# Effects of Hydrologic Connectivity on Pond Environmental Characteristics in a Coastal Marsh System

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# Effects of Hydrologic Connectivity on Pond Environmental Characteristics in a Coastal Marsh System

Sung-Ryong Kang[1,*] and Sammy L. King[2]

**Abstract** - The patterns of hydrologic connectivity in coastal marsh systems may affect the variation of environmental variables. In this study, we examine the effects of hydrologic connectivity patterns on environmental variables among freshwater, brackish, and saline marsh ponds and between pond types (permanently connected pond [PCP], temporarily connected pond [TCP]) in coastal Louisiana. TCPs did not completely dry although they were only temporarily connected by surface water to permanent bodies of water. The patterns of daily water depth within a pond type across marshes and between pond types within a marsh did not clearly indicate differences. We found few environmental differences between our hydrological groups PCP and TCP. The salinity increased from inland (i.e., freshwater marsh) towards the ocean (i.e., saline marsh), but percent cover of submerged aquatic vegetation (SAV) decreased in the same direction.

## Introduction

Hydrologic connectivity refers to the passage of water from one part of the landscape to another (Bracken and Croke 2007) and the spatiotemporal exchange pathways of water and energy along longitudinal, lateral, and vertical dimensions (Amoros and Bornette 2002, Ward et al. 1999). Hydrologic connectivity in coastal wetlands is affected by regionally varied tidal flooding and freshwater flow based on the connected channel from coast to upstream (Doyle et al. 2007). There is evidence that brackish and saline marshes in coastal areas are tidally connected to the estuary by one or more channels (Rozas and Minello 2010), but freshwater marshes do not have a regular inundation pattern (Mitsch and Gosselink 2000) because their long distance from the ocean limits the influence of the tidal cycle.

The patterns of hydrologic connectivity in coastal marsh systems are important drivers of environmental processes. Decreasing salinity from the coast (e.g., saline marsh) towards inland (e.g., freshwater marsh) due to reduced longitudinal hydrologic connectivity of the marsh to the sea (i.e., saltwater and freshwater intrusion; Sumner and Belaineh 2005) is typical for coastal marsh systems (Chabreck 1988). Connectivity of marsh ponds to adjacent marsh, other ponds, and to natural and artificial drainages (i.e., man-made canals) may also influence environmental variables. For instance, increased water depth (i.e., flood flow) due to hydrologic connection can decrease water temperature (Alvarez-Borrego and Alvarez-Borrego 1982). Thus, tidally flooded ponds that are hydrologically connected with other ponds, channels, and emergent marshes (i.e., relatively high water depth) may also have cooler temperatures than infrequently flooded ponds

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in coastal marshes. Ponds with cooler temperature may have higher dissolved oxygen concentrations (Hunter et al. 2009). Furthermore, hydrologic connectivity and pond characteristics in coastal marshes have important consequences for ecological functions. Variation in hydrological connectivity can potentially affect aquatic organism assemblages. For example, the presence and depth of water can positively or negatively impact movements of nekton (Fernandes et al. 2009, Kang and King 2013a) and macroinvertebrates (Kang and King 2013b , Leigh and Sheldon 2009, Zilli and Marchese 2011).

Chabreck (1971) noted that there are over 5.3 million ponds in coastal Louisiana, including over 870,000 in the Chenier Plain region. These ponds provide important habitat for a wide range of fish and wildlife species (La Peyre et al. 2007, O'Connell and Nyman 2010), yet little information exists on comparison of water depth, SAV cover, and water chemistry within these ponds. A clear understanding of the relationships between hydrologic connectivity and environmental variables of marsh ponds of the Gulf coast would enhance our understanding of pond characteristics in coastal systems and potential and current habitat value of marsh ponds for fish and wildlife species. The principal objectives of this study are to: 1) compare variation of water depth, SAV cover, and water chemistry among freshwater, brackish, and saline marsh ponds and 2) examine the effects of hydrologic connectivity (i.e., permanently connected pond [PCP]: permanently connected to a channel during all seasons, temporarily connected pond [TCP]: temporarily connected by surface water to the surrounding marsh but not permanently connected to a channel) on environmental variables. We hypothesized that 1) saline marsh ponds have greater salinity and dissolved oxygen (DO), but shorter duration of hydrologic disconnection, lower temperatures, and less cover of SAV than freshwater and brackish marsh ponds and 2) across marsh types, PCPs have greater water depth, SAV coverage, and DO and lower temperatures than TCPs.

