mission-Aransas Estuary, and the Guadalupe Estuary are represented in each plot by gray, blue, and red bars, respectively (see Appendix B for coefficient values and Appendix C for R^2 and conditional R^2 values).

As with the lag 0 blue crab models, the lag 0 white shrimp models for yearly, seasonal, and monthly temporal divisions are very similar to one another (Figure 4.11), and reflect the same relationships seen in the direct correlations that were done between each pair of variables (Figure 4.6). Strong negative effects of salinity on trawl white shrimp abundances dominate all lag 0 models across all spatial divisions.

In the lag 1 white shrimp models for the monthly temporal division (Figure 4.12), despite strong density dependence along the diagonal of the B-matrix, strong negative effects of salinity are still seen on the trawl white shrimp abundances, and positive effects of temperature on seine white shrimp abundances are consistently detected across the estuaries.

White shrimp density dependence disappears in the season lag 1 models (Figure 4.12), which is likely due to the relatively short life span of white shrimp and their yearly migration patterns. Strong positive effects of river discharge and possible predatory effects of southern flounder on trawl shrimp abundance that were not evident in the lag 0 models or lag 1 month models were detected at a lag of 1 season. The same is true for the year lag 1 models, and, as with the blue crab models, positive effects of salinity were detected in addition to the positive effects of river discharge at these longer time lags.

The month lag 2 models (Figure 4.13) are similar to the month lag 1 models, with the exceptions that positive effects of temperature were detected for trawl shrimp rather than the seine shrimp and that significant negative effects of southern flounder abundance on white shrimp seine abundance are detected across all bays and both estuaries. As observed for the blue crab models, the season lag 2 models for white shrimp reflect the same relationships seen in the year lag 1 models, but with an absence of density dependence for white shrimp. Since the white shrimp life cycle takes place within one year the year lag 2 models did not contain consistent or plausible interactions between white shrimp and other model variables.

Overall, strong negative effects of salinity on trawl shrimp abundance were detected in all lag 0 models and at lags of 1 and 2 months. Negative effects of southern flounder and positive effects of river discharge on trawl white shrimp abundances were detected on the time scale of a season to one year. Due to the relatively short life cycle of white shrimp and their seasonal migration patterns, model results with lags greater than one year were not consistent. Of the models with lags less than one year, the season lag 1 model was the configuration that most effectively accounted for changes in white shrimp abundances in the system over time (see Appendix C for R^2 and conditional R^2 values).

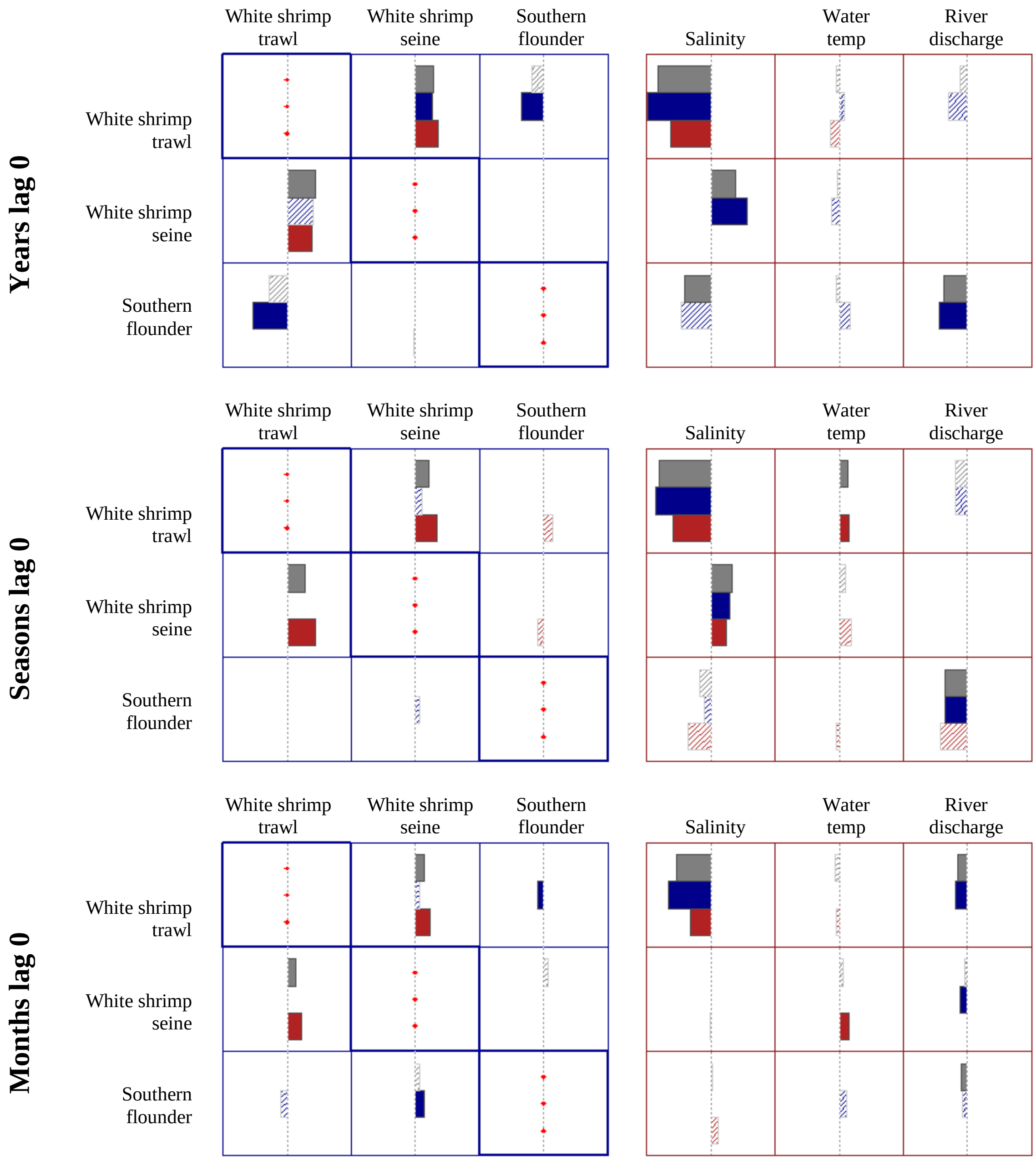

Figure 4.11 Interaction coefficient plots for lag 0 white shrimp MAR models run on time-series averaged by yearly, seasonal, and monthly temporal divisions. Each bar represents the direction and strength of the effect of a column variable on a row variable, such that bars extending to the right and left of the center dotted lines represent positive and negative interactions, respectively (horizontal axis limits are ±0.85). Model results for all bays (gray bars), the Mission-Aransas Estuary (blue bars), and the Guadalupe Estuary (red bars) are shown. Hatched bars represent values with 95% confidence intervals that overlap 0. Dots in place of bars represent interactions restricted to 0.

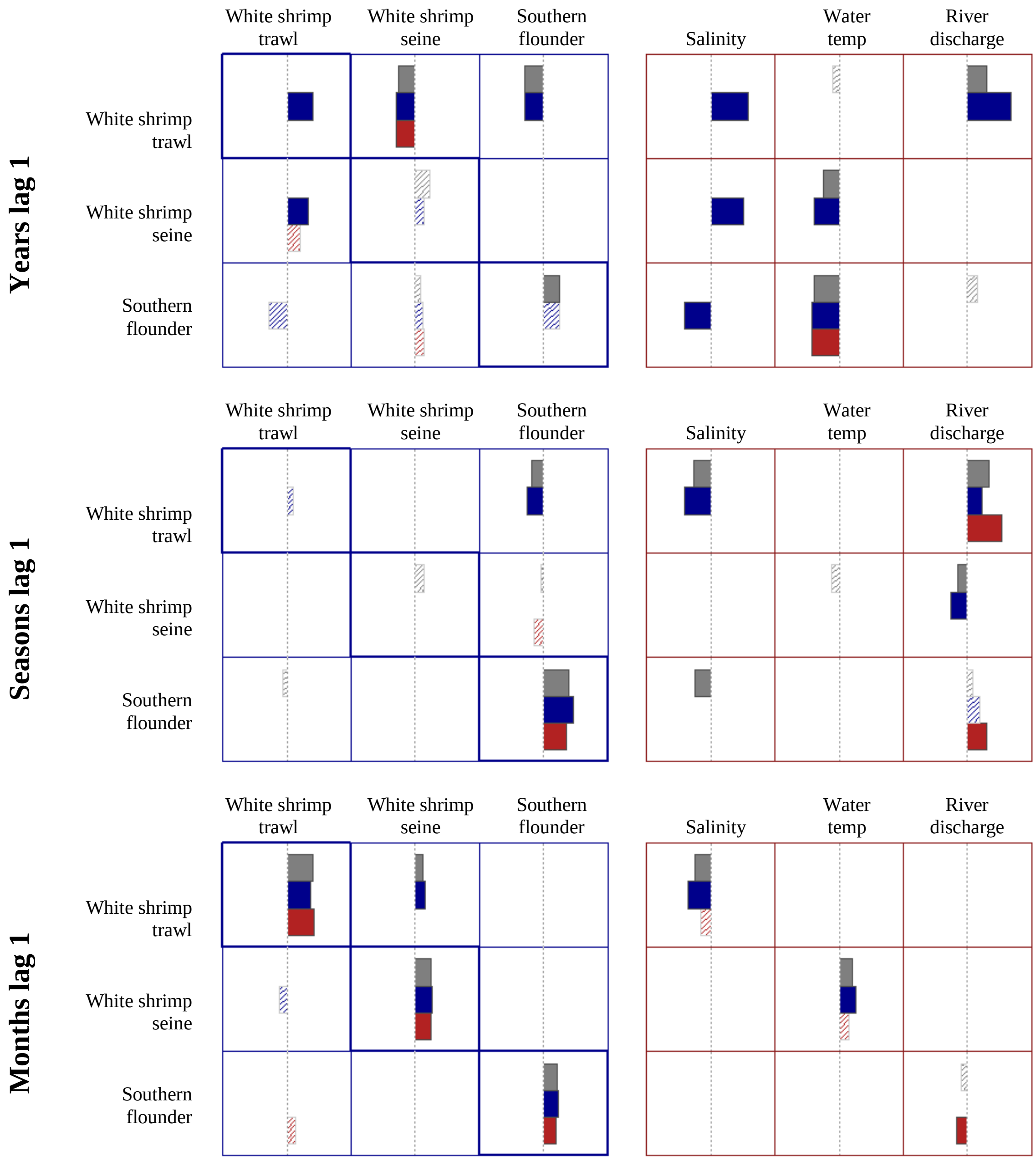

Figure 4.12 Interaction coefficient plots for lag 1 white shrimp MAR models run on time-series averaged by yearly, seasonal, and monthly temporal divisions. Each bar represents the direction and strength of the effect of a column variable on a row variable, such that bars extending to the right and left of the center dotted lines represent positive and negative interactions, respectively (horizontal axis limits are ±0.85). Model results for all bays (gray bars), the Mission-Aransas Estuary (blue bars), and the Guadalupe Estuary (red bars) are shown. Hatched bars represent values with 95% confidence intervals that overlap 0.

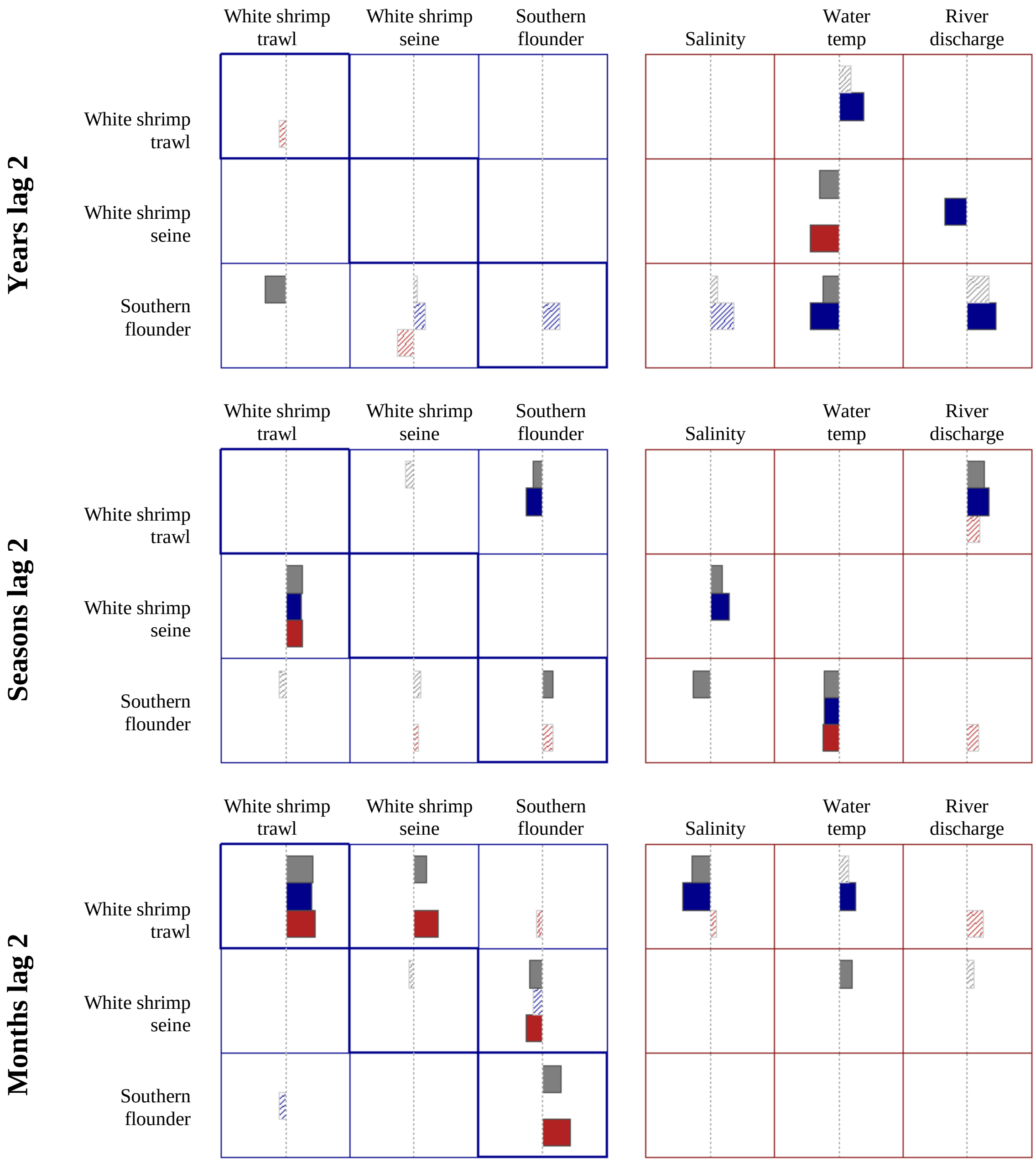

Figure 4.13 Interaction coefficient plots for lag 2 white shrimp MAR models run on time-series averaged by yearly, seasonal, and monthly temporal divisions. Each bar represents the direction and strength of the effect of a column variable on a row variable, such that bars extending to the right and left of the center dotted lines represent positive and negative interactions, respectively (horizontal axis limits are ±0.85). Model results for all bays (gray bars), the Mission-Aransas Estuary (blue bars), and the Guadalupe Estuary (red bars) are shown. Hatched bars represent values with 95% confidence intervals that overlap 0.

5.0.0 CONCLUSIONS

For blue crab, the MAR model results point to negative effects of predators and of high temperatures at all temporal scales examined. Because blue crab predators and water temperature both demonstrate significant increasing trends over time (Figures 4.2 and 4.4, respectively), these two factors are very plausible candidates for contributing to the overall decrease seen in trawl and gillnet blue crab abundances for the time period examined in this study. It is possible that the higher temperatures themselves and the low dissolved oxygen conditions associated with them have combined detrimental effects on blue crab populations.

There is presently concern that decreasing freshwater inflows to estuaries along the Texas coast could have negative impacts on blue crab populations, but direct relationships between freshwater flows and blue crab abundance have been difficult to demonstrate. The MAR model results from this study imply why this may be. The models show strong negative effects of salinity on blue crab abundances at short time scales, and, since salinity is closely correlated with freshwater inflows, this seems to imply a simple connection between freshwater inputs and blue crab abundances. However, direct relationships between river discharge and blue crab abundance were only seen in models with lags of one to two years. This indicates that freshwater inflows may affect conditions other than salinity that positively influence blue crab populations at longer time scales.

