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Research paper

Fish species as indicators of freshwater inflow within a subtropical estuary in the Gulf of Mexico

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ABSTRACT

As anthropogenic pressures on fresh water continues, a balance must be achieved to ensure estuaries receive sufficient riverine inputs to sustain ecosystem health. With increased demand on freshwater resources upstream, salinities in the coastal systems may increase, providing an opportunity for encroachment or invasion by species with a higher salt tolerance. These events compromise ecosystem function, integrity and sustainability, particularly of native estuarine habitats. Estuarine dependent teleost fish species may be considered appropriate bioindicators of abiotic stressors. While estuarine fish have a wide tolerance of many environmental conditions, each species has its own tolerance range and/or sensitivity, and at specific phases during their life cycle. A statistical analysis was conducted to better understand the relationship of *Ictalurus furcatus* (blue catfish), *Brevoortia patronus* (Gulf menhaden) and *Lagodon rhomboides* (pinfish) to abiotic parameters associated with freshwater inflows (i.e. salinity, nutrients, turbidity, etc). Data for this study were collected in Galveston Bay, Texas (USA) by various state agencies and spanned 124 seasons between 1979 and 2010. Distance based linear models were run to determine correlations between the selected indicator species and water quality parameters known to be related to freshwater inflows. These relationships were visualized with Spearman vectors overlain on principal coordinates analysis plots. Blue catfish and Gulf menhaden displayed a significant inverse correlation with salinity and significant positive correlation with $NO_3^- + NO_2^-$ (μM), DIN:DIP and turbidity (NTU). During periods of drought, blue catfish were found closest to the river mouth, where salinity was lowest when considering other locations within Galveston Bay. Gulf menhaden maintain a wider distribution across the Bay as they have a wider salinity range tolerance. Pinfish display a significant positive correlation with salinity and temperature within Galveston Bay; as bioindicators this species is expected to be more tolerant to higher salinities. These relationships support the potential use of these species as beneficial indicators of changing estuarine conditions, namely freshwater inflows. Further study is essential to determine if these and/or other species can be applied to other bays along the Texas coast as well as other sub-tropical estuarine systems in which they are found.

1. Introduction

More than 40% of the world's population live within 100 km of the coast leading to continuous pressure in bays, estuaries and nearshore environments due to increased urban development and growing demands on fisheries resources (IOC/UNESCO, 2011). This growth in coastal populations globally results in increased volumes of freshwater diverted upstream for agriculture and human populations and recycled as returned flows (i.e., effluent, power plants, etc.). The returned flows may contain elevated levels of nutrients as a result of common waste water treatment procedures (Oki and Kanae, 2006) as well as pharmaceuticals and other human by-products. Demands on freshwater inflows in many coastal states around the country and the world, reflect the need to develop suitable indicators and/or metrics of estuarine health.

Freshwater inflows (FWI) contribute to the fluctuation of estuarine environmental parameters including but not limited to salinity, organic matter, turbidity, nutrient concentrations and sediment loading, all of which are important to the survival and success of the estuarine flora and fauna (Alber, 2002; Copeland, 1966; Dorado et al., 2015; Lester and Gonzalez, 2011; Palmer et al., 2011; Palmer and Montagna, 2013; Roelke et al., 2013). Periodic pulses of FWI can influence estuarine systems by enhancing primary productivity, contributing to species biodiversity and supporting energy transfer between trophic levels (Flemer and Champ, 2006; Roelke et al., 2013). Estuarine ecosystem health is fundamentally dependent on FWI further supporting the need

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to find balance between the supply and demand on coastal resources and ecosystem services (Alber, 2002; Boesch et al., 1984; Longley, 1994; Nixon, 1995; Quigg et al., 2009).

In this current study, we focused on individual fish species as indicators of freshwater inflows, and to a lesser extent, the health of the bay. Bioindicators can be a species, a population or community that reflects the abiotic or biotic state of an environment and can represent the impact of environmental change on a habitat, community or ecosystem (McGeoch, 1998). Biological resources, such as teleost fish, have been utilized as bioindicators of ecological health and sustainability of an ecosystem due to their physiological requirements at various life stages and sensitivity to changing environmental parameters (i.e. salinity, turbidity, dissolved oxygen, temperature) (Alber, 2002; Bortone, 2005; Glibert et al., 2011; Govoni, 1997; Palmer et al., 2011). Longley (1994) reported on the use of various fish including *Pogonias cromis* (black drum), *Sciaenops ocellatus* (red drum), *Cynoscion nebulosus* (sea trout), crustaceans (*Callinectes sapidus* (blue crab), *Litopenaeus setiferus* (white shrimp) and *Farfantepenaeus aztecus* (brown shrimp), and mollusks (*Rangia cuneata*; Atlantic rangia), *Crassostrea virginica*; Eastern-oysters) as part of an earlier modeling effort for Galveston Bay to determine inflow-harvest relationships. These sport and/or commercially important fisheries species were chosen to develop inflow requirements. While the model has many advantages (see also Alber, 2002), a key concern was that it overlooked other fauna with different inflow requirements. More recently in Galveston Bay, Espey et al. (2009) suggested that *Ictalurus furcatus* (blue catfish) be considered as a bioindicator of low salinities ($\leq$15 psu), *Brevoortia patronus* (Gulf menhaden) of intermediate salinities (> 15–25 psu) and *Lagodon rhomboides* (pinfish) of high salinities (> 25 psu).