## Field-Site Description

The Chenier Plain comprises the western region of the Louisiana coast. The Chenier Plain sediments were transported by the westward coastal current in the Gulf of Mexico and reworked in periods of low deposition (Byrne et al. 1959, Gould and McFarland 1959). The Chenier Plain is characterized by beach ridges that limit tidal exchange to a few inlets at the mouths of the rivers and tidal creeks/bayous (Visser et al. 2000). Chenier marshes in Louisiana are affected by oil pipeline canals and water control structures (Gunter and Shell 1958, Morton 1973).

We conducted the study in Rockefeller State Wildlife Refuge (RSWR: 29°40'93"N, 92°48'45"W) and White Lake Wetlands Conservation Area (WLWCA: 29°52'50"N, 92°31'11"W) in the Chenier Plain of southwestern Louisiana between April 2009 and May 2010 (Figs. 1, 2). Both are included in the Mermentau River Basin. The area extended north to south across three (freshwater, brackish, saline) vegetation-salinity areas defined and mapped by Chabreck and Linscombe (1997). RSWR and WLWCA are not hydrologically connected by a channel due to water-control structures between the two areas. WLWCA had water-control structures that slowed water release from the marshes (Morton 1973), and RSWR had flap gates, weirs, and gated culverts to facilitate water-level and salinity management (Wicker et al. 1983). We classified marsh types on the basis of marsh vegetation (i.e., freshwater marsh: *Panicum hemitomon* Schultes [Maidencane] and *Sagittaria lancifolia* L. [Bulltongue Arrowhead]; brackish marsh: *Spartina patens* (Aiton) Muhl [Saltmeadow Cordgrass]; saline