The white shrimp MAR model results indicate that higher salinities strongly negatively impact white shrimp abundance at time scales on the order of months. Potential predatory effects of southern founder on white shrimp were seen at larger, seasonal time scales. Similar to the blue crab models, positive effects of river discharge were only detected at larger time lags of seasons to one year, reaffirming the notion that freshwater inflows have multiple modes of effects on the estuarine system that manifest at different temporal scales.

6.0.0 FUTURE DIRECTIONS

This study focused on building MAR models using data collected in the Mission-Aransas and Guadalupe estuaries, but similar monitoring data is also available for the rest of the estuaries along the Texas coast. Models for each of the estuaries in this study were generally very similar to one another, but an analysis of other estuaries along the coast could reveal larger scale spatial gradients of the influences of key drivers on focal species populations. The community stability statistics that can be estimated from MAR model results would also be interesting to compare between models for different estuaries along the coast.

The entire available time-series for each variable was used to estimate the models in this study, but conducting separate MAR analyses for wet and dry periods might reveal variable influences of drivers or different community states between these two sets of conditions. The community stability statistics estimated from these models could be used to determine whether the system tends to be more or less stable during periods of higher rainfall.

For this study, yearly and seasonal time-series were constructed for each environmental variable by averaging the data over 6 or 12 month periods. For blue crab and white shrimp, however, it is possible that extremes in environmental conditions, as opposed to averages, could play an important role in their population dynamics. MAR models run with environmental time-series consisting of maximum or minimum values may reveal effects that are not detected in models run with averaged data. For example, if a mass mortality event is caused by temperatures exceeding a species' maximum or minimum tolerance threshold, the model may not be able to link low abundance to temperature if extreme temperature values are obscured by averaging the data.

In addition to sampling for species abundance, the TPWD coastal monitoring program also collects size data on the species collected in their samples, and for adult blue crab, sex data as well. These data could be incorporated into MAR models to assess the influences of various factors on blue crab and white shrimp sizes and to see whether male and female blue crabs respond differently to environmental drivers.

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APPENDIX A

Datasets acquired in preparation for this study. Datasets selected for use in MAR models are shown in bold. Temporal coverage values represent the date ranges for data that were acquired for this study and in some cases do not necessarily represent the full extent of the time-series.

Data type	Source	Details	Temporal Coverage
Species abundance time-series			
	TPWD Coastal Fisheries monitoring program	**Major bays:**	
		Aransas Bay	
		San Antonio Bay	
		Gear types:	
		Gill net	**1975-2013**
		Otter trawl	**1982-2013**
		Bag seine	**1976-2013**
Water quality parameters			
	TPWD Coastal Fisheries monitoring program	**See above**	1975-2013
	Mission-Aransas NERR System-Wide Monitoring Program	Stations:	2007-2013
		Ship Channel	
		Aransas Bay	
		Copano East	
		Copano West	
		Mesquite Bay	
	Texas Coastal Ocean Observation Network	Stations:	
		Port Aransas 009	1993-2013
		Copano Bay 036	2010-2013
		Aransas Wildlife Refuge 202	2012-2013
		Seadrift 031	1996-2013
		Port O'Connor 057	1995-2013
		GBRA1 127	2004-2013
		GBRA2 130	2004-2013
Meteorological data			
	Mission-Aransas NERR System-Wide Monitoring Program	Stations:	
		Copano East	2007-2013
	Texas Coastal Ocean Observation Network	Stations:	
		Port Aransas 009	1993-2013
		Copano Bay 036	2012-2013
		Aransas Wildlife Refuge 202	2012-2013
		Seadrift 031	1996-2013
		Port O'Connor 057	1995-2013

	NOAA National Climatic Data Center	**Stations:** **Corpus Christi International Airport**	 **1982-2013**
	NOAA National Data Buoy Center	Stations: PTAT2	 1984-2013
River flow data			
	U.S. Geological Survey	**Stations:** **Guadalupe Rv at Victoria (08176500)** **San Antonio Rv at Goliad (08188500)** **Copano Ck nr Refugio (08189200)** **Mission Rv at Refugio (08189500)** **Aransas Rv nr Skidmore (08189700)**	 1934-2015 1924-2015 1982-2015 1939-2015 1964-2015
	Texas Water Development Board	Major bays: Aransas Bay San Antonio Bay	 1941-2009 1941-2009
Climate oscillation indices			
	NOAA Climate Prediction Center	**Indices:** **El Niño-Southern Oscillation** **Pacific Decadal Oscillation** **Southern Oscillation Index**	 **1950-2014** **1900-2014** **1951-2014**
Longshore current patterns			
	Texas Automated Buoy System	Stations: Buoy D Buoy W	 1995-2013 2001-2013
Commercial landing data			
	Marine Aquatic Products Reports (TPWD)	**Major Bays:** **Aransas Bay** **San Antonio Bay** **Species:** **Blue Crab** **White Shrimp**	 **1975-2014** **1975-1989, 2008-2014**

APPENDIX B

Coefficient values and their 95% confidence bounds for each of the final environmental, blue crab, and white shrimp MAR models. Coefficients with confidence bounds not overlapping 0 are shown in bold.

Environmental Lag 0

		Years								
	Variate	Salinity	Water Temp	Dissolved Oxygen	Turb	River Discharge	North Wind	ENSO	SOI	PDO
All Bays	Salinity								**0.44** **(.23,.65)**	**-0.27** **(-.49,-.08)**
	Water Temp						**-0.57** **(-.82,-.31)**	**-0.46** **(-.81,-.08)**	**-0.89** **(-1.35,-.43)**	**-0.55** **(-.75,-.36)**
	Dissolved Oxygen	**-0.5** **(-.69,-.29)**	**-0.24** **(-.36,-.12)**		-0.08 (-.26,.09)	-0.06 (-.29,.17)	0.18 (-.02,.39)		0.07 (-.12,.3)	**0.19** **(.01,.35)**
	Turb		-0.14 (-.32,.05)			**0.46** **(.27,.66)**	**0.31** **(.01,.59)**	-0.21 (-.61,.23)	0.28 (-.17,.82)	0.13 (-.1,.36)
	River Discharge						**-0.24** **(-.43,-.05)**		**-0.81** **(-.97,-.61)**	
	North Wind							**-0.7** **(-.98,-.45)**	**-1.24** **(-1.47,-1.04)**	
Mission-Aransas Estuary	Salinity								0.3 (-.07,.62)	-0.27 (-.63,.01)
	Water Temp						**-0.62** **(-.99,-.3)**	-0.49 (-1.01,.01)	**-0.98** **(-1.63,-.42)**	**-0.54** **(-.83,-.21)**
	Dissolved Oxygen	**-0.44** **(-.68,-.2)**	**-0.24** **(-.42,-.05)**		-0.03 (-.33,.2)	-0.11 (-.42,.25)	-0.02 (-.24,.21)	0.07 (-.32,.38)		**0.23** **(.01,.45)**
	Turb	**-0.38** **(-.67,-.18)**					**0.41** **(.12,.71)**		**0.35** **(.04,.65)**	-0.15 (-.44,.13)
	River Discharge						-0.23 (-.55,.12)		**-0.78** **(-1.11,-.42)**	
	North Wind							**-0.7** **(-1.13,-.28)**	**-1.24** **(-1.59,-.93)**	
Guadalupe Estuary	Salinity								**0.57** **(.32,.82)**	**-0.28** **(-.51,-.05)**
	Water Temp						**-0.51** **(-.85,-.13)**	-0.43 (-.91,0)	**-0.8** **(-1.41,-.18)**	**-0.57** **(-.81,-.21)**
	Dissolved Oxygen	**-0.62** **(-.93,-.22)**	**-0.28** **(-.42,-.12)**		-0.05 (-.24,.17)	-0.11 (-.52,.23)	**0.29** **(.07,.53)**	-0.13 (-.37,.11)		0.09 (-.16,.35)
	Turb	**0.46** **(.01,1.07)**				**0.75** **(.29,1.15)**	**0.38** **(.08,.68)**		**0.44** **(.06,.8)**	**0.53** **(.12,.85)**
	River Discharge						**-0.25** **(-.45,-.04)**		**-0.83** **(-1.03,-.65)**	
	North Wind							**-0.7** **(-1.14,-.32)**	**-1.24** **(-1.62,-.96)**	

Environmental Lag 0

		Seasons								
	Variate	Salinity	Water Temp	Dissolved Oxygen	Turb	River Discharge	North Wind	ENSO	SOI	PDO
All Bays	Salinity								**0.37 (.18,.54)**	**-0.22 (-.35,-.11)**
All Bays	Water Temp						**-0.41 (-.56,-.24)**	**-0.47 (-.73,-.2)**	**-0.55 (-.84,-.25)**	**-0.26 (-.41,-.11)**
All Bays	Dissolved Oxygen	**-0.52 (-.66,-.38)**	**-0.23 (-.33,-.14)**		-0.02 (-.13,.08)	-0.13 (-.28,0)	**0.12 (.03,.22)**			**0.17 (.05,.29)**
All Bays	Turb	**-0.3 (-.49,-.11)**	**-0.19 (-.34,-.03)**			**0.23 (.02,.42)**	0.15 (-.04,.32)	-0.02 (-.29,.24)	0.32 (-.01,.68)	
All Bays	River Discharge								**-0.49 (-.65,-.36)**	
All Bays	North Wind							**-0.66 (-.88,-.43)**	**-1.13 (-1.32,-.92)**	
Mission-Aransas Estuary	Salinity								**0.29 (.04,.52)**	**-0.2 (-.37,-.06)**
Mission-Aransas Estuary	Water Temp						**-0.45 (-.68,-.24)**	**-0.44 (-.81,-.14)**	**-0.57 (-.97,-.22)**	**-0.25 (-.43,-.05)**
Mission-Aransas Estuary	Dissolved Oxygen	**-0.45 (-.63,-.29)**	**-0.17 (-.32,-.05)**		0 (-.14,.12)	-0.15 (-.34,.06)	0.04 (-.11,.18)	0.09 (-.1,.24)		**0.18 (.01,.37)**
Mission-Aransas Estuary	Turb	**-0.44 (-.64,-.26)**	-0.23 (-.43,.02)				0.15 (-.06,.38)	0.08 (-.33,.45)	0.28 (-.17,.71)	-0.19 (-.41,0)
Mission-Aransas Estuary	River Discharge								**-0.43 (-.63,-.24)**	
Mission-Aransas Estuary	North Wind							**-0.66 (-.93,-.4)**	**-1.13 (-1.42,-.87)**	
Guadalupe Estuary	Salinity								**0.45 (.21,.71)**	**-0.24 (-.41,-.11)**
Guadalupe Estuary	Water Temp						**-0.36 (-.59,-.11)**	**-0.51 (-.83,-.13)**	**-0.53 (-.95,-.09)**	**-0.28 (-.49,-.06)**
Guadalupe Estuary	Dissolved Oxygen	**-0.62 (-.84,-.39)**	**-0.31 (-.42,-.17)**			-0.17 (-.4,.02)	**0.22 (.09,.35)**		0.1 (-.06,.25)	0.14 (-.03,.29)
Guadalupe Estuary	Turb		-0.09 (-.3,.11)			**0.51 (.21,.75)**	0.18 (-.05,.41)		**0.43 (.16,.7)**	**0.23 (.01,.47)**
Guadalupe Estuary	River Discharge								**-0.55 (-.75,-.38)**	
Guadalupe Estuary	North Wind							**-0.66 (-.95,-.38)**	**-1.13 (-1.38,-.86)**	

Environmental Lag 1

	Variate	Years: Salinity	Water Temp	Dissolved Oxygen	Turb	River Discharge	North Wind	ENSO	SOI	PDO
All Bays	Salinity							**-0.52 (-.73,-.34)**		
	Water Temp							0.36 (-.1,.79)	**0.46 (.03,.9)**	
	Dissolved Oxygen							**0.39 (.24,.53)**		
	Turb								**-0.18 (-.37,-.02)**	
	River Discharge							**0.44 (.18,.67)**		-0.19 (-.48,.03)
	North Wind							**-0.54 (-.94,-.11)**	**-0.87 (-1.25,-.46)**	
Mission-Aransas Estuary	Salinity							**-0.52 (-.81,-.26)**		
	Water Temp							0.5 (-.04,1.04)	**0.57 (.05,1.15)**	
	Dissolved Oxygen							**0.28 (.11,.45)**		
	Turb								**-0.32 (-.64,-.01)**	-0.28 (-.61,.06)
	River Discharge							**0.3 (.02,.58)**		
	North Wind							-0.54 (-1.13,.03)	**-0.87 (-1.48,-.34)**	
Guadalupe Estuary	Salinity							**-0.53 (-.78,-.28)**		
	Water Temp									-0.27 (-.56,.01)
	Dissolved Oxygen								**-0.51 (-.71,-.29)**	
	Turb									**0.3 (.02,.57)**
	River Discharge							**0.34 (.08,.61)**		
	North Wind							-0.54 (-1.1,0)	**-0.87 (-1.42,-.28)**	

Environmental Lag 1

	Variate	Seasons: Salinity	Water Temp	Dissolved Oxygen	Turb	River Discharge	North Wind	ENSO	SOI	PDO
All Bays	Salinity								**0.59 (.47,.71)**	
All Bays	Water Temp									**-0.16 (-.28,-.03)**
All Bays	Dissolved Oxygen								**-0.41 (-.55,-.28)**	**0.13 (0,.25)**
All Bays	Turb							-0.29 (-.56,.03)	**-0.46 (-.72,-.16)**	
All Bays	River Discharge								**-0.49 (-.61,-.38)**	
All Bays	North Wind							-0.27 (-.57,.01)	**-0.66 (-.94,-.39)**	
Mission-Aransas Estuary	Salinity								**0.56 (.39,.73)**	
Mission-Aransas Estuary	Water Temp									-0.11 (-.31,.09)
Mission-Aransas Estuary	Dissolved Oxygen								**-0.43 (-.59,-.28)**	
Mission-Aransas Estuary	Turb							-0.3 (-.71,.11)	**-0.45 (-.86,-.01)**	
Mission-Aransas Estuary	River Discharge								**-0.45 (-.63,-.26)**	
Mission-Aransas Estuary	North Wind								**-0.41 (-.59,-.23)**	
Guadalupe Estuary	Salinity								**0.62 (.45,.78)**	
Guadalupe Estuary	Water Temp									**-0.21 (-.43,-.04)**
Guadalupe Estuary	Dissolved Oxygen								**-0.54 (-.71,-.39)**	
Guadalupe Estuary	Turb									**0.25 (.06,.43)**
Guadalupe Estuary	River Discharge								**-0.54 (-.7,-.36)**	
Guadalupe Estuary	North Wind								**-0.41 (-.59,-.24)**	

Environmental Lag 2

	Variate	Years								
		Salinity	Water Temp	Dissolved Oxygen	Turb	River Discharge	North Wind	ENSO	SOI	PDO
All Bays	Salinity									0.06 (-.13,.3)
	Water Temp								**0.28 (.02,.55)**	0.24 (-.05,.52)
	Dissolved Oxygen									0.06 (-.12,.22)
	Turb							-0.07 (-.26,.12)		
	River Discharge							**-0.79 (-1.24,-.35)**	**-0.5 (-.91,-.06)**	
	North Wind							**-0.27 (-.5,-.03)**		**0.49 (.23,.75)**
Mission-Aransas Estuary	Salinity									0.07 (-.25,.36)
	Water Temp								0.28 (-.07,.62)	0.33 (-.1,.74)
	Dissolved Oxygen							-0.07 (-.27,.12)		
	Turb									-0.18 (-.44,.09)
	River Discharge							**-0.98 (-1.53,-.41)**	**-0.61 (-1.18,-.03)**	
	North Wind							-0.27 (-.61,.07)		**0.49 (.08,.89)**
Guadalupe Estuary	Salinity									0.05 (-.24,.33)
	Water Temp								0.2 (-.06,.49)	
	Dissolved Oxygen									0.11 (-.16,.36)
	Turb									0.18 (-.15,.46)
	River Discharge							-0.25 (-.51,.04)		
	North Wind							-0.27 (-.59,.08)		**0.49 (.14,.82)**