By examining trends of the fish community in response to FWI across 124 seasons between 1979 and 2010, we are working towards developing a better understanding of the ecological health and sustainability of Galveston Bay, Texas (USA). The watershed spans 62,200 km^2 and includes two major metropolitan areas (Houston and the Dallas/Fort Worth meteroplex) and two major rivers (Trinity and San Jacinto Rivers). Water resource managers must be able to meet current and future societal demands placed on the freshwater supply while still meeting the inflow criteria necessary to maintain beneficial inflows. In this study, we evaluated blue catfish, Gulf menhaden and pinfish against measured environmental parameters associated with FWI (salinity, temperature, nutrients, etc.) to determine their use as bioindicators of FWI in Galveston Bay.

2. Materials and methods

2.1. Study area and freshwater inflows

Galveston Bay, also referred to as the Trinity-San Jacinto Estuary (29.5°N, 94.8°W), is composed of five major sub-bays: Trinity Bay, Upper Galveston Bay, Lower Galveston Bay, West and East Bays (Fig. 1). The water quality parameters in West and East Bays are significantly different from Trinity Bay, Upper and Lower Galveston Bay and therefore have been excluded from this analysis (see Steichen and Quigg, 2015 for details). Trinity River supplies approximately 55% of the freshwater to Galveston Bay while the San Jacinto River provides 16%, with lower volume contributions from the remaining combined sub-watersheds (12%) (Guthrie et al., 2012). The hydrology of the Bay allows for rapid changes in salinity (Orlando et al., 1993; TDWR, 1982) as FWI discharges from the Trinity and San Jacinto Rivers into the northern reaches of the Bay (Fig. 1).

Gaged flows were obtained from United States Geological Survey (USGS) stream flow gages located at on the Trinity River at Romayor (USGS 08066500), San Jacinto River (USGS 08072000), and Buffalo Bayou at Lake Houston (USGS 08074000). Surface inflow volumes were calculated by summing gaged inflows (USGS), ungaged inflows (modeled by TWDB), and return flows, while subtracting diversions (TWDB, 2015). The ungaged inflows were estimated using the Texas Rainfall-Runoff (TxRR) model (Matsumoto, 1992). Ungaged runoff was calculated as the sum of 1) computed runoff, using a rain-runoff simulation model, based on precipitation over the watershed, 2) flow diverted from streams by municipal, industrial, agricultural, and other users, and 3) unconsumed flow returned to streams (Guthrie et al., 2012; TWDB, 2015). Exchange with waters from the Gulf of Mexico occurs through a narrow pass separating Galveston Island and Bolivar Peninsula (Fig. 1) and San Luis Pass at the far south end of the island (not shown). Wind forcing and FWI were important mixing mechanisms in this shallow (~2.1 m average) microtidal (0.15–0.5 m) bay system.

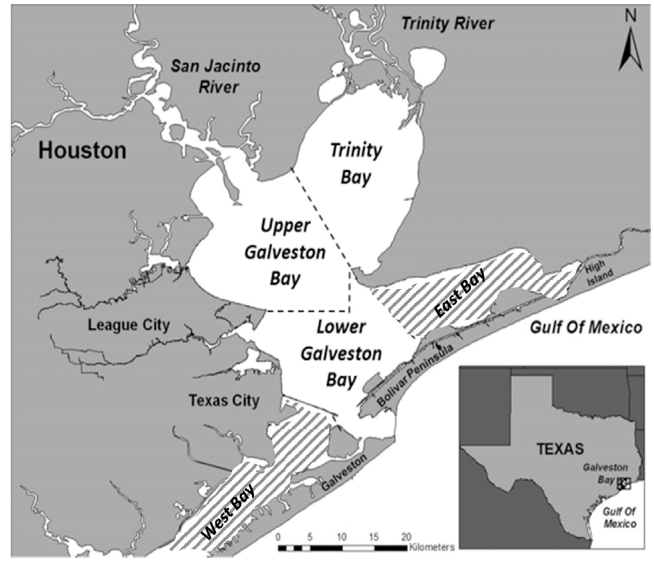

Fig. 1. Map of Galveston Bay (located along the upper Texas coast in the Gulf of Mexico (inset)) showing the bay segments including Trinity Bay, Upper Galveston Bay and Lower Galveston Bay. West and East Bays are shown with hash marks as they were not included in the analysis.

2.2. Data acquisition for meta-analysis

Fisheries and environmental data used to perform this meta-analysis was collected in Galveston Bay from 1979 to 2010 by Texas Parks and Wildlife Department (TPWD) – Coastal Fisheries Division. The data from approximately 4600 sampling events was utilized in this meta-analysis to determine relationships between the catch per unit effort (CPUE) of potential bioindicator species and the environmental parameters associated with FWI. The CPUE was calculated by summing the species count data collected with the bay trawl to determine the catch per hour per season (TPWD, 2012).

Bay trawls were conducted in the open waters of the bay (> 1 m) and were designed to catch juvenile and sub-adult fish and invertebrates (TPWD, 2012). Due to the area of the bay (~1544 km^2), TPWD partitioned Galveston Bay into 2 zones. Each zone was further divided into sample grids which were one minute latitude by one minute longitude in size. Each sample grid was comprised of 144 sample gridlets that were five seconds latitude by 5 s longitude. The sampling strategy was random where 10 bay trawls were conducted monthly in each zone. The sample grids were randomly selected in each zone and after each sample grid was selected the sample gridlet was randomly chosen. Weather permitting there were a total of 20 bay trawls conducted across Galveston Bay on a monthly basis (TPWD, 2012).

Environmental water quality data were obtained from the Texas Commission on Environmental Quality (TCEQ) Surface Water Quality Monitoring program (SWQM) from 1979 to 2010. Salinity (measured practical salinity unit scale, psu), temperature (°C), turbidity (NTU),