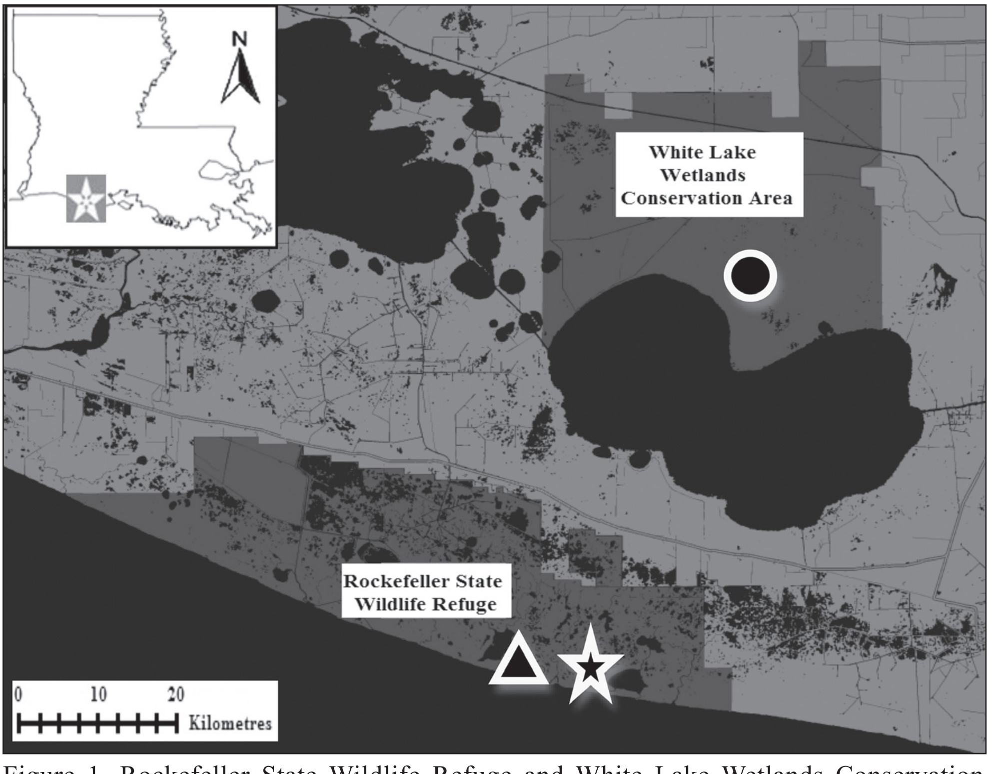


Figure 1. Rockefeller State Wildlife Refuge and White Lake Wetlands Conservation Area study sites located in southwestern Louisiana (Modified Google Map, https://maps.google.com, accessed 16 November 2012). Star = saline marsh, triangle = brackish marsh, and circle = freshwater marsh used in this study.

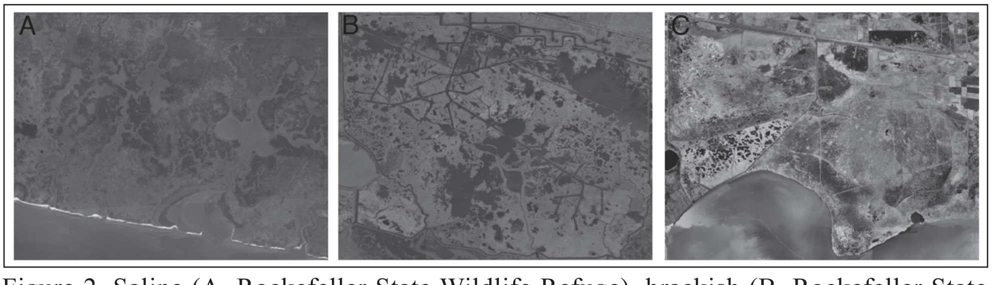


Figure 2. Saline (A, Rockefeller State Wildlife Refuge), brackish (B, Rockefeller State Wildlife Refuge), and freshwater (C, White Lake Wetlands Conservation Area) marshes used in this study.

marsh: *Spartina alterniflora* Loisel [Smooth Cordgrass]) and salinity fluctuations (i.e., freshwater marsh: 0.1–3.4 ppt, brackish marsh: 1.0–8.4 ppt, saline marsh: 8.1–29.4 ppt).

The 42,400-ha RSWR consists of 17 impoundments. Unit Six (7200 ha) of RSWR was selected as our tidal brackish marsh. The dominant plant species in this unit were Saltmeadow Cordgrass and *Typha latifolia* L. (Broadleaf Cattail). Moreover, an unmanaged area of similar size and dominated by Smooth Cordgrass was selected as tidal saline marsh habitat. The average daily tidal range in Unit Six and the unmanaged area next to Unit Six during the sampling period was 3.6 cm and 5.5 cm, respectively (Coastwide Reference Monitoring System, http://www.lacoast.gov/crms2/Home.aspx, 2009–2010). Mineral soils were dominant in RSWR marsh ponds. WLWCA is a 28,719-ha freshwater marsh that is dominated by Maidencane and Bulltongue Arrowhead. Organic soil was dominant in WLWCA marsh ponds.

## Methods

### Experiment design

Ponds in freshwater, brackish, and saline marshes were identified from long-term observations (J. Linscombe, Louisiana Department of Wildlife and Fisheries, Rockefeller State Wildlife Refuge and White Lake Wetlands Conservation Area, LA, pers. comm.), aerial photographs, and field visits and classified as either a PCP or a TCP. TCPs did not have an obvious connecting channel to permanent water bodies. In the marshes, PCPs typically had a gradually sloped bank, whereas TCPs had a more vertical bank. In each marsh type, we randomly selected three PCPs and three TCPs (total of 18 ponds = three marsh types x six ponds) for more intensive study.