Blue Crab Lag 0

		Years								
	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
All Bays	Blue crab gill		-0.07 (-.28,.17)	0.16 (-.01,.33)	**-0.24 (-.44,-.08)**	**-0.28 (-.46,-.08)**	**-0.2 (-.35,-.05)**	-0.18 (-.44,.06)	-0.13 (-.31,.04)	0.07 (-.16,.27)
	Blue crab trawl	-0.07 (-.29,.16)		**0.32 (.15,.48)**	0.19 (-.03,.4)	**-0.32 (-.53,-.07)**	-0.12 (-.3,.07)	-0.1 (-.32,.15)	**-0.36 (-.5,-.21)**	-0.03 (-.22,.17)
	Blue crab seine	**0.24 (.04,.45)**	**0.35 (.16,.54)**			**0.27 (.04,.48)**	-0.05 (-.19,.12)	**-0.24 (-.42,-.07)**	0.13 (-.05,.28)	
	Red drum	**-0.27 (-.42,-.1)**				**0.32 (.18,.45)**	0.05 (-.13,.24)	**-0.29 (-.48,-.11)**	-0.03 (-.16,.1)	
	Black drum	**-0.25 (-.42,-.06)**	**-0.26 (-.44,-.06)**	**0.21 (.05,.36)**	**0.32 (.16,.5)**		**0.26 (.09,.44)**	**0.26 (.04,.44)**	-0.03 (-.16,.11)	0.14 (-.07,.32)
	Spotted seatrout	**-0.24 (-.41,-.05)**	-0.14 (-.32,.05)		0.08 (-.12,.26)	**0.32 (.11,.54)**		**-0.3 (-.56,-.04)**	-0.03 (-.19,.12)	-0.04 (-.27,.23)
Mission-Aransas Estuary	Blue crab gill		0.17 (-.16,.47)	0.19 (-.05,.43)	**-0.31 (-.57,-.06)**	-0.15 (-.46,.18)	**-0.31 (-.59,-.11)**	**-0.29 (-.57,-.01)**	-0.06 (-.33,.2)	0.13 (-.12,.35)
	Blue crab trawl			0.21 (-.04,.4)		**-0.36 (-.6,-.07)**	-0.06 (-.4,.15)	-0.08 (-.41,.15)	**-0.46 (-.68,-.25)**	
	Blue crab seine	0.34 (-.04,.73)	0.28 (-.15,.66)		-0.12 (-.47,.24)	**0.44 (.15,.83)**	-0.04 (-.37,.26)	-0.2 (-.51,.09)	0.11 (-.21,.44)	
	Red drum	**-0.36 (-.62,-.08)**	0.24 (-.07,.51)			**0.42 (.21,.64)**	0.03 (-.25,.28)	**-0.44 (-.71,-.2)**	0.02 (-.21,.22)	
	Black drum	-0.15 (-.48,.16)	**-0.4 (-.63,-.06)**	**0.26 (.06,.45)**	**0.43 (.17,.67)**		0.14 (-.25,.5)	**0.35 (.03,.61)**	-0.1 (-.31,.13)	0.15 (-.15,.42)
	Spotted seatrout	**-0.41 (-.68,-.13)**			**0.2 (0,.5)**					**0.32 (.1,.53)**
Guadalupe Estuary	Blue crab gill		-0.24 (-.45,.05)	0.14 (-.17,.38)		**-0.52 (-.71,-.33)**		-0.14 (-.37,.1)	-0.19 (-.43,.03)	
	Blue crab trawl	-0.25 (-.49,.05)		**0.46 (.21,.65)**		-0.15 (-.43,.12)	-0.2 (-.44,.04)		**-0.27 (-.49,-.07)**	0.09 (-.17,.28)
	Blue crab seine	0.15 (-.15,.42)	**0.42 (.13,.67)**			0.06 (-.25,.33)	0.07 (-.14,.32)	**-0.29 (-.53,-.07)**	0.13 (-.1,.38)	
	Red drum					**0.42 (.19,.63)**			0.05 (-.11,.23)	
	Black drum	**-0.25 (-.47,-.03)**			**0.23 (.01,.49)**		**0.44 (.27,.65)**	0.15 (-.17,.45)	0.05 (-.12,.23)	0.09 (-.17,.38)
	Spotted seatrout					**0.62 (.41,.84)**				0.05 (-.16,.26)

Blue Crab Lag 0

		Seasons								
	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
All Bays	Blue crab gill		-0.05 (-.21,.09)	0.1 (-.02,.24)	**-0.18 (-.32,-.06)**	**-0.23 (-.37,-.08)**	-0.1 (-.25,.05)	-0.16 (-.37,.04)	-0.12 (-.25,0)	0 (-.16,.14)
	Blue crab trawl	-0.04 (-.19,.08)		**0.17 (.06,.3)**	0.11 (-.03,.25)	**-0.24 (-.37,-.1)**	**-0.16 (-.28,-.04)**	**-0.22 (-.37,-.06)**	**-0.28 (-.38,-.18)**	0.01 (-.15,.15)
	Blue crab seine	0.11 (-.01,.25)	**0.19 (.07,.33)**			0.12 (-.01,.24)	-0.02 (-.12,.09)	**-0.23 (-.35,-.1)**	0.06 (-.05,.19)	
	Red drum	**-0.16 (-.27,-.06)**	0.09 (-.04,.22)			**0.35 (.23,.46)**	0.12 (-.01,.25)	**-0.21 (-.37,-.04)**	-0.01 (-.12,.08)	0 (-.13,.14)
	Black drum	**-0.19 (-.3,-.07)**	**-0.21 (-.34,-.09)**	**0.11 (.01,.23)**	**0.34 (.21,.46)**		**0.23 (.1,.35)**	**0.23 (.09,.36)**	-0.06 (-.17,.05)	0.11 (-.05,.23)
	Spotted seatrout	-0.1 (-.22,.05)	**-0.16 (-.28,-.04)**	-0.02 (-.1,.08)	0.13 (-.01,.27)	**0.27 (.11,.42)**		**-0.24 (-.42,-.08)**	0.03 (-.09,.14)	0.02 (-.16,.19)
Mission-Aransas Estuary	Blue crab gill		0.15 (-.05,.34)	0.15 (0,.32)	**-0.28 (-.47,-.09)**	-0.12 (-.32,.09)	-0.07 (-.28,.12)	-0.22 (-.5,.07)	-0.11 (-.3,.06)	-0.02 (-.23,.16)
	Blue crab trawl	0.11 (-.06,.27)		0.09 (-.08,.26)		**-0.3 (-.48,-.13)**	-0.08 (-.24,.06)	**-0.24 (-.42,-.05)**	**-0.3 (-.45,-.15)**	-0.03 (-.24,.16)
	Blue crab seine	**0.23 (.06,.43)**				**0.18 (.03,.35)**			0.03 (-.11,.2)	
	Red drum	**-0.24 (-.42,-.07)**		0.02 (-.14,.17)		**0.25 (.06,.43)**	0.16 (-.02,.34)	**-0.37 (-.59,-.17)**	-0.01 (-.14,.13)	-0.07 (-.25,.1)
	Black drum	-0.11 (-.33,.07)	**-0.32 (-.5,-.14)**	**0.18 (.05,.33)**	**0.29 (.1,.47)**		0.19 (-.07,.4)	0.2 (-.01,.41)	-0.11 (-.26,.05)	0.09 (-.12,.27)
	Spotted seatrout	-0.08 (-.28,.1)		-0.1 (-.29,.07)	0.19 (-.02,.39)	0.24 (-.04,.48)		-0.2 (-.44,.02)	(-.15,.14)	0.14 (-.05,.34)
Guadalupe Estuary	Blue crab gill		**-0.18 (-.37,0)**			**-0.43 (-.59,-.27)**			-0.1 (-.3,.07)	0.13 (-.03,.28)
	Blue crab trawl	**-0.2 (-.37,-.01)**		**0.27 (.08,.44)**	0.13 (-.05,.35)	-0.15 (-.37,.04)	**-0.24 (-.4,-.07)**	-0.18 (-.44,.12)	**-0.23 (-.38,-.08)**	0.07 (-.2,.37)
	Blue crab seine	0.07 (-.16,.26)	**0.26 (.07,.45)**			-0.05 (-.25,.11)	0.12 (-.05,.28)	**-0.33 (-.66,-.06)**		-0.06 (-.43,.21)
	Red drum		0.14 (-.04,.31)	-0.06 (-.23,.14)		**0.47 (.3,.64)**	0.07 (-.13,.27)	0.02 (-.29,.32)	-0.03 (-.17,.11)	0.13 (-.15,.38)
	Black drum	**-0.24 (-.38,-.1)**	-0.12 (-.27,.04)	-0.01 (-.17,.14)	**0.39 (.24,.54)**		**0.28 (.14,.39)**	0.19 (-.02,.4)	-0.01 (-.17,.14)	0.11 (-.11,.32)
	Spotted seatrout	-0.13 (-.35,.05)	**-0.24 (-.4,-.08)**		0.05 (-.15,.25)	**0.35 (.15,.54)**		**-0.31 (-.6,-.06)**		-0.1 (-.42,.22)

Blue Crab Lag 0

		Months								
	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
All Bays	Blue crab gill		0.04 (-.05,.12)	0.07 (0,.15)	**-0.11 (-.2,-.02)**	**-0.11 (-.19,-.03)**	**-0.1 (-.19,-.02)**	**-0.14 (-.25,-.04)**	-0.05 (-.13,.02)	-0.09 (-.18,.01)
	Blue crab trawl	0.03 (-.05,.12)		**0.1 (.02,.18)**		**-0.09 (-.17,-.02)**	**-0.07 (-.15,0)**	**-0.18 (-.27,-.09)**	**-0.18 (-.25,-.11)**	0.01 (-.08,.1)
	Blue crab seine	0.07 (0,.15)	**0.1 (.02,.17)**		0.04 (-.04,.12)	0.03 (-.06,.12)	0.02 (-.05,.1)	**-0.16 (-.25,-.06)**	0 (-.08,.08)	-0.05 (-.15,.04)
	Red drum	**-0.09 (-.15,-.01)**	0.03 (-.05,.1)	0.03 (-.04,.09)		**0.4 (.31,.47)**	**0.09 (.01,.18)**	**-0.17 (-.26,-.06)**	**-0.08 (-.15,-.01)**	-0.06 (-.16,.04)
	Black drum	**-0.09 (-.15,-.02)**	**-0.08 (-.15,-.02)**	0.03 (-.05,.1)	**0.4 (.32,.47)**		**0.17 (.09,.24)**	**0.16 (.07,.24)**	0.01 (-.06,.07)	**0.11 (.02,.2)**
	Spotted seatrout	**-0.09 (-.17,-.02)**	**-0.06 (-.14,0)**		**0.11 (.02,.21)**	**0.2 (.1,.28)**		**-0.16 (-.25,-.07)**	0.03 (-.05,.1)	-0.01 (-.09,.08)
Mission-Aransas Estuary	Blue crab gill		0.1 (-.01,.21)	**0.12 (.02,.21)**	-0.11 (-.23,0)	**-0.14 (-.25,-.02)**	**-0.16 (-.29,-.04)**	**-0.15 (-.28,-.02)**	-0.02 (-.12,.08)	-0.05 (-.17,.06)
	Blue crab trawl	0.11 (-.01,.23)		0.08 (-.03,.18)		-0.08 (-.19,.02)	-0.05 (-.16,.05)	**-0.16 (-.3,-.03)**	**-0.2 (-.32,-.09)**	0.01 (-.13,.14)
	Blue crab seine	**0.13 (.02,.23)**	0.08 (-.03,.18)		**0.12 (.01,.22)**	0.07 (-.06,.18)	0.04 (-.07,.16)	-0.07 (-.17,.02)	-0.03 (-.14,.08)	
	Red drum	-0.09 (-.19,.01)		0.09 (0,.18)		**0.35 (.24,.46)**	0.1 (-.02,.21)	**-0.31 (-.45,-.15)**	-0.02 (-.11,.08)	**-0.15 (-.26,-.02)**
	Black drum	**-0.12 (-.22,-.02)**	-0.08 (-.17,.01)	0.06 (-.04,.16)	**0.37 (.27,.46)**		**0.14 (.02,.26)**	**0.2 (.08,.32)**	0.01 (-.08,.1)	**0.15 (.03,.26)**
	Spotted seatrout	**-0.15 (-.25,-.05)**			0.12 (-.02,.25)	**0.15 (.02,.28)**		**-0.18 (-.3,-.08)**	-0.02 (-.13,.09)	0.03 (-.09,.14)
Guadalupe Estuary	Blue crab gill		-0.02 (-.12,.09)		**-0.17 (-.29,-.06)**			-0.09 (-.2,.03)	-0.08 (-.19,.02)	
	Blue crab trawl	-0.04 (-.13,.06)		**0.12 (.01,.23)**		-0.08 (-.2,.03)	-0.07 (-.18,.03)	**-0.2 (-.35,-.07)**	**-0.16 (-.28,-.05)**	(-.13,.15)
	Blue crab seine	0.03 (-.07,.12)	**0.12 (0,.24)**			-0.02 (-.15,.12)	0.02 (-.09,.12)	**-0.16 (-.28,-.04)**		
	Red drum		0.05 (-.03,.14)			**0.47 (.36,.57)**			**-0.13 (-.22,-.04)**	
	Black drum	-0.07 (-.17,.03)	**-0.1 (-.19,-.01)**	-0.01 (-.12,.1)	**0.44 (.31,.55)**		**0.2 (.1,.31)**		(-.09,.1)	0.01 (-.1,.09)
	Spotted seatrout	-0.04 (-.15,.08)	-0.06 (-.16,.04)		0.09 (-.06,.21)	**0.24 (.13,.38)**			**0.11 (0,.2)**	0.03 (-.07,.13)

Blue Crab Lag 1

		Years								
	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
All Bays	Blue crab gill	**0.27** **(.06,.44)**		0.05 (-.11,.2)	-0.06 (-.22,.12)	-0.19 (-.36,.01)	-0.05 (-.2,.12)	**0.36** **(.1,.59)**	-0.1 (-.25,.05)	**0.23** **(0,.45)**
	Blue crab trawl		**0.35** **(.18,.47)**			**-0.17** **(-.31,-.03)**			**-0.36** **(-.5,-.24)**	
	Blue crab seine	**0.19** **(.01,.4)**		0.18 (-.01,.32)	(-.21,.16)	0.17 (-.03,.4)	0.02 (-.18,.22)	**0.46** **(.18,.74)**	-0.14 (-.3,.03)	**0.35** **(.08,.61)**
	Red drum	**-0.23** **(-.41,-.07)**			**0.22** **(.02,.39)**			**-0.2** **(-.37,-.05)**		
	Black drum	**-0.25** **(-.44,-.05)**			0.07 (-.1,.23)	**0.39** **(.16,.52)**	0.04 (-.14,.23)	-0.02 (-.17,.14)	0.07 (-.08,.21)	
	Spotted seatrout	**-0.26** **(-.46,-.07)**	-0.06 (-.24,.13)	-0.05 (-.21,.12)	0.07 (-.1,.26)	0.05 (-.17,.26)	**0.26** **(.06,.4)**		0.11 (-.06,.26)	0.16 (-.01,.3)
Mission-Aransas Estuary	Blue crab gill	**0.28** **(.02,.46)**			**-0.26** **(-.47,-.04)**				**-0.21** **(-.43,-.02)**	
	Blue crab trawl		**0.26** **(.04,.42)**	0.01 (-.15,.2)		**-0.23** **(-.45,-.07)**		0.18 (-.07,.42)	**-0.44** **(-.61,-.27)**	**0.29** **(.05,.51)**
	Blue crab seine	**0.33** **(.04,.59)**	-0.16 (-.42,.16)	0.07 (-.2,.27)	(-.27,.28)	0.26 (-.09,.56)		**0.41** **(.1,.7)**	**-0.31** **(-.55,-.09)**	**0.34** **(.04,.64)**
	Red drum	**-0.3** **(-.55,-.05)**		0.05 (-.2,.26)	0.25 (-.03,.46)			**-0.24** **(-.47,-.04)**		
	Black drum				0.21 (-.04,.49)	**0.41** **(.08,.58)**			**0.22** **(.02,.44)**	
	Spotted seatrout		**-0.34** **(-.59,-.08)**		**0.33** **(.07,.53)**					0.1 (-.13,.31)
Guadalupe Estuary	Blue crab gill	0.27 (-.02,.47)			-0.08 (-.35,.19)		-0.24 (-.47,.01)			-0.05 (-.26,.17)
	Blue crab trawl		**0.37** **(.07,.54)**			-0.18 (-.43,.05)			**-0.31** **(-.54,-.09)**	
	Blue crab seine		0.16 (-.15,.39)							
	Red drum				0.26 (-.02,.45)					
	Black drum					**0.62** **(.32,.76)**				
	Spotted seatrout	**-0.32** **(-.55,-.07)**			0.07 (-.19,.33)		**0.39** **(.08,.54)**			0.14 (-.07,.34)

