Understanding Nekton Use of Estuarine Habitats in the Northern Gulf of Mexico

Guidebook for Natural Resource Managers and Restoration Practitioners
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Acronyms

BACI	before-after, control-impact
NVB	non-vegetated bottom
SAV	submerged aquatic vegetation
SE	standard error
USFWS	U.S. Fish and Wildlife Service

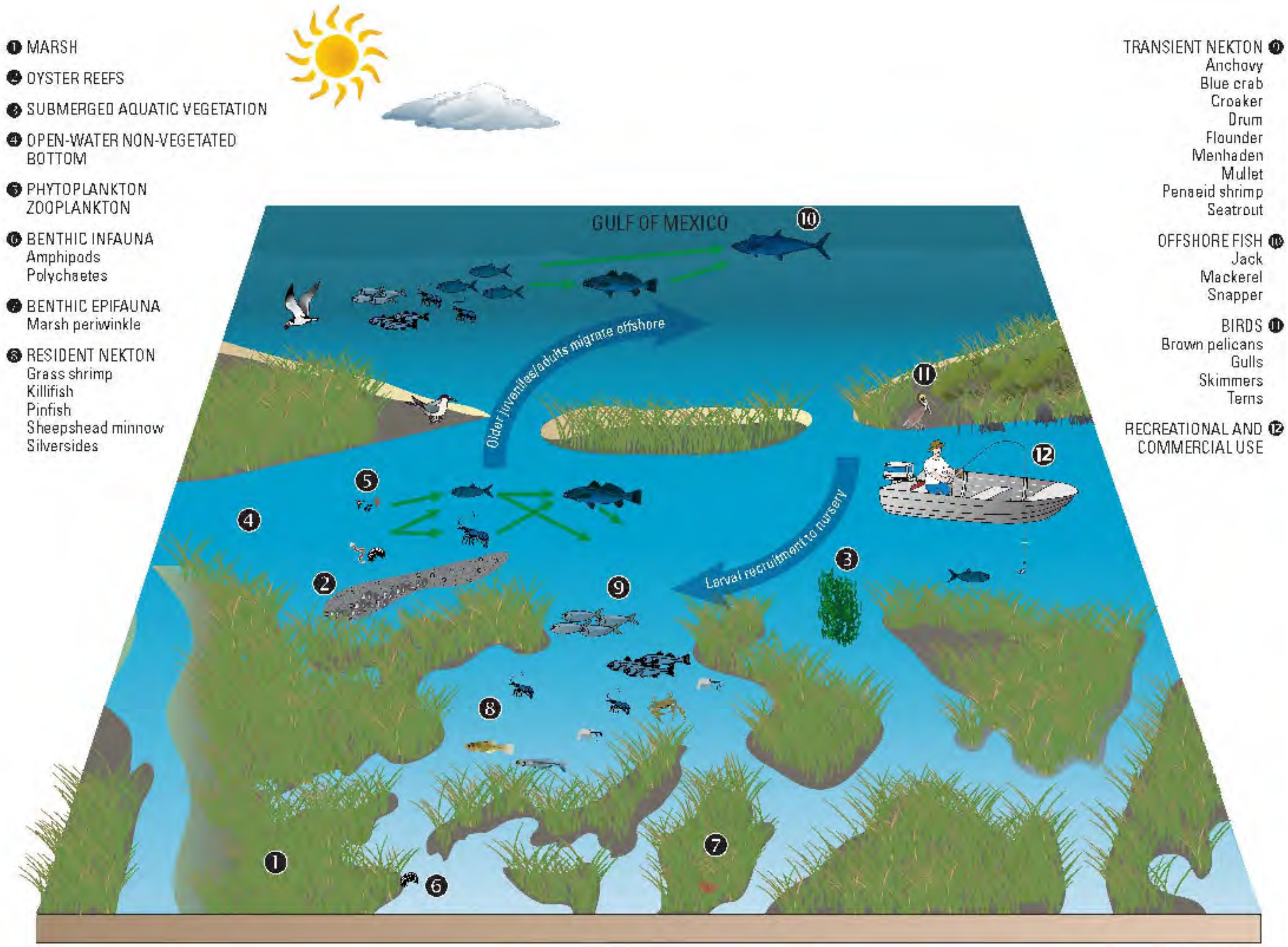
1. Introduction

1.1 Importance of Estuarine Habitats

Shallow estuarine environments in the northern Gulf of Mexico serve as important habitats for many ecologically and economically important fish and crustacean species (referred to collectively as "nekton"). The habitats in these areas, including marsh, oyster reef, submerged aquatic vegetation (SAV), and shallow open-water non-vegetated bottom (NVB), are home to resident species – such as grass shrimp and killifish – that remain in the estuarine system year-round and serve as prey resources for larger organisms (Figure 1). These habitats are also used episodically by transient species for refuge, juvenile development, and/or foraging when not offshore. These shallow water systems also facilitate ecological connectivity between estuarine and marine environments through the exchange of nutrients, energy, and organisms (Deegan, 1993; Deegan et al., 2000). Many of the transient species that use estuarine habitats – such as brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), blue crab (*Callinectes sapidus*), Gulf menhaden (*Brevoortia patronus*), spotted seatrout (*Cynoscion nebulosus*), and red drum (*Sciaenops ocellatus*) – are commercially and recreationally important (O'Connell et al., 2005). Over 95% of the U.S. commercial fisheries landings (by weight) in the Gulf of Mexico are estimated to be composed of estuarine-dependent species (Chambers, 1992; Lellis-Dibble et al., 2008). With the Gulf of Mexico accounting for approximately 14% of the total U.S. domestic commercial fisheries landings (by weight) and 16% of the total dollar value in 2017 (NMFS, 2018), these habitats are not only important sources of commercially important species for the Gulf of Mexico but for the U.S. domestic commercial fishery industry more broadly.

Many of these estuarine habitats, however, are experiencing extensive land loss and degradation. Wetlands along the Gulf Coast are being lost due to a variety of factors, including the engineering of the Mississippi River, storms, subsidence, relative sea level rise, construction of canals for oil and gas development, and urban and rural development (Boesch et al., 1994; Day et al., 2000, 2007; Dahl and Stedman, 2013). Between