We deployed a water-level recorder in the interior of each pond in November 2008 to measure water depth once every four hours (i.e., daily water depths) until the end of the study in May 2010. In addition, a staff gage was established at the border between the emergent marsh and the pond to measure disconnection of surface water. Based on this measurement, we calculated two hydrologic metrics: the duration of isolation (DI) and the connected water depth (CWD). DI is the number of days the pond is disconnected from the emergent marsh. Thus, DI is the number of days that water was 0 cm deep at the pond/marsh interface. CWD was the water depth at the border between the pond and the emergent marsh. CWD was determined by comparing water depths at the continuous water-level recorder and the staff gage, and a basic arithmetic equation was used to predict water depth measurements at the staff gage (HOBOware software Pro 3.0). Monthly water depth measurements at the staff gage were always within 1 cm of the predicted values.

To assess variation in environmental variables across pond types in the three marsh types, salinity (ppt), DO (mg/l), and water temperature (°C) were measured monthly with a YSI Model 85 Water Quality Monitor. These variables were measured 2–3 cm above the sediment at each sampling point (pond edge) between 08:00 AM and 5:00 PM. Percent cover of SAV in a 1- x 1-m frame was also randomly determined at three plots in each pond, and mean SAV cover was calculated for each pond. Rainfall data were obtained from the Coastwide Reference Monitoring System (http://www.lacoast.gov/crms2/Home.aspx).

**Statistical analyses**

Analyses of variance (ANOVA) and *t*-tests (Proc Mixed, Version 9.2, SAS Institute, NC) were used to test for statistical differences in environmental variables. ANOVAs were used for analyses within a pond type across marshes (e.g., comparison of PCPs value among freshwater, brackish, saline marsh) and *t*-tests were used between pond types within a marsh (e.g., PCPs vs. TCPs value in freshwater marsh). We used one-way ANOVAs with one fixed effect for each response variable (environmental variable). For ANOVA analyses, data were tested for normality with the Shapiro-Wilk test. In the event that the residuals were not normally distributed, the data were log-transformed. Significance of ANOVA testing were evaluated using post-hoc comparisons of Tukey adjusted least squared means.

## Results

The mean diameter of the randomly selected PCPs and TCPs was 99.0 ± 14.6 m (mean ± SE) and 75.4 ± 17.7 m, respectively. In all marshes, TCPs disconnected from the surrounding emergent marsh in June 2009. Thereafter, TCPs in brackish and saline marshes were reconnected to surrounding areas in August 2009; freshwater TCPs were reconnected in September 2009 (Fig. 3). PCPs and TCPs always contained some water in the pond interior with the exception of one saline TCP that dried completely.

Within a pond type across marshes, CWD (cm) in brackish PCPs was higher than saline PCPs ($F_{2,3561} = 3.15$, $P < 0.05$); CWD in TCPs did not differ among marsh types (Table 1). Between pond types within a marsh, freshwater TCPs had higher CWD than PCPs ($P = 0.02$). DI (days) of TCPs did not differ among marsh

Table 1. Comparison of means (± SE) of connectivity factors[A] ($n = 7668$), SAV cover[B] ($n = 90$), and water chemistry[C] ($n = 252$), within a pond type across marshes from April 2009–May 2010 (c.f. Kang and King 2013b). CWD = connected water depth, DI = duration of isoltaion, and DO = dissolved oxygen.