Blue Crab Lag 1

	Variate	Seasons: Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
All Bays	Blue crab gill	0.11 (-.02,.21)	0.02 (-.11,.14)	0.08 (-.05,.2)	-0.1 (-.23,.02)		**-0.22 (-.35,-.09)**		**-0.15 (-.27,-.04)**	**0.14 (.02,.26)**
	Blue crab trawl		**0.52 (.4,.62)**			-0.07 (-.18,.04)			**-0.22 (-.32,-.13)**	
	Blue crab seine			**0.27 (.13,.37)**			-0.04 (-.17,.07)			**0.18 (.06,.3)**
	Red drum		0.09 (-.06,.21)	-0.03 (-.15,.09)	**0.17 (.02,.29)**	0.09 (-.04,.23)	**0.14 (.02,.27)**	-0.03 (-.2,.15)	**0.17 (.06,.27)**	0.11 (-.07,.26)
	Black drum	**-0.15 (-.26,-.04)**	-0.02 (-.13,.08)		0.07 (-.04,.18)	**0.4 (.25,.5)**	**0.18 (.07,.28)**	0.11 (-.03,.26)	0.1 (0,.21)	-0.02 (-.17,.12)
	Spotted seatrout	**-0.2 (-.33,-.08)**	-0.04 (-.18,.1)		0.13 (-.02,.26)	0.13 (-.01,.28)	**0.23 (.09,.34)**	0.01 (-.14,.17)	-0.01 (-.13,.11)	0.1 (-.04,.25)
Mission-Aransas Estuary	Blue crab gill	-0.07 (-.27,.1)	0.02 (-.19,.2)	0.15 (-.03,.34)	-0.16 (-.37,.03)		**-0.3 (-.5,-.12)**	**-0.25 (-.46,-.03)**	**-0.21 (-.38,-.06)**	0.01 (-.2,.2)
	Blue crab trawl		**0.59 (.41,.7)**			-0.07 (-.2,.06)			**-0.23 (-.35,-.11)**	
	Blue crab seine			**0.27 (.07,.41)**			-0.07 (-.25,.11)			**0.19 (.03,.36)**
	Red drum	-0.13 (-.3,.03)			**0.29 (.09,.43)**			-0.09 (-.33,.11)	0.08 (-.07,.24)	0.15 (-.06,.36)
	Black drum	**-0.18 (-.35,-.03)**			**0.2 (.05,.37)**	**0.44 (.27,.57)**		**0.18 (.05,.34)**	0.09 (-.04,.23)	
	Spotted seatrout		-0.17 (-.37,0)		**0.23 (.02,.41)**	0.04 (-.1,.22)	**0.36 (.15,.49)**	0.11 (-.12,.31)		0.09 (-.1,.3)
Guadalupe Estuary	Blue crab gill	**0.23 (.05,.38)**	0.07 (-.1,.25)	0.01 (-.18,.19)	-0.06 (-.26,.12)	-0.17 (-.37,.03)		**0.3 (.01,.58)**	-0.13 (-.3,.04)	**0.36 (.09,.63)**
	Blue crab trawl		**0.45 (.28,.57)**			-0.06 (-.24,.09)			**-0.21 (-.37,-.07)**	
	Blue crab seine	0.09 (-.09,.26)		**0.32 (.12,.46)**	-0.15 (-.34,.05)	**0.25 (.04,.47)**	-0.05 (-.23,.14)	0.23 (-.07,.49)	-0.1 (-.26,.06)	**0.36 (.08,.63)**
	Red drum		0.1 (-.07,.25)			0.15 (-.06,.29)			**0.22 (.05,.41)**	0.12 (-.06,.27)
	Black drum	-0.1 (-.28,.06)	0.08 (-.08,.23)			**0.39 (.18,.52)**	**0.3 (.12,.45)**		0.14 (0,.3)	-0.09 (-.24,.06)
	Spotted seatrout	**-0.27 (-.43,-.09)**		0.05 (-.14,.23)	0.07 (-.12,.28)	**0.28 (.06,.45)**		-0.07 (-.37,.19)	(-.15,.15)	0.07 (-.23,.31)

Blue Crab Lag 1

		Months								
	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
All Bays	Blue crab gill	**0.19 (.09,.28)**			-0.09 (-.21,.02)	**-0.15 (-.27,-.04)**		**-0.09 (-.19,0)**	-0.04 (-.13,.08)	
	Blue crab trawl		**0.47 (.38,.55)**	0.08 (0,.18)		**-0.13 (-.22,-.05)**			**-0.13 (-.22,-.05)**	**0.13 (.05,.21)**
	Blue crab seine	0.02 (-.08,.11)					**0.13 (.03,.23)**	**-0.14 (-.25,-.04)**		0.05 (-.07,.15)
	Red drum	**-0.17 (-.27,-.07)**			**0.25 (.16,.34)**		**0.11 (.01,.21)**	**-0.16 (-.25,-.07)**		
	Black drum	-0.03 (-.13,.06)	-0.04 (-.13,.05)			**0.31 (.21,.4)**	**0.16 (.07,.26)**		-0.04 (-.14,.05)	-0.02 (-.12,.08)
	Spotted seatrout	-0.09 (-.18,.01)		-0.09 (-.18,.02)	-0.03 (-.13,.09)	**0.19 (.08,.29)**	**0.16 (.06,.26)**	**-0.16 (-.27,-.04)**	0 (-.1,.1)	-0.04 (-.16,.07)
Mission-Aransas Estuary	Blue crab gill	**0.17 (.04,.29)**		**0.15 (.02,.28)**	**-0.19 (-.33,-.06)**	**-0.18 (-.32,-.03)**	0.07 (-.07,.21)	-0.12 (-.27,.01)	-0.04 (-.19,.08)	
	Blue crab trawl	0.1 (-.02,.24)	**0.41 (.26,.53)**	0.11 (-.03,.24)	-0.04 (-.16,.1)	-0.13 (-.27,.01)			**-0.15 (-.26,-.01)**	**0.14 (.01,.25)**
	Blue crab seine	0.06 (-.07,.19)	0.04 (-.09,.18)			0.11 (-.03,.25)	**0.15 (.01,.29)**		-0.12 (-.24,.02)	0.07 (-.06,.19)
	Red drum	**-0.19 (-.32,-.06)**			**0.15 (.02,.27)**			**-0.25 (-.39,-.12)**		
	Black drum					**0.28 (.15,.4)**			-0.11 (-.24,.02)	
	Spotted seatrout	-0.07 (-.21,.07)			-0.01 (-.18,.13)	**0.17 (.02,.35)**	0.11 (-.02,.26)	**-0.2 (-.38,-.03)**	0.01 (-.11,.14)	(-.17,.15)
Guadalupe Estuary	Blue crab gill	**0.25 (.09,.39)**								
	Blue crab trawl		**0.53 (.39,.64)**			-0.1 (-.2,.02)		**-0.12 (-.23,0)**	-0.11 (-.22,.02)	
	Blue crab seine		0.12 (-.02,.24)	0.14 (0,.26)		**-0.14 (-.27,-.01)**	**0.15 (.01,.28)**	-0.13 (-.32,.05)	**0.15 (.02,.29)**	0.07 (-.13,.24)
	Red drum	**-0.18 (-.29,-.04)**			**0.45 (.29,.59)**	**-0.16 (-.32,-.03)**	**0.19 (.07,.34)**	-0.14 (-.32,.02)	-0.02 (-.16,.12)	-0.04 (-.23,.13)
	Black drum	-0.06 (-.2,.09)		-0.03 (-.17,.09)	0.01 (-.15,.16)	**0.35 (.19,.51)**	**0.21 (.07,.34)**		0.03 (-.1,.17)	0.04 (-.09,.17)
	Spotted seatrout	-0.11 (-.25,.03)		-0.12 (-.28,.02)	-0.09 (-.25,.06)	**0.2 (.03,.36)**	**0.21 (.05,.34)**		-0.01 (-.15,.11)	0 (-.14,.15)

Blue Crab Lag 2

		Years								
	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
All Bays	Blue crab gill	0.17 (-.01,.3)			**-0.22 (-.37,-.08)**			**0.34 (.2,.48)**		
All Bays	Blue crab trawl	0.04 (-.13,.22)	**0.34 (.17,.48)**	-0.09 (-.25,.08)	-0.14 (-.34,.02)	**-0.23 (-.4,-.05)**		**0.38 (.15,.62)**	**-0.17 (-.34,-.02)**	**0.26 (.03,.47)**
All Bays	Blue crab seine	0.08 (-.13,.27)	-0.12 (-.32,.05)	0.19 (-.04,.33)		0.16 (-.05,.36)	-0.07 (-.26,.12)	**0.27 (.09,.43)**	**-0.29 (-.47,-.13)**	
All Bays	Red drum	**-0.23 (-.4,-.06)**		-0.07 (-.25,.1)	0.02 (-.15,.17)					**0.22 (.07,.37)**
All Bays	Black drum				**0.19 (.02,.36)**	**0.34 (.16,.46)**		0.07 (-.14,.31)	0.13 (-.02,.26)	0.11 (-.09,.34)
All Bays	Spotted seatrout	**-0.36 (-.53,-.2)**	**0.16 (.03,.31)**		0.11 (-.07,.27)	0.14 (-.05,.32)			**0.17 (.03,.32)**	
Mission-Aransas Estuary	Blue crab gill				-0.4 (-.62,-.16)					
Mission-Aransas Estuary	Blue crab trawl	-0.01 (-.25,.21)	**0.26 (.05,.43)**	-0.18 (-.37,.04)		**-0.33 (-.53,-.14)**		**0.49 (.26,.73)**	**-0.31 (-.49,-.16)**	**0.29 (.05,.48)**
Mission-Aransas Estuary	Blue crab seine								-0.23 (-.5,.03)	
Mission-Aransas Estuary	Red drum				**0.29 (.03,.49)**					
Mission-Aransas Estuary	Black drum					**0.42 (.2,.58)**				
Mission-Aransas Estuary	Spotted seatrout	**-0.28 (-.5,-.07)**			0.2 (-.03,.43)			0.07 (-.16,.27)		
Guadalupe Estuary	Blue crab gill	0.18 (-.03,.36)		0.09 (-.11,.29)	-0.18 (-.41,.01)			0.22 (-.14,.54)		**-0.34 (-.7,-.01)**
Guadalupe Estuary	Blue crab trawl		**0.41 (.14,.57)**		-0.3 (-.56,.01)	-0.22 (-.48,.02)		0.34 (-.07,.75)		0.28 (-.13,.71)
Guadalupe Estuary	Blue crab seine							0.23 (-.04,.46)		
Guadalupe Estuary	Red drum	-0.2 (-.42,0)	-0.1 (-.28,.12)	0.02 (-.2,.23)	-0.08 (-.33,.11)			**0.5 (.14,.83)**		**0.65 (.3,1)**
Guadalupe Estuary	Black drum	**-0.24 (-.46,-.06)**		0.06 (-.11,.28)	0.18 (-.06,.4)		**0.33 (.12,.51)**	**0.38 (.05,.72)**	0.14 (-.06,.33)	**0.45 (.13,.77)**
Guadalupe Estuary	Spotted seatrout	**-0.39 (-.6,-.19)**	0.16 (-.04,.36)		0.06 (-.18,.3)	0.11 (-.16,.39)	**0.26 (.01,.5)**	0.11 (-.27,.43)	0.07 (-.12,.25)	0.13 (-.21,.44)

Blue Crab Lag 2

		Seasons								
	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
All Bays	Blue crab gill	**0.14 (.01,.26)**			-0.07 (-.18,.06)	**-0.19 (-.33,-.05)**			-0.05 (-.17,.08)	
	Blue crab trawl	0.03 (-.09,.13)	**0.35 (.22,.44)**	-0.03 (-.13,.08)		**-0.16 (-.28,-.04)**		**0.29 (.14,.44)**	**-0.27 (-.37,-.16)**	**0.3 (.11,.44)**
	Blue crab seine	0.1 (-.03,.24)	**0.14 (0,.28)**	0.08 (-.06,.21)	-0.13 (-.27,.02)	**0.19 (.04,.34)**		**0.2 (.03,.38)**	-0.01 (-.13,.11)	**0.2 (.03,.37)**
	Red drum	-0.1 (-.22,.03)			**0.23 (.09,.35)**	**0.14 (.02,.27)**		**-0.16 (-.29,-.05)**	0 (-.12,.12)	
	Black drum				**0.14 (.01,.27)**	**0.46 (.33,.56)**		0.01 (-.1,.13)	**0.11 (0,.22)**	
	Spotted seatrout	**-0.16 (-.28,-.04)**	**-0.23 (-.35,-.1)**	-0.09 (-.2,.02)	0.03 (-.12,.16)	0.08 (-.05,.21)	**0.25 (.12,.36)**	-0.04 (-.21,.14)		0.08 (-.07,.24)
Mission-Aransas Estuary	Blue crab gill				**-0.28 (-.46,-.1)**					
	Blue crab trawl	-0.07 (-.22,.07)	**0.29 (.13,.41)**	0.02 (-.13,.15)	-0.14 (-.28,.01)	**-0.21 (-.36,-.04)**		**0.17 (0,.36)**	**-0.32 (-.45,-.2)**	**0.35 (.19,.5)**
	Blue crab seine	**0.19 (.02,.37)**	0.04 (-.16,.23)		-0.07 (-.26,.12)	**0.26 (.06,.46)**			**-0.19 (-.35,-.02)**	
	Red drum			-0.01 (-.19,.15)	**0.33 (.14,.46)**			-0.11 (-.31,.12)		0.13 (-.08,.37)
	Black drum				0.17 (-.01,.36)	**0.43 (.24,.57)**			**0.16 (0,.31)**	
	Spotted seatrout		**-0.31 (-.5,-.14)**			0 (-.17,.19)	**0.31 (.11,.46)**			0.06 (-.1,.22)
Guadalupe Estuary	Blue crab gill	**0.21 (.01,.37)**	-0.06 (-.26,.12)		0.05 (-.15,.25)	**-0.23 (-.44,-.02)**			-0.1 (-.26,.06)	
	Blue crab trawl		**0.35 (.14,.48)**			-0.1 (-.29,.06)			**-0.26 (-.43,-.11)**	
	Blue crab seine		0.15 (-.05,.32)							
	Red drum				**0.33 (.12,.48)**					
	Black drum				0.09 (-.09,.29)	**0.47 (.23,.63)**	0.09 (-.06,.26)	0.01 (-.26,.26)	0.05 (-.12,.19)	0.06 (-.22,.32)
	Spotted seatrout	**-0.22 (-.39,-.05)**	**-0.22 (-.4,-.07)**		0.02 (-.16,.19)	0.18 (-.02,.38)	0.17 (-.04,.32)	**-0.27 (-.54,-.01)**	0.09 (-.08,.26)	-0.08 (-.33,.19)