| | Saline | | Brackish | | Freshwater | |
|---|---|---|---|---|---|---|
| | PCP | TCP | PCP | TCP | PCP | TCP |
| CWD (cm) | 13.8 (3.12) | 20.9 (3.44) | 28.1 (7.42) | 31.2 (7.48) | 19.4 (6.40) | 18.2 (5.43) |
| DI (days) | 0.0 (0.00) | 1.3 (0.95) | 0.0 (0.00) | 3.8 (2.73) | 0.0 (0.00) | 8.5 (4.75) |
| SAV cover (%) | 0.0 (0.00) | 0.0 (0.00) | 14.2 (4.77) | 12.1 (4.07) | 34.5 (4.39) | 32.0 (5.52) |
| Salinity (ppt) | 13.1 (2.14) | 12.3 (2.51) | 4.1 (1.21) | 4.0 (1.06) | 0.9 (0.24) | 0.3 (0.06) |
| DO (mg/l) | 4.5 (0.58) | 4.0 (0.53) | 4.4 (0.60) | 4.6 (0.43) | 2.8 (0.73) | 2.5 (0.66) |
| Temperature (°C) | 24.8 (2.94) | 25.3 (3.35) | 23.2 (3.17) | 23.7 (3.33) | 24.3 (3.46) | 23.4 (3.23) |

[A]18 sampling ponds x 426 days = 7668 samples (connected water depth, duration of isolation)
[B]18 sampling ponds x 5 seasons = 90 samples (SAV cover)
[C]18 sampling ponds x 14 months = 262 samples (salinity, dissolved oxygen, temperature)

types ($P$ = 0.08). Also, DI between pond types within a marsh did not statistically differ (freshwater marsh: $P$ = 0.14; brackish: $P$ = 0.23; saline: $P$ = 0.21). All ponds were disconnected from the emergent marsh for a similar amount of time during 2009–2010.

Within a pond type across marshes, saline PCPs and TCPs had greater salinity than brackish and freshwater PCPs and TCPs (PCPs: $F_{2,123}$ = 26.97, $P$ < 0.01; TCPs: $F_{2,123}$ = 34.54, $P$ < 0.01) (Table 1). In freshwater marshes, salinity was higher in PCPs (0.9 ± 0.23) than in TCPs (0.3 ± 0.07; $t$ = 2.42, $P$ = 0.04); salinity

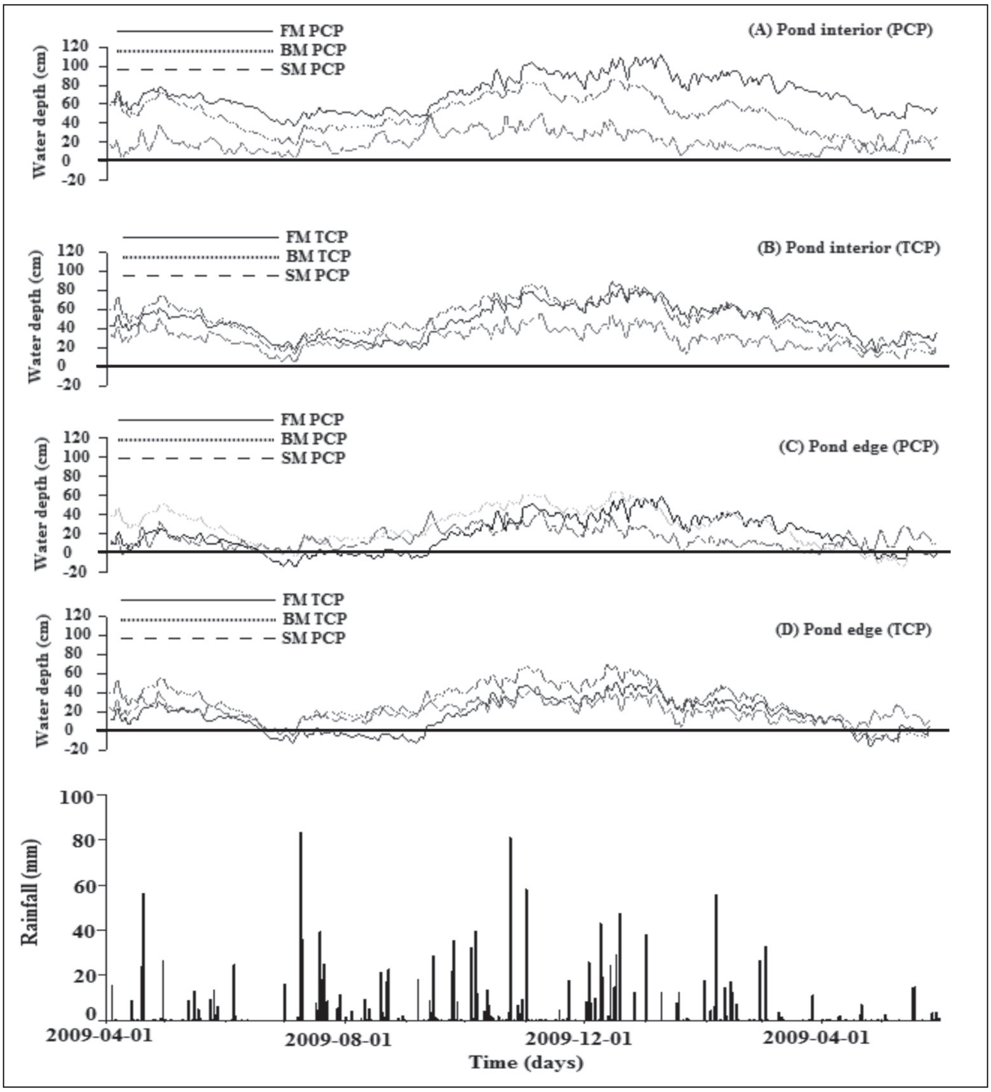


Figure 3. Daily average water depths of connected water depth at the pond interior (A, B) and edge (C, D) in randomly selected freshwater, brackish, and saline marsh permanently connected ponds (PCPs) and temporarily connected ponds (TCPs) from April 2009 through May 2010 (each line represents the average of the 3 PCPs and 3 TCPs). The bottom graph represents rainfall variation.

did not differ between PCPs and TCPs in brackish ($P$ = 0.98) and saline marshes ($P$ = 0.77). Within pond types across marshes, DO (mg/l) was higher in saline and brackish than in freshwater PCPs ($F_{2,123}$ = 7.05, $P$ < 0.01) and TCPs ($F_{2,123}$ = 9.85, $P$ < 0.01). There were no differences in DO between pond types within a marsh (Table 1). Temperature did not differ within a pond type across marshes and between pond types within a marsh (Table 1). Within pond types across marshes, freshwater PCPs and TCPs had greater SAV cover than brackish and saline PCPs and TCPs, respectively (PCPs: $F_{2,42}$ = 9.88, $P$ = 0.01; TCPs: $F_{2,42}$ = 8.43, $P$ = 0.02) (Table 1). No differences were observed between pond types within a marsh.

## Discussion

The patterns of daily water depth within a pond type across marshes and between pond types within a marsh did not clearly indicate differences. We found few environmental differences between our hydrological groups PCP and TCP. The salinity increased from inland (i.e., freshwater marsh) towards the ocean (i.e., saline marsh) but percent cover of SAV decreased in the same direction. These patterns are typical for coastal marsh systems, which are characterized by abiotic gradients resulting from the convergence of the freshwater environment with the adjacent marine environment (Day 1981, Martino and Able 2003, Weinstein et al.1980).

Most environmental variables differed across marsh types as expected. Previous studies (Adam 1990, Noel and Chumra 2011, Sumner and Belaineh 2005) noted that seawater and freshwater inputs, groundwater-surface water interflow, precipitation, and evaporation are major contributors to temporal variability of salinity. In our study, it is likely that salinity in freshwater and brackish marsh may have been affected by rainfall, but the tidal cycle may override this effect in saline marsh ponds. The lack of SAV in saline ponds was also consistent with previous research; presence and absence of SAV within Louisiana marsh ponds is generally inversely related to salinity (Chabreck 1971), and SAV only occasionally occurs in saline ponds (Adair et al. 1994, Merino et al. 2009).