Blue Crab Lag 2

		Months								
	Variate	Blue crab gill	Blue crab trawl	Blue crab seine	Red drum	Black drum	Spotted seatrout	Salinity	Water Temp	River Discharge
All Bays	Blue crab gill	0.14 (-.02,.29)			**-0.23 (-.39,-.08)**			-0.06 (-.22,.1)		
	Blue crab trawl		**0.38 (.25,.54)**			-0.06 (-.21,.08)			**-0.19 (-.35,-.04)**	
	Blue crab seine				**0.22 (.07,.35)**			-0.14 (-.26,.01)		
	Red drum	-0.07 (-.23,.08)			**0.24 (.08,.42)**			-0.16 (-.3,.01)		
	Black drum	-0.15 (-.31,0)	-0.11 (-.27,.06)			**0.2 (.04,.36)**			**-0.22 (-.37,-.08)**	
	Spotted seatrout	**-0.16 (-.31,-.02)**	-0.09 (-.24,.07)	-0.11 (-.27,.05)	0.14 (-.03,.28)		0.11 (-.06,.28)		-0.15 (-.31,.01)	
Mission-Aransas Estuary	Blue crab gill	**0.22 (.03,.41)**	0.15 (-.06,.36)		**-0.33 (-.54,-.1)**	0.23 (-.01,.46)		**-0.25 (-.46,-.06)**	**0.21 (.02,.41)**	
	Blue crab trawl		**0.39 (.17,.61)**			-0.12 (-.34,.07)			-0.19 (-.41,.02)	
	Blue crab seine						**0.29 (.07,.5)**			
	Red drum	-0.05 (-.24,.13)	**-0.23 (-.42,-.04)**		**0.39 (.2,.59)**	**-0.31 (-.54,-.06)**		-0.14 (-.33,.05)	-0.07 (-.3,.14)	
	Black drum								**-0.21 (-.42,-.03)**	
	Spotted seatrout	-0.16 (-.39,.04)			0.2 (-.03,.39)					
Guadalupe Estuary	Blue crab gill				**-0.29 (-.52,-.03)**					
	Blue crab trawl		**0.34 (.13,.53)**	**0.21 (.01,.41)**		0.01 (-.2,.2)	-0.05 (-.24,.15)	-0.14 (-.33,.05)	-0.21 (-.4,.01)	
	Blue crab seine				**0.28 (.07,.51)**			**-0.28 (-.51,-.06)**		
	Red drum								-0.2 (-.44,.02)	
	Black drum	**-0.3 (-.51,-.09)**	-0.15 (-.39,.07)		-0.08 (-.35,.17)	**0.31 (.09,.56)**			-0.19 (-.43,.02)	
	Spotted seatrout		**-0.25 (-.45,-.01)**			**0.31 (.13,.51)**			-0.16 (-.39,.06)	

White Shrimp Lag 0

	Variate	White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
		Years					
All Bays	White shrimp trawl		**0.25** **(.09,.39)**	-0.16 (-.33,.01)	**-0.69** **(-.91,-.48)**	-0.04 (-.18,.09)	-0.09 (-.36,.11)
	White shrimp seine	**0.37** **(.16,.57)**			**0.33** **(.15,.53)**	-0.03 (-.2,.15)	
	Southern flounder	-0.24 (-.47,.02)			**-0.35** **(-.64,-.02)**	-0.03 (-.2,.15)	**-0.32** **(-.6,-.06)**
Mission-Aransas Estuary	White shrimp trawl		**0.23** **(.01,.44)**	**-0.29** **(-.5,-.06)**	**-0.84** **(-1.11,-.57)**	0.07 (-.12,.28)	-0.26 (-.56,.03)
	White shrimp seine	0.34 (-.01,.61)			**0.48** **(.11,.76)**	-0.1 (-.37,.14)	
	Southern flounder	**-0.46** **(-.87,-.07)**			-0.4 (-.82,.03)	0.14 (-.06,.41)	**-0.38** **(-.71,-.08)**
Guadalupe Estuary	White shrimp trawl		**0.3** **(.13,.51)**		**-0.53** **(-.73,-.34)**	-0.12 (-.32,.07)	
	White shrimp seine	**0.33** **(.07,.53)**					
	Southern flounder		-0.02 (-.37,.32)				

White Shrimp Lag 0

	Variate	Seasons					
		White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
All Bays	White shrimp trawl		**0.18** **(.08,.27)**	0 (-.13,.11)	**-0.68** **(-.85,-.53)**	**0.11** **(.03,.21)**	-0.15 (-.31,.01)
	White shrimp seine	**0.24** **(.11,.37)**			**0.28** **(.14,.42)**	0.08 (-.03,.18)	
	Southern flounder	0 (-.16,.17)			-0.15 (-.38,.08)		**-0.3** **(-.51,-.09)**
Mission-Aransas Estuary	White shrimp trawl		0.08 (-.05,.24)		**-0.73** **(-.95,-.53)**		-0.17 (-.39,.04)
	White shrimp seine				**0.26** **(.08,.45)**		
	Southern flounder		0.06 (-.08,.2)		-0.08 (-.36,.19)		**-0.3** **(-.55,-.07)**
Guadalupe Estuary	White shrimp trawl		**0.28** **(.17,.42)**	0.11 (-.09,.26)	**-0.5** **(-.64,-.36)**	**0.14** **(.01,.27)**	
	White shrimp seine	**0.37** **(.23,.54)**		-0.08 (-.34,.18)	**0.21** **(.06,.38)**	0.15 (0,.3)	
	Southern flounder				-0.29 (-.62,.03)	-0.04 (-.2,.12)	-0.36 (-.68,0)

White Shrimp Lag 0

		Months					
	Variate	White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
All Bays	White shrimp trawl		**0.11** **(.03,.19)**		**-0.46** **(-.55,-.36)**	-0.05 (-.11,.02)	**-0.13** **(-.22,-.03)**
	White shrimp seine	**0.12** **(.04,.2)**		0.05 (-.02,.11)		0.05 (-.02,.13)	-0.04 (-.11,.03)
	Southern flounder		0.06 (-.02,.13)		0.02 (-.09,.12)		**-0.09** **(-.18,0)**
Mission-Aransas Estuary	White shrimp trawl		0.05 (-.07,.15)	**-0.09** **(-.18,-.01)**	**-0.57** **(-.68,-.44)**		**-0.16** **(-.28,-.04)**
	White shrimp seine						**-0.11** **(-.2,-.01)**
	Southern flounder	-0.08 (-.18,.02)	**0.12** **(.01,.22)**			0.1 (0,.2)	-0.07 (-.19,.04)
Guadalupe Estuary	White shrimp trawl		**0.19** **(.08,.29)**		**-0.28** **(-.37,-.17)**	-0.04 (-.13,.06)	
	White shrimp seine	**0.18** **(.07,.32)**		-0.01 (-.12,.09)	-0.01 (-.1,.08)	**0.12** **(.02,.23)**	
	Southern flounder				0.1 (-.03,.22)		

White Shrimp Lag 1

		Years					
	Variate	White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
All Bays	White shrimp trawl		**-0.23** **(-.39,-.07)**	**-0.25** **(-.43,-.1)**		-0.08 (-.25,.08)	**0.25** **(.09,.42)**
	White shrimp seine		0.19 (-.01,.34)			**-0.21** **(-.38,-.03)**	
	Southern flounder		0.07 (-.11,.23)	**0.2** **(.02,.34)**		**-0.33** **(-.48,-.16)**	0.14 (-.02,.3)
Mission-Aransas Estuary	White shrimp trawl	**0.35** **(.08,.54)**	**-0.25** **(-.45,-.07)**	**-0.25** **(-.47,-.02)**	**0.5** **(.18,.78)**		**0.57** **(.27,.84)**
	White shrimp seine	**0.28** **(.03,.57)**	0.12 (-.14,.31)		**0.44** **(.23,.67)**	**-0.33** **(-.56,-.12)**	
	Southern flounder	-0.24 (-.47,.03)	0.09 (-.13,.31)	0.2 (-.07,.42)	**-0.35** **(-.57,-.13)**	**-0.36** **(-.64,-.14)**	
Guadalupe Estuary	White shrimp trawl		**-0.26** **(-.52,-.01)**				
	White shrimp seine	0.18 (-.07,.43)					
	Southern flounder		0.11 (-.13,.35)			**-0.35** **(-.58,-.13)**	

White Shrimp Lag 1

	Variate	Seasons					
		White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
All Bays	White shrimp trawl			**-0.16** **(-.27,-.05)**	**-0.23** **(-.4,-.08)**		**0.28** **(.14,.43)**
	White shrimp seine		0.12 (-.02,.24)	-0.04 (-.16,.08)		-0.1 (-.21,.03)	**-0.13** **(-.26,-.02)**
	Southern flounder	-0.05 (-.17,.08)		**0.34** **(.2,.45)**	**-0.21** **(-.41,-.03)**		0.07 (-.1,.25)
Mission-Aransas Estuary	White shrimp trawl	0.08 (-.09,.25)		**-0.22** **(-.36,-.08)**	**-0.35** **(-.56,-.17)**		**0.19** **(.01,.37)**
	White shrimp seine						**-0.22** **(-.38,-.04)**
	Southern flounder			**0.39** **(.21,.54)**			0.16 (-.02,.34)
Guadalupe Estuary	White shrimp trawl						**0.46** **(.29,.6)**
	White shrimp seine			-0.13 (-.32,.05)			
	Southern flounder			**0.3** **(.1,.45)**			**0.26** **(.11,.43)**

White Shrimp Lag 1

	Variate	Months					
		White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
All Bays	White shrimp trawl	**0.34** **(.25,.43)**	**0.11** **(.01,.2)**		**-0.21** **(-.31,-.12)**		
	White shrimp seine		**0.21** **(.11,.31)**			**0.18** **(.08,.27)**	
	Southern flounder			**0.18** **(.08,.27)**			-0.08 (-.17,.03)
Mission-Aransas Estuary	White shrimp trawl	**0.31** **(.18,.45)**	**0.13** **(0,.26)**		**-0.3** **(-.44,-.2)**		
	White shrimp seine	-0.1 (-.22,.03)	**0.22** **(.08,.34)**			**0.22** **(.09,.35)**	
	Southern flounder			**0.2** **(.07,.32)**			
Guadalupe Estuary	White shrimp trawl	**0.37** **(.24,.49)**			-0.13 (-.26,.01)		
	White shrimp seine		**0.21** **(.05,.36)**			0.13 (-.01,.25)	
	Southern flounder	0.12 (-.03,.25)		**0.16** **(.02,.28)**			**-0.15** **(-.29,-.02)**

White Shrimp Lag 2

	Variate	Years					
		White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
All Bays	White shrimp trawl					0.16 (-.01,.36)	
	White shrimp seine					**-0.25 (-.44,-.07)**	
	Southern flounder	**-0.27 (-.46,-.11)**	0.05 (-.15,.22)		0.1 (-.18,.37)	**-0.2 (-.38,-.02)**	0.28 (-.01,.55)
Mission-Aransas Estuary	White shrimp trawl					**0.33 (.07,.62)**	
	White shrimp seine						**-0.29 (-.56,-.05)**
	Southern flounder		0.15 (-.08,.38)	0.23 (-.02,.42)	0.32 (-.05,.63)	**-0.38 (-.62,-.09)**	**0.38 (.04,.72)**
Guadalupe Estuary	White shrimp trawl	-0.08 (-.33,.17)					
	White shrimp seine					**-0.37 (-.65,-.13)**	
	Southern flounder		-0.22 (-.46,.06)				

White Shrimp Lag 2

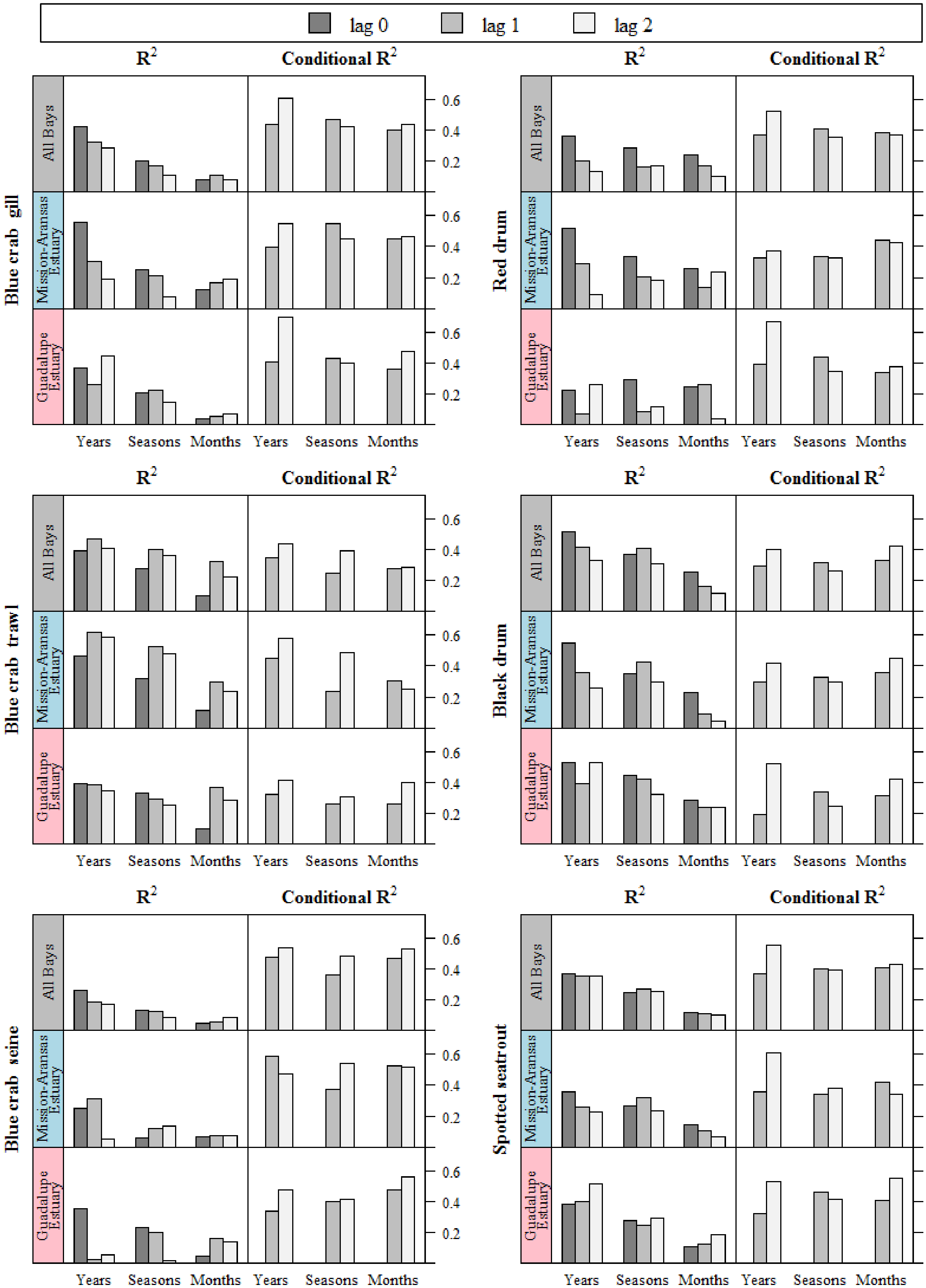
		Seasons					
	Variate	White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
All Bays	White shrimp trawl		-0.11 (-.22,.01)	**-0.13 (-.25,-.02)**			**0.22 (.1,.34)**
	White shrimp seine	**0.22 (.1,.35)**			**0.17 (.04,.3)**		
	Southern flounder	-0.08 (-.2,.05)	0.09 (-.03,.21)	**0.13 (.02,.25)**	**-0.23 (-.34,-.11)**	**-0.2 (-.32,-.08)**	
Mission-Aransas Estuary	White shrimp trawl			**-0.23 (-.4,-.07)**			**0.28 (.09,.45)**
	White shrimp seine	**0.2 (.03,.38)**			**0.25 (.06,.43)**		
	Southern flounder					**-0.2 (-.35,-.03)**	
Guadalupe Estuary	White shrimp trawl						0.17 (-.01,.34)
	White shrimp seine	**0.22 (.04,.37)**					
	Southern flounder		0.06 (-.11,.23)	0.12 (-.06,.29)		**-0.2 (-.37,-.03)**	0.15 (-.03,.32)

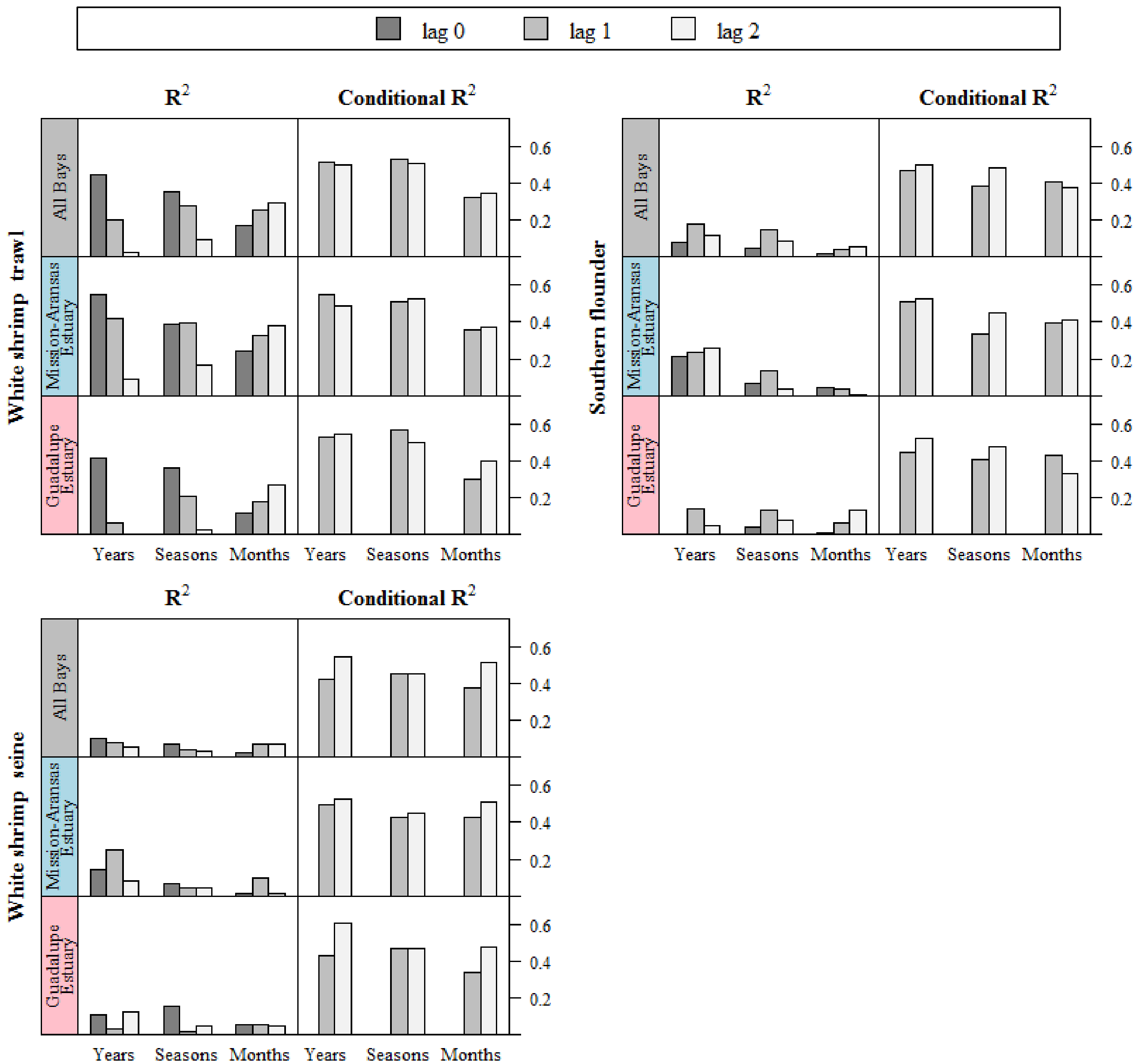
White Shrimp Lag 2

	Variate	Months					
		White shrimp trawl	White shrimp seine	Southern flounder	Salinity	Water Temp	River Discharge
All Bays	White shrimp trawl	**0.36** **(.22,.49)**	**0.17** **(.03,.29)**		**-0.24** **(-.4,-.09)**	0.13 (-.01,.26)	
	White shrimp seine		-0.07 (-.21,.09)	**-0.17** **(-.31,-.02)**		**0.18** **(.03,.33)**	0.08 (-.06,.21)
	Southern flounder			**0.24** **(.1,.39)**			
Mission-Aransas Estuary	White shrimp trawl	**0.34** **(.11,.53)**			**-0.36** **(-.57,-.17)**	**0.22** **(.02,.42)**	
	White shrimp seine			-0.12 (-.31,.05)			
	Southern flounder	-0.08 (-.28,.13)					
Guadalupe Estuary	White shrimp trawl	**0.39** **(.15,.61)**	**0.31** **(.1,.52)**	-0.09 (-.28,.09)	0.08 (-.19,.35)		0.21 (-.03,.47)
	White shrimp seine			**-0.22** **(-.45,-.01)**			
	Southern flounder			**0.36** **(.15,.56)**			

APPENDIX C

R^2 and conditional R^2 values for the regressions for each species included in the final blue crab and white shrimp MAR models. The values are shown in figures for each set of models and also listed in tables. 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.


lag 0
lag 1
lag 2
R2
Conditional R2
All Bays
Mission-Aransas Estuary
Guadalupe Estuary
Blue crab gill
Red drum
Blue crab trawl
Black drum
Blue crab seine
Spotted seatrout
Years
Seasons
Months
0.2
0.4
0.6


lag 0
lag 1
lag 2
R2
Conditional R2
White shrimp trawl
Southern flounder
White shrimp seine
All Bays
Mission-Aransas Estuary
Guadalupe Estuary
0.6
0.4
0.2
Years
Seasons
Months

Blue Crab Lag 0

	Variate	Years		Seasons		Months	
		R^2	Cond. R^2	R^2	Cond. R^2	R^2	Cond. R^2
All Bays	Blue crab gill	0.42	-	0.20		0.08	-
	Blue crab trawl	0.39	-	0.28		0.10	-
	Blue crab seine	0.26	-	0.13		0.05	-
	Red drum	0.36	-	0.28		0.24	-
	Black drum	0.51	-	0.37		0.25	-
	Spotted seatrout	0.37	-	0.25		0.12	-
Mission-Aransas Estuary	Blue crab gill	0.56	-	0.25		0.12	-
	Blue crab trawl	0.46	-	0.32		0.11	-
	Blue crab seine	0.25	-	0.06		0.07	-
	Red drum	0.52	-	0.34		0.26	-
	Black drum	0.55	-	0.35		0.23	-
	Spotted seatrout	0.35	-	0.27		0.15	-
Guadalupe Estuary	Blue crab gill	0.37	-	0.21		0.04	-
	Blue crab trawl	0.39	-	0.33		0.11	-
	Blue crab seine	0.35	-	0.23		0.05	-
	Red drum	0.23	-	0.29		0.25	-
	Black drum	0.53	-	0.44		0.29	-
	Spotted seatrout	0.38	-	0.28		0.11	-

Blue Crab Lag 1

	Variate	Years		Seasons		Months	
		R^2	Cond. R^2	R^2	Cond. R^2	R^2	Cond. R^2
All Bays	Blue crab gill	0.32	0.44	0.17	0.47	0.11	0.40
	Blue crab trawl	0.47	0.34	0.40	0.25	0.32	0.28
	Blue crab seine	0.18	0.48	0.12	0.36	0.06	0.47
	Red drum	0.20	0.37	0.16	0.40	0.17	0.38
	Black drum	0.41	0.29	0.40	0.31	0.16	0.33
	Spotted seatrout	0.35	0.37	0.27	0.40	0.11	0.41
Mission-Aransas Estuary	Blue crab gill	0.31	0.40	0.21	0.55	0.17	0.45
	Blue crab trawl	0.61	0.44	0.53	0.23	0.29	0.30
	Blue crab seine	0.31	0.59	0.12	0.37	0.07	0.53
	Red drum	0.29	0.32	0.21	0.33	0.14	0.44
	Black drum	0.36	0.29	0.43	0.33	0.09	0.36
	Spotted seatrout	0.25	0.36	0.32	0.35	0.11	0.42
Guadalupe Estuary	Blue crab gill	0.26	0.41	0.22	0.43	0.06	0.36
	Blue crab trawl	0.38	0.33	0.29	0.26	0.37	0.26
	Blue crab seine	0.02	0.34	0.20	0.40	0.16	0.47
	Red drum	0.07	0.39	0.09	0.44	0.26	0.34
	Black drum	0.39	0.19	0.42	0.34	0.24	0.31
	Spotted seatrout	0.40	0.32	0.25	0.46	0.12	0.41

Blue Crab Lag 2

	Variate	Years		Seasons		Months	
		R^2	Cond. R^2	R^2	Cond. R^2	R^2	Cond. R^2
All Bays	Blue crab gill	0.28	0.60	0.11	0.42	0.08	0.43
	Blue crab trawl	0.41	0.44	0.36	0.39	0.22	0.29
	Blue crab seine	0.17	0.54	0.08	0.48	0.09	0.53
	Red drum	0.13	0.52	0.17	0.35	0.10	0.37
	Black drum	0.33	0.40	0.30	0.26	0.11	0.42
	Spotted seatrout	0.36	0.55	0.25	0.39	0.10	0.43
Mission-Aransas Estuary	Blue crab gill	0.19	0.54	0.07	0.45	0.19	0.46
	Blue crab trawl	0.59	0.58	0.48	0.49	0.23	0.25
	Blue crab seine	0.05	0.47	0.14	0.54	0.07	0.52
	Red drum	0.09	0.38	0.18	0.33	0.23	0.42
	Black drum	0.26	0.42	0.30	0.29	0.04	0.45
	Spotted seatrout	0.23	0.61	0.23	0.38	0.07	0.34
Guadalupe Estuary	Blue crab gill	0.44	0.70	0.15	0.40	0.08	0.47
	Blue crab trawl	0.34	0.42	0.25	0.31	0.29	0.40
	Blue crab seine	0.05	0.47	0.02	0.42	0.14	0.56
	Red drum	0.26	0.67	0.12	0.35	0.04	0.37
	Black drum	0.53	0.52	0.32	0.25	0.24	0.42
	Spotted seatrout	0.51	0.53	0.30	0.41	0.19	0.55

White Shrimp Lag 0

	Variate	Years		Seasons		Months	
		R^2	Cond. R^2	R^2	Cond. R^2	R^2	Cond. R^2
All Bays	White shrimp trawl	0.45	-	0.35	-	0.17	-
	White shrimp seine	0.10	-	0.07	-	0.02	-
	Southern flounder	0.08	-	0.05	-	0.01	-
Mission-Aransas Estuary	White shrimp trawl	0.55	-	0.38	-	0.24	-
	White shrimp seine	0.15	-	0.07	-	0.01	-
	Southern flounder	0.21	-	0.07	-	0.04	-
Guadalupe Estuary	White shrimp trawl	0.42	-	0.36	-	0.12	-
	White shrimp seine	0.11	-	0.15	-	0.05	-
	Southern flounder	0.00	-	0.04	-	0.01	-

White Shrimp Lag 1

	Variate	Years		Seasons		Months	
		R^2	Cond. R^2	R^2	Cond. R^2	R^2	Cond. R^2
All Bays	White shrimp trawl	0.20	0.51	0.27	0.52	0.25	0.32
	White shrimp seine	0.08	0.42	0.04	0.45	0.07	0.38
	Southern flounder	0.18	0.47	0.15	0.38	0.04	0.41
Mission-Aransas Estuary	White shrimp trawl	0.42	0.55	0.40	0.51	0.32	0.36
	White shrimp seine	0.25	0.49	0.05	0.43	0.10	0.42
	Southern flounder	0.24	0.51	0.14	0.34	0.04	0.39
Guadalupe Estuary	White shrimp trawl	0.06	0.52	0.21	0.57	0.18	0.30
	White shrimp seine	0.03	0.43	0.02	0.47	0.06	0.34
	Southern flounder	0.14	0.44	0.13	0.41	0.06	0.43

White Shrimp Lag 2

	Variate	Years		Seasons		Months	
		R^2	Cond. R^2	R^2	Cond. R^2	R^2	Cond. R^2
All Bays	White shrimp trawl	0.02	0.50	0.09	0.51	0.29	0.34
	White shrimp seine	0.05	0.55	0.04	0.45	0.07	0.51
	Southern flounder	0.12	0.50	0.09	0.48	0.06	0.38
Mission-Aransas Estuary	White shrimp trawl	0.09	0.49	0.16	0.53	0.38	0.37
	White shrimp seine	0.08	0.53	0.04	0.45	0.02	0.51
	Southern flounder	0.26	0.52	0.04	0.45	0.01	0.41
Guadalupe Estuary	White shrimp trawl	0.01	0.54	0.03	0.50	0.27	0.40
	White shrimp seine	0.12	0.61	0.05	0.47	0.05	0.48
	Southern flounder	0.05	0.52	0.08	0.47	0.14	0.33

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

Dr. Edward Buskey, Dr. Lindsay Scheef, and Dr. Jianhong Xue
Contract #1400011712
TWDB/BBASC Comments to Final Report

REQUIRED CHANGES

General Draft Final Report Comments:

Please add the following statement to the cover page of the final report:

PURSUANT TO SENATE BILL 1 AS APPROVED BY THE 83RD 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.

This study scope of work focused on reviewing available literature related to white shrimp and blue crab abundances in the Mission-Aransas and Guadalupe Estuaries, as well as on conducting a multivariate autoregressive (MAR) analysis of the long-term Texas Parks and Wildlife Department's fisheries independent survey data. The goal of this effort was to assess the effects of freshwater inflow and other potential drivers on the abundances of blue crab and white shrimp in the Mission-Aransas and Guadalupe Estuaries. The report adequately addresses the study goals and objectives described in the Scope of Work.

Please check the document thoroughly for grammar, spelling, and typographical errors.

Please ensure that citations are consistently reported in the text and in the references section. Where applicable, please emphasize the difference between findings that were summarized from another literature review versus data that were cited from the direct source.

It is unclear if the findings of the first section derived from the literature, agrees with, informs, or is at odds with, the analyses of the second part. Please consider ways in which the two parts of the report could be synthesized.

Please be sure to include with the final report the final or best-fit blue crab and white shrimp models in equation form along with quantitative measures of statistical significance of coefficients associated with variables as well as the overall equations.

Specific Draft Final Report Comments:

1. Part I, Section 3.1.0, page 17, 1st ¶, last sentence: Please include the more recent series of TWDB reports documenting updates to freshwater inflow estimates for Texas estuaries. See the TWDB website (http://www.twdb.texas.gov/surfacewater/bays/coastal_hydrology/index.asp).

    Included for Mission-Aransas Estuary, Schoenbaechler et al. (2011), and for Guadalupe Estuary, Guthrie and Lu (2010). Added them to References Section as well as Table 1.1.

2. Part I, Section 3.2.0, page 18: Please check and provide citations for statements about water use in the Guadalupe River Basin. TCEQ and South Texas Water Master records report consumptive use in the Guadalupe-San Antonio River Basin as a maximum of about 268 kacft/yr through 2010 and a 2000-2010 average of only 208 kacft/yr.

    Revised the third paragraph as follows: "From 1941-2009, gaged inflow in Guadalupe Estuary accounted for approximately 85% of the combined FWI, while ungaged inflow accounted for nearly 15% of the combined FWI. Gaged inflow in Mission-Aransas Estuary, however, only accounted for 29% of the combined FWI, while ungaged inflow accounted for nearly 70% of the combined FWI. Although a growing population with increasing demands for water is another cause of reduced FWI in the state of Texas, annual freshwater withdrawals (i.e., diversions) from Guadalupe Estuary from 1977-2009 declined (Guthrie and Lu, 2010). Likewise, annual withdrawals from Guadalupe and Mission-Aransas estuaries accounted for relatively small percentages (only about 3% and 0.03%, respectively) of their combined FWIs. However, there is still uncertainty about future FWIs in these two estuaries. Johns (2004) demonstrated that Guadalupe Estuary will be significantly threatened during periods of low rainfall if all of the currently authorized surface water permits were fully used and if wastewater reuse increased to 50%. Additionally, the possibility of large-scale groundwater contributions, which is still under study, has been indicated as a potentially important component of FWI in Mission-Aransas Estuary, particularly during dry periods (Johns, 2004)."

3. Part I, Section 4.3.4, page 31: It is stated, "Estevez (2002) found juveniles exhibited a stronger relationship to inflow than adults, and the two year antecedent average inflows explained most of the variance in landings of blue crab in Texas." This text appears to be based on the information found in Estevez (2002) page 1297. However, the entire work by Estevez is a summary of the findings of others. Please cite the original source material or appropriately qualify the citation as a summary by another.

    The original source was unfortunately not specified in the summary by Estevez (2002). Replaced with: "In a more recent review concerning FWI needs in Texas, Estevez (2002) reported that juveniles exhibited a stronger relationship to inflow than adults, and the two-year antecedent average inflows explained most of the variance in blue crab landings."

4. Part I, Section 5.3.4, page 38, 1st ¶ and page 45: Please correct the inconsistent reporting of the citation ‘Williamson *et al*., 1977’ in the text and ‘Williamson, S.C. 1977’ reported in the References section.

   Corrected the citation where necessary to ‘Williamson 1977.’

5. Part I, Section 5.3.4, page 39, last sentence: The sentence refers to changes over “recent decades” but the citation is from 1977 so it must refer to data from the 1940’s to 1960’s. Please clarify the statement. Also, please clarify the extent of the geographic scope as well, if possible.