Some environmental variables, however, did not vary as expected. We expected PCPs that are hydrologically connected with other ponds and channels to have cooler temperatures than TCPs. Although freshwater and saline TCPs had higher CWD than PCPs, water temperatures did not differ. Noel and Chumra (2011) observed that tidewater reaching marsh ponds rapidly equalized the water temperature in the ponds with the temperature of the incoming seawater (relatively lower temperature). In this case, the relatively short duration of hydrologic disconnection of our saline TCPs may have minimized temperature differences between pond types. The freshwater PCPs can be several kilometers from the deeper water (e.g., White Lake) and are connected by shallow, vegetated ditches with little water flow, thus temperatures may not vary between PCPs and TCPs in freshwater marsh. TCPs in freshwater marsh were permanently flooded presumably due to groundwater connectivity through highly organic soils, although TCPs were only temporarily connected by surface water to the emergent marsh and channel. Classic temporary ponds (e.g., Williams 1987) are isolated from both surface and subsurface waters for a period of time each year. Groundwater connections through highly mineral soils of the brackish and saline marshes appear to be less prevalent, or at least of lower influence, and water depths are more greatly influenced by marsh management (brackish marsh; Bolduc and Afton 2004) and tidal influence (saline marsh).

Both large-scale and local hydrologic modifications are common throughout the entire Chenier Plain of Louisiana and may have affected our results (Gunter and Shell 1958). The Mermentau River Project resulted in large-scale water-level control in the lower basin and successfully reduced salinities, although storm surges from Hurricanes Rita (2005) and Ike (2009) did increase salinities. At the local scale, structural marsh management (SMM) undoubtedly influenced pond characteristics in the brackish marsh. SMM is a common practice in Louisiana whereby levees are placed in the marsh and an outlet is fit with water-control structures to allow controlled connectivity with outside waters to facilitate flooding, drawdown, and salinity control (Cowan et al. 1988). Impoundments are common in coastal Louisiana, comprising 17% of the inland area of the Chenier Plain (Gosselink et al. 1979) and 30% of the total wetland area (370,658 ha) in the coastal zone (Day et al. 1990). In our study, water depth in PCPs was greater in managed marsh ponds (brackish marsh) than in unmanaged marsh ponds (saline marsh) even though both marshes were located in the same area and separated by a levee (i.e., SMM). This finding was possibly due to the limited tidal influence and the relatively slow drainage of water following large rainfall events during 2009–2010.

We should expect the role of hydrologic connectivity in the overall ecology of a marsh system to be complex. Our understanding of how plant and animal communities respond to these hydrologic characteristics is still rudimentary. Disconnection from the emergent marsh and channel limits or stops movement of nekton to/from the pond (Lake 2003, Szedlmayer and Able 1993); however, groundwater connections can continue to allow survival for some period of time after disconnection, at least in the freshwater marsh. At a local scale, SMM also can restrict direct access of transient species by reducing or blocking water exchange (Kang and King 2013a, Morton 1973, Rozas and Minello 1999). Anthropogenic (e.g., marsh management [Chabreck 1988] and mosquito control ditches [Balling and Resh 1983]) or natural (e.g., shoreline erosion [Louisiana Coastal Wetlands Conservation and Restoration Task Force 1998]) activities that convert TCPs to PCPs can potentially alter habitat heterogeneity and affect aquatic organism assemblages.

Variation of environmental variables (e.g., lower salinity) in the sampled brackish ponds that were converted from saline ponds by SMM is a typical example of anthropogenic management. In this case, decreased salinity values in brackish ponds may result in increased density of macroinvertebrates (Boix et al. 2008, Kang and King 2013b) and resident nekton (Kang and King 2013a, Rozas and Minello 1999). In addition, lower variability in water levels and the relatively short duration of isolation in saline TCPs may provide a stable refuge for aquatic organisms due to decreased rate of water exchange. Relationships between different pond connection types (i.e., directly vs. indirectly connected to channel) and vegetation (Balling and Resh 1983), macroinvertebrates (Barnby et al. 1985), and nekton (Connolly 2005) have been studied in brackish and saline marsh ponds, but little information is available for freshwater marsh ponds. Additional research is needed that links environmental characteristics to biological communities in these systems to enhance wetland conservation and restoration efforts.

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