   Replaced with: “Furthermore, in the northern GoM during the 1950s and 1960s, observed increases in salinity caused a shift in the dominant species from white shrimp to brown shrimp (Christmas and Etzold, 1977).”

6. Part I, Section 5.3.5, page 40, 2nd ¶: Please define ‘demersal’ and any other jargon that may be less familiar to the layperson.

   Replaced with: “Hypoxia, defined as dissolved oxygen <2 mg l^{-1}, has been observed in large areas of the northwestern GoM (up to 20,000 km^2), including coastal Texas, and has led to the loss of habitat available to nekton and demersal “bottom-dwelling” species (Rabalais et al., 2001).”

7. Part I, Section 6.0.0, page 42: In the discussion at the middle of this paragraph, there appears a discussion of temperature and salinity effects on both species. The words "optimal" are used several times but it is not clear if these are referring to the most recently cited work (Copeland and Bechtel (1974) or if this is an opinion / determination of the current authors. Please clarify the source of these determinations. If the source is Copeland and Bechtel, please provide a qualification given the geographic extent of their source data.

   The second paragraph in Section 6.0.0 refers to a review by Copeland and Bechtel (1974) and has been changed so that is begins with “Copeland and Bechtel (1974) stated in a review…”. To clarify the geographic extent of their source data, we included the following: “According to the literature and data sources used by Copeland and Bechtel (1974)...” as well as “...from studies conducted in the GoM and on the Atlantic coast to ascertain ranges of each factor for each species…”.

8. Part I, Section 5.3.4, page 47, 1st ¶ and page 45: Please correct the inconsistent reporting of the citation ‘Adams *et al*., 2014’ in the text and ‘Adams, J.B. 2014’ reported in the References section.

   Corrected the citation where necessary to ‘Adams 2014.’

9. Part I, Sec. 6.0.0, page 46, 1st ¶: It is stated that "During periods of peak recruitment, for example, river diversions that reduce estuarine salinities over large areas of available habitat may inhibit growth and productivity in the affected areas (Rozas and Minello, 2011).” Please check this statement or provide context. In Texas, a “river diversion” represents a withdrawal from the river and will reduce freshwater inflow and increase salinity. There are some examples in the literature, related to the potential to reintroduce freshwater from the

Mississippi River, under the levees and to adjacent estuarine marshes, which are called "diversions," but those are highly specific to that context. Please provide clarification.

Replaced with: "During periods of peak recruitment, for example, FWI that reduces estuarine salinities over large areas of available habitat may inhibit growth and productivity in the affected areas (Rozas and Minello, 2011)."

10. Part I, Sec. 6.0.0, pages 46 – 47: There is a discussion on the history of freshwater inflow science and management by Texas State agencies, but there is no mention of the Senate Bill 3 process which recently established environmental flow standards for rivers and bays in Texas, including the Mission-Aransas and Guadalupe Estuaries, also the process through which this study was funded. Please include a brief discussion on the Senate Bill 3 process and the analyses conducted to determine freshwater inflow standards for the Guadalupe and Mission-Aransas Estuaries. See this website for more information: http://www.tceq.state.tx.us/assets/public/permitting/watersupply/water_rights/eflows/20110301guadbbest_transmission.pdf.

Added: "More recently, the Texas Legislature recognized the need to establish environmental flow standards and incorporate nutrients and sediment into the legislative charge. The Senate Bill 3 (SB3) Environmental Flows Process was established in 2007 under the Texas Legislature to characterize a balance between human water needs and the health of the environment. The law created a public process by which State authorities would solicit input from scientists and stakeholders before establishing legal FWI standards for estuaries. Through the Senate Bill 3 process, the state was divided into eleven different regions. Each of these regions appointed their own Basin and Bay Expert Science Team (BBEST) and Basin and Bay Area Stakeholders Committee (BBASC). The BBESTs are made up of scientists and technical experts with knowledge of region-specific issues and/or experience in developing flow recommendations. They developed flow regime recommendations based on best-available science and provided their findings to the BBASCs. The BBASCs are composed of members reflecting various stakeholder groups (e.g., agriculture, recreational water use, municipalities, commercial fishing, regional water planning, etc.). Each stakeholder committee was tasked with considering the BBEST recommendations in conjunction with water policy information and incorporating their own recommendations into a Work Plan for Adaptive Management to be submitted to the Texas Commission on Environmental Quality (TCEQ) for consideration in the establishment of legal minimum flow standards. Within their adaptive management plans, the BBASCs also identified several social, climatic, physical, and biological areas of research that are essential for improving FWI recommendations."

"In 2011, the FWI recommendations for Guadalupe and Mission-Aransas estuaries were determined using the Hydrology-based Environmental Flow Regime (HEFR) methodology and reported by the Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Expert Science Team (GSA BBEST) (GSA BBEST, 2011). These environmental flow regime recommendations include not only seasonal schedules of FWI quantities, but also descriptions of guiding principles for how these flow quantities are to be applied in different environmental contexts, from low- to high-flow situations. The consideration and direct translation of the FWI recommendations by TCEQ is generally expected by GSA BBEST to ensure that such recommendations will support a sound ecological environment in both Guadalupe and Mission-Aransas estuaries."

11. Part I, Section 7.0.0 Summary, pages 49, summary point #2: Please re-phrase the first sentence to indicate that Aransas-Copano and San Antonio bays are in Texas.

    Replaced with: "In Texas, the blue crab fishery experienced significant downward trends in abundance and size from 1982-2005 coastwide, as well as in Mission-Aransas and Guadalupe estuaries."

12. Part I, Section 7.0.0, page 49, summary point #3: Please check and revise if necessary the reference to "16%" of freshwater inflow withdrawn annually from the Guadalupe River Basin. See comment #1 above.

    Replaced with: "Along the Texas coast, FWI varies year to year, primarily due to variations in precipitation, but is also affected by climate change. From 1941-2009, annual FWI to Guadalupe Estuary showed no significant change (p-value = 0.09), while Mission-Aransas Estuary exhibited a slightly positive and significant effect in FWI (p-value = 0.02) over that ~70-year period. However, with a growing population, annual water demands are expected to increase from the current levels of 3% and 0.03% of the FWI totals that reach Guadalupe and Mission-Aransas estuaries, respectively."

13. Part I, Section 7.0.0, page 49, summary point #4: This summary point is based on dated information. Please consider citing more recent work, and consider the analyses conducted in Part II of this report.

    Replaced with: "In Guadalupe Estuary, the largest blue crab commercial landings occurred during years of greatest river inflow from 1965-1975. Similarly, white shrimp catch and commercial landings were also significantly correlated with spring (May-June) FWI from 1959-1975. Elevated spring flows reduced salinity and loaded nutrients and organic matter into the system, which may have benefited newly arrived postlarvae. However, poor correlations between blue crab abundance and FWI in Guadalupe Estuary have also been reported in many recent studies since 2005, and the multivariate time-series modeling study in Part II of this report indicated that FWI might influence blue crab and white shrimp populations at longer time scales. "

14. Part I, Section 7.0.0, 1st sentence, page 50: Please correct, "Pressed FWI…" to "Pulsed FWI…"

    Replaced with: "FWI is critical to the ecological stability of an estuary, but it also may influence a multitude of additional environmental factors that together can have a significant positive or negative impact on blue crab and white shrimp populations. For example, FWI that is released in subtle pulses (i.e., intermittent delivery) during months of peak recruitment may be sufficient to sustain salinity gradients, deliver nutrients and sediments, and cover nursery habitat necessary for the well-being of young recruits. In contrast, FWI that is fully pressed (i.e., continuous delivery) may cause abrupt changes in salinity and dissolved oxygen, for example, over extensive areas, which can cause negative effects on the undeveloped young (e.g., physiological impairment). Water resource management should consider not only the quantity of FWI, but also the timing and magnitude necessary to maintain healthy environmental parameters suitable for all inhabitants."

15. Part I, Section 7.0.0 Summary, page 50, #6: More recently, freshwater inflow *regimes* were determined using new approaches by the Guadalupe-San Antonio Basin and Bay Expert Science Team (G-SA BBEST) for the Senate Bill 3 process to establish environmental flows. Please also include these more recent developments for freshwater inflow recommendations. The BBEST report can be found online here: http://www.tceq.state.tx.us/assets/public/permitting/watersupply/water_rights/eflows/20110301guadbbest_transmission.pdf. Also, TCEQ does consider freshwater inflows to these and other estuaries in the water rights permitting process as part of their statutory and agency rule requirements. Please check and revise the last sentence.

    The following paragraph is added as the 7th paragraph in Section 6.0.0 following the BBEST paragraph: "In 2011, the FWI recommendations for Guadalupe and Mission-Aransas estuaries were determined using the Hydrology-based Environmental Flow Regime (HEFR) methodology and reported by the Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Expert Science Team (GSA BBEST) (GSA BBEST, 2011). These environmental flow regime recommendations include not only seasonal schedules of FWI quantities, but also descriptions of guiding principles for how these flow quantities are to be applied in different environmental contexts, such as low-flow versus high-flow situations. The consideration and direct translation of the FWI recommendations by TCEQ is generally expected by GSA BBEST to ensure that such recommendations will support a sound ecological environment in both Guadalupe and Mission-Aransas estuaries."

    Included in References Section as well as Table 1.1: "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."

    The 8th paragraph in Section 6.0.0 is replaced with: "Since the FWI recommendations in each estuary are implemented by TCEQ, plans of managing inflows to a particular estuary based on monthly optimal requirements may not include effects of long-term interactions with adjacent estuaries or the resulting biological consequences (Tolan, 2007). In addition, large-scale climate variability, such as El Niño, has cumulative effects on basin-wide stream discharge, and dominates FWI to Texas estuaries at interannual times, but to our knowledge, has not been recognized. Thus, water management decisions should also consider the interannual changes by large-scale global climate influences (Longley, 1994; Tolan, 2007). Overall, an improved understanding of FWI and its role in an estuary, we hope, will enable more effective management of limited water supplies in the future."

16. Part I, References, page 52: Please correct the Bricker *et al.*, 1999 reference to a format consistent with the report.

    This reference was used to inform the reader of hypoxia only. It does not discuss blue crab, white shrimp, FWI, or a specific geographic area. Therefore, this reference does not have any special characters from the key associated with it in the left-hand margin.

17. Part II, Section 2.2.0, page 68 - 69: Please include in the discussion of previous studies information regarding the TPWD/TWDB (1998) and HDR (2009) work in the development of equations relating blue crab and white shrimp harvest to freshwater inflow. These equations use freshwater inflow as an independent variable which explains 45% and 54% of the annual variation in the respective blue crab and white shrimp harvests and represent the "best available science" prior to the SB3 environmental flows process. Please see the references listed at the end of this document.

    The references to the TPWD/TWDB report's spatial analysis in this section were expanded, but discussion of the harvest equations was not added. This section primarily focuses on previous analyses of the TPWD species abundance data. Also, the TPWD/TWDB and HDR reports do not appear to include the measures of percent variability explained that are referred to in this comment.

18. Part II, Section 3.1.0, page 72: Please include any refined data sets, including those of blue crab/white shrimp catch, with the final report. Please identify any excluded observations (*i.e.* outliers) and the basis or criteria for exclusion.

    As stated in the Scope of Work, all original data and code used to format the datasets used in the models and to generate the final models will be included with the final report.

19. Part II, Section 3.3.0, pages 73 – 78: Please clarify the differences between "preliminary," "primary," and "final" models.

    The single mention of primary models was omitted and a sentence referencing the section where final models are discussed was added to Section 3.3.0.

20. Part II, Sec. 3.3.1., page 75, 1st full ¶: Please change the phrase "modeled freshwater inflow from the Texas Water Development Board" to "freshwater inflow estimates from the Texas Water Development Board." TWDB freshwater inflow estimates include gaged river flow *and* modeled flow in ungaged watersheds (which accounts for modeled runoff, diverted flows and returned flows). Consider for future studies (and to remain consistent with Guadalupe-San Antonio Basin and Bay Expert Science Team BBEST analyses) that TWDB freshwater inflow datasets are now available through 2014 for all basins and can be requested

from coastal-data@twdb.texas.gov. Also in this section, please include the specific USGS gage stations that were used in the study, including the name and USGS gage number.

The word "modeled" was changed to "estimated," and a statement that the TWDB data were available through 2014 was added. The specific stations associated with the NERR, TCOON, USGS, NDBC, NCDC, and TABS datasets were not given in this section because they are listed in the table in Appendix A. The reference to this table in Section 3.1.0 was edited to more clearly state that the stations are listed in the table.

21. Part II, page 76: Section 3.3.3 is missing. Please ensure the numbering scheme is accurate.

    Section 3.3.4 was changed to 3.3.3, and section 3.3.5 was changed to 3.3.4.

22. Part II, Section 3.4, page 78, last sentence: Please include the actual numerical values of coefficients derived through the MAR analyses in the report or an appendix.

    An appendix containing tables of all model coefficients and their upper and lower confidence bounds was added.

23. Part II, 4.3.1., page 90: Please define/describe 'bootstrapping' the first time it is mentioned in the text.

    A paragraph providing a description of bootstrapping was added to section 3.4.0 where the structure of the model is discussed.

24. Part II, 4.3.2, pages 92 – 98: Please include, either in the text or in an appendix, the blue crab models in equation form along with quantitative measures of statistical significance of coefficients associated with variables as well as the overall equations. Please also include a discussion of the best model/equation for calculation of abundance based on freshwater inflow (the only variable directly affected by SB3 environmental flow standards), including how much variation in abundance the equation explains. Please discuss how the model/equation compares with previous equations developed by TWDB/TPWD and/or HDR.

    An appendix containing tables of all model coefficients and their upper and lower confidence bounds and an appendix containing the R^2 and conditional R^2 values from the models were added.

    Since the model framework used in this study was multivariate, models containing only freshwater discharge as a predictor variable were not run. The TWDB/TPWD/HDR harvest models and the MAR models in this study have dramatically different structures and cannot be directly compared.

25. Part II, 4.3.2, pages 99 - 103: Please include, either in the text or in an appendix, the white shrimp models in equation form along with quantitative measures of statistical significance of coefficients associated with variables as well as the overall equations. Please also include a discussion of the best model/equation for calculation of abundance based on freshwater inflow (the only variable directly affected by SB3 environmental flow standards), including how much variation in abundance the equation explains. Please discuss how the model/equation compares with previous equations developed by TWDB/TPWD and/or HDR.

An appendix containing tables of all model coefficients and their upper and lower confidence bounds and an appendix containing the R^2 and conditional R^2 values from the models were added.

Since the model framework used in this study was multivariate, models containing only freshwater discharge as a predictor variable were not run. The TWDB/TPWD/HDR harvest models and the MAR models in this study have dramatically different structures and cannot be directly compared.

26. Part II, References, page 106: The citation is incomplete for MacNally, R. *et al.* 2010. Please list each author.

The citation was corrected.

Figures and Tables Comments:

1. Table of Contents: Please correct the page number listing for the Introduction from 12 to 14.

Corrected and updated.

2. Table of Contents: Please correct the page number listing for the Overview under Part II from page 63 to page 66.

Corrected and updated.

3. Part II, Section 4.3.1, pages 91 – 103, Figures 4.7 – 4.12: In each of these figures, values of the horizontal axis are not given. Please provide clarification about values of the horizontal axes.

The captions of all of these figures were amended to include more detail on how to interpret them, including what the x-axis limits are.

4. Part II, Section 4.3.1, page 103, Figure 4.12: There are two Figures labeled 4.12. Please correct the second one to Figure 4.13.

The figure label was corrected.

5. Appendix A: Please include the USGS gage name and number used in the analysis.

Gage numbers were added to the table.

SUGGESTED CHANGES

Specific Draft Final Report Comments:

1. Part I, Section 1.0 and 2.0: These sections refer to "runoff," for example, "The health and resilience of estuarine ecosystems are maintained by freshwater runoff as well as water exchange with the coastal ocean." Consider also mentioning that other components besides runoff are important contributions to the Guadalupe Estuary. For example, spring flows in the Guadalupe River and wastewater in the San Antonio River can be important contributions to the system.

Replaced "freshwater runoff" with "FWI" in the sentence quoted above. Here, we are generally describing freshwater inflow as water that enters the system primarily via rivers.

2. Part I, Section 2.1.0, page 16, ¶, 2nd sentence: Consider restating "climate (such as temperature)" to "climate factors (such as temperature)."

   Reworded "climate (such as temperature)" to "climate factors (such as temperature)."

3. Part I, Section 3.2.0, page 17 – 18: Freshwater inflow is assessed with a dataset that ends in 1987. Consider providing an assessment of recent freshwater inflow trends since 1987, which also will provide consistency with the analysis performed in Part II that uses data ranging from 1982 – 2013.

   Section 3.2.0 as follows: "There are seven estuaries along the Texas coast (Figure 3.1), with a general decrease from north to south in both FWI and rainfall (Table 3.2). Guadalupe and Mission-Aransas estuaries are among them with moderate (2,664 × 10^6 m^3 y^{-1} or 2,160,000 acre-feet y^{-1}) and low (265 × 10^6 m^3 y^{-1} or 215,000 acre-feet y^{-1}) FWI, respectively (based on 1941-1999 averages that include the precipitation and evaporation components; Tolan, 2007). These values are similar to the values reported by Longley (1994) of 2,340,000 acre-feet y^{-1} for Guadalupe and 430,000 acre-feet y^{-1} for Mission-Aransas estuaries, however these combined FWI values are based on 1941-1987 averages and did not include precipitation or evaporation components. The most recent reports of FWI in Guadalupe and Mission-Aransas estuaries include, for accuracy, the necessary components (i.e., gaged and ungaged flows, diversions, return flow, evaporation, and precipitation) during an approximate 70-year period from 1941-2009, and were conducted by Guthrie and Lu (2010) and Schoenbaechler et al. (2011), respectively (based on TWDB hydrology dataset version #TWDB201004). FWI balance was calculated for Guadalupe and Mission-Aransas estuaries in terms of their annual average values during the 70-year period as 2,270,000 acre-feet y^{-1} and 280,000 acre-feet y^{-1}, respectively. Although a general but steady decrease in water flow occurs from the northeastern region of Texas near the Louisiana state line due south along the coast to the Mexican border (Kim and Montagna, 2009), annual FWI to Guadalupe Estuary revealed no significant changing trend (*p*-value = 0.09), while Mission-Aransas Estuary exhibited a slight increase in FWI that was significant (*p*-value = 0.02) over the 70-year period (Figure 3.2; Guthrie and Lu, 2010 and Schoenbaechler et al., 2011, respectively)."

   "According to model-derived FWI rates of Guadalupe and Mission-Aransas estuaries from 1941-2009, big variations occurred monthly (Figure 3.3; only for 1941-1987; Longley, 1994) and annually (Figure 3.2) as a result of drought and flood conditions. Drought perhaps has led to the most dramatic reduction in FWI in Texas and is connected to large-scale weather patterns. In 1956, after 10 years of the worst droughts in Texas history, river discharge to the Texas coast dropped approximately 86% below average (Longley, 1994), and FWI in both Guadalupe and Mission-Aransas estuaries reached historic all-time lows (Figure 3.2). On the other hand, for example, elevated FWI to Guadalupe Estuary in 1987 (130% above average) was due to heavy precipitation following an extended wet period that saturated the soil (Longley, 1994). Some of the monthly peaks were attributed to hurricanes and tropical storms. For example, two of the three largest inflow peaks in Mission-Aransas Estuary were recorded during hurricanes. "

"From 1941-2009, gaged inflow in Guadalupe Estuary accounted for approximately 85% of the combined FWI, while ungaged inflow accounted for nearly 15% of the combined FWI. Gaged inflow in Mission-Aransas Estuary, however, only accounted for 29% of the combined FWI, while ungaged inflow accounted for nearly 70% of the combined FWI. Although a growing population with increasing demands for water is another cause of reduced FWI in the state of Texas, annual freshwater withdrawals (i.e., diversions) from Guadalupe Estuary from 1977-2009 declined (Guthrie and Lu, 2010). Likewise, annual withdrawals from Guadalupe and Mission-Aransas estuaries accounted for relatively small percentages (only 3% and 0.03%, respectively) of their combined FWIs. However, there is still uncertainty about future FWIs in these two estuaries. Johns (2004) demonstrated that Guadalupe Estuary will be significantly threatened during periods of low rainfall if all of the currently authorized surface water permits were fully used and if wastewater reuse increased to 50%. Additionally, the possibility of large-scale groundwater contributions, which is still under study, has been indicated as a potentially important component of FWI in Mission-Aransas Estuary, particularly during dry periods (Johns, 2004)."

4. Part I, Section 4.2.0, page 26, last ¶: Please clarify if the following statement is the current author's assessment of the reviewed data or an assessment of another author, in which case please provide a reference: "Brackish rivers and bays offer an important habitat for blue crab mating, and increased salinity from reduced FWI is generally harmful to blue crab populations, at least in the short term."

   Replaced with: "Rounsefell (1964) identified low salinity marsh habitat as important nursery grounds for juveniles, suggesting an increase in salinity from reduced FWI may be harmful to blue crab populations, at least in the short term." Also, added to References Section as well as Table 1.1.

5. Part I, Section 4.3.4, pages 31 – 32: Consider moving the discussion based on data from Mense and Wenner (1989) and Sandoz and Rogers (1944) out of the Mission-Aransas and Guadalupe Estuaries specific section and into the general discussion on Blue Crab since these studies were not conducted in Texas.

   Moved discussion based on data from Mense and Wenner (1989) and Sandoz and Rogers (1944) to Section 4.2.0, second paragraph.

6. Part I, Section 5.3.4, page 38, last sentence: If the author considered salinity as a factor, consider adding clarification on how salinity affected the author's results/conclusions.

   The section is titled "Dependency on FWI and salinity" and the paragraph is discussing FWI, primarily. Changes in salinity are caused by FWI, however, so we included the words "reduced salinity" throughout the paragraph for clarification.

7. Part I, Section 6.0.0, page 42: This entire page is one paragraph. Consider identifying break points which will make it easier to read.

   Divided into 3 paragraphs for an easier read.

8. Part I, Section 6.0.0, page 43, Table 6.1: Please consider providing a more recent, updated observation than the Childress et al., 1975 review and perhaps even consider replacing with a statement based on data compiled and analyzed in Part II of the report by Scheef and Buskey.

   Added the following into Table 6.1: "However, poor correlations between blue crab abundance and FWI in San Antonio Bay have also been reported in more recent studies (e.g., Hamlin, 2005; Ward, 2012). The multivariate time-series modeling study in Part II indicated that FWI might influence blue crab at longer time scales."

9. Part I, Section 6.0.0, page 46, 1st ¶: The concluding remark: "Thus, FWI, although a critical element of estuarine health, could be planned during periods that yield minimal interaction with the major factors aforementioned" is a confusing statement. Please add clarification to the meaning of this statement.

   Replaced with: "Thus, FWI, although a critical element of estuarine health, could be planned in a manner that yields minimal interaction with the major factors listed in Tables 6.1 and 6.2. For example, as stated by Zein-Eldin and Renaud (1986), "simultaneously providing marsh areas with sufficient covering water for the young while lowering salinities (<20-25‰) during hotter summer months when young white shrimp are most numerous in the estuarine areas" would provide optimal conditions for survival."

10. Part I, Section 7.0.0 Summary, pages 49, #1: Consider emphasizing that male blue crabs remain in the estuary when mature while female blue crabs emigrate to the GoM when mature.

    Replaced with: "In the GoM, both blue crab and white shrimp exhibit similar life cycles: 1) spawn at the mouth of an estuary during warm months (i.e., July-August for blue crab and March-September for white shrimp); 2) enter an estuary as postlarvae and settle in shallow nursery habitat to complete juvenile development; and 3) migrate to the GoM once mature (except for male blue crab which remain in the estuary)."

11. Part I, Section 7.0.0 Summary, pages 49, #2 and #3: Please maintain a consistent naming convention for bays and estuaries throughout the report to avoid confusion. Also, consider addressing the apparent disconnect between the period of record in #2 and #3 summary points, wherein #2 refers to catch data during a time period of 1982 – 2005 but #3, refers to freshwater inflow data during a time period of 1941 – 1987. For the reader that only has time to read the summary bullet points, this has the potential to give an impression that the connection between abundance and freshwater inflow was not assessed in this report.

Where studies which were evaluated in this review use Aransas-Copano and/or San Antonio bays, we have included Mission-Aransas and/or Guadalupe estuaries (respectively) in parentheses and adjacent. Also, we have included the following sentence in Section 4.3.1, last sentence of first paragraph: "Some of the studies discussed in this review refer to Mission-Aransas and Guadalupe estuaries as Aransas-Copano and San Antonio bays, respectively, and we feel it is noteworthy to inform the reader of this discrepancy to prevent any confusion."

In Section 7.0.0 Summary, summary points #2 and #3, the observation period of FWI data have been revised from 1941-1987 to 1941-2009 so that they match up and compare more accurately and recently to the catch data, which is from 1982-2005.

12. Part I, Section 7.0.0 Summary, pages 49 - 50, #5: The second and third sentences in this summary point appear to be contradictory. Please provide clarification.

    Replaced with: "For example, FWI that is released in subtle pulses (i.e., intermittent delivery) during months of peak recruitment may be sufficient to sustain salinity gradients, deliver nutrients and sediments, and cover nursery habitat necessary for the well-being of new recruits. In contrast, FWI that is fully pressed (i.e., continuous delivery) may cause abrupt changes in salinity and dissolved oxygen, for example, over extensive areas which can cause negative effects on the undeveloped offspring (e.g., physiological impairment)."

13. Part II, Section 1.0.0., pages 66 – 67: The importance of freshwater inflow as a principal driver underlying this work is evident at the outset of this section. The terminology shifts to either "environmental factors" or "abiotic factors" or "exogenous drivers." The use of these terms has the potential to increase reading difficulty by non-expert readers, including stakeholders. Consider some effort to adopt a more uniform terminology or provide definitions for new terms.

    The instance of "exogenous drivers" was deleted, and the two occurrences of "abiotic factors" were changed to "environmental factors."

14. Part II, Section 3.3.1., page 73, 2nd ¶: Potential predators of blue crab and white shrimp are described as "gill sample species," "species," or "predators." Consider the use of a single term to avoid confusion for the reader. Also, consider adding a description as to why a negative correlation between a predator and focal species is significant and what level of negative correlation should be considered significant enough to deem the species a predator.

    Correlations with the focal species were run for every species in the gillnet sample dataset, rather than just for suspected predator species. The occurrences of "gill sample species" and "species" are actually referring to all species in the dataset, not just predators. The wording was altered to make this more clear. The correlation coefficients themselves, rather than their significance levels, were used to select predator species to include in the models. The wording was also altered to make this more clear.

15. Part II, Section 4.1.0, page 80: Consider that the explanations offered for observed trends of selected predators may be unnecessary given that model output does not include information about the effect of stocking or fishing regulations on these species.

    Although the assessment of predator species abundance drivers was not a focus of this study, it seemed appropriate to briefly mention the management efforts that are commonly referred to when considering the population trends of these fish species.

16. Part II, Sec. 4.3.0, pages 88-103, pages 89 – 103, Figures 4.7 through 4.12. These figures are extremely important to this report, conveying the results of an immense amount of research. There is only one short description at the top of page 90 beginning with the words "For example" that gives the most basic information. Only by linking that text for PDO and salinity at Lag 0, with the single subplot for "PDO" and "sal" in Figure 4.7, upper left, related to the "C-Matrix" does a reader get the most basic level of interpretation, namely, that the negative axis must be to the left. Please consider providing additional description/discussion to aid thorough interpretation of results.

    The captions of all of these figures were amended to include more detail on how to interpret them, including what the x-axis limits are.

17. Part II, Section 4.3.2 and 4.3.3: Were equations for calculation of catch as a function of freshwater inflow and/or other variables developed? If so, please describe the measures of statistical significance of the equations and how they compare to the Scheef/Buskey abundance equations as well as the TPWD/TWDB and/or HDR harvest equations.

    Equations for calculation of catch as a function of freshwater inflow were not developed as part of this study. Technically, equations for calculation of abundance were not developed either. The coefficients of the MAR models represent the relative influence of each variable in the model on the other variables in the model. All abundance data and environmental data were standardized prior to model application so that the coefficients within the resulting model could be directly compared to one another. Therefore, the MAR model coefficients cannot be applied to non-standardized data to calculate actual abundance values, and they cannot be directly compared to coefficients in models estimated from non-standardized data.

    Direct comparisons between the TPWD/TWDB/HDR harvest equations and the MAR models in this study would be difficult. The TPWD/TWDB/HDR harvest equations represent freshwater inflows as sums for pairs of months, resulting in several coefficients for inflows in each species model, but include no other variables. The MAR models generated in this study consist of a single freshwater inflow coefficient for each modeled species along with coefficients for several other variables. Therefore, the harvest models and MAR models have dramatically different structures. While the percent variability explained for each species could potentially be compared between the harvest and MAR models, these values do not appear to be included in the TPWD/TWDB or HDR harvest equation reports.

18. Part II, Section 5.0.0, page 104: An important finding of this study is the significant positive correlations between abundance and catch data for blue crab and white shrimp, indicating that catch data continues to be of significant value as an indicator if abundance. Please consider mentioning this finding in the conclusions section.

Commercial catch data were primarily included in this study to assess whether commercial harvest had measurably consistent negative impacts on the abundances of blue crab and white shrimp that warranted the inclusion of catch as a variable in the models. More detailed analyses examining the relationship between abundance and catch and assessing the influence of other variables, such as commercial license buyback, on catch were not conducted.

The TPWD commercial fishing license buyback programs for blue crab and white shrimp, established in 1998 and 1995, respectively, are believed to have had strong negative impacts on the harvest of those species (particularly for shrimp). A comparison of the abundance and catch trends in Figures 4.1 and 4.3 suggests that the correlation between crab abundance and crab catch before the license buyback was established is primarily responsible for the significance of the overall correlation. Also, these figures indicate that the strong correlation between shrimp abundance and shrimp catch was likely coincidental because the limited number of post-buyback catch values included in the analysis happened to coincide with the lowest shrimp abundance values included in the analysis.

It therefore seems premature to state that catch data can continue to be used as an indicator of abundance without further investigation.

Figures and Tables Comments:

1. Table of Contents, page iii: Consider adding the Scope of Work, List of Figures, and List of Tables to the Table of Contents directory.

We added the List of Figures and List of Tables to the Table of Contents. However, we did not include the Scope of Work in this review.

2. Part II, Section 3.3.1, page 74, Figure 3.1: This figure does not show "Negative correlations" per se, but rather species for which negative correlations exist. Consider providing clarification to the Figure title.

The figure title was amended to read "Presence of negative correlations".

3. Part II, Section 3.3.1, page 74, Figure 4.7: Consider specifying in the plot title that the data represent the yearly temporal division.

The figure was edited to more clearly indicate that it represents the yearly temporal division models.

4. Part II, Section 4.2.0, page 87, Figure 4.6 and Part II, Section 4.2.3, page 98, Figure 4.10: These figures show potentially significant correlations between red drum abundance and freshwater inflow. Was an equation developed quantifying this relationship? If yes, please consider providing the quantitative measures of statistical significance along with the

equation and consider comparing to the TPWD/TWDB and HDR equations which portrayed the relationship as explaining 67% of the annual variation in red drum harvest.

Technically, equations for calculation of abundance were not developed as part of this study. The coefficients of the MAR models represent the relative influence of each variable in the model on the other variables in the model. All abundance data and environmental data were standardized prior to model application so that the coefficients within the resulting model could be directly compared to one another. Therefore, the MAR model coefficients cannot be applied to non-standardized data to calculate actual abundance values.

Direct comparisons between the TPWD/TWDB/HDR harvest equations and the MAR models in this study would be difficult. The TPWD/TWDB/HDR harvest equations represent freshwater inflows as sums for pairs of months, resulting in several coefficients for inflows in each species model, but include no other variables. The MAR models generated in this study consist of a single freshwater inflow coefficient for each modeled species along with coefficients for several other variables. Therefore, the harvest models and MAR models have dramatically different structures. While the percent variability explained for each species could potentially be compared between the harvest and MAR models, these values do not appear to be included in the TPWD/TWDB or HDR harvest equation reports.

References

Texas Parks & Wildlife Department and Texas Water Development Board. 1998. "Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas," Coastal Studies Technical Report No. 98-1, December 1998.

HDR Engineering, Inc., "2011 Regional Water Plan Study 4 Part A Environmental Studies," South Central Texas Regional Water Planning Group, Texas Water Development Board, April 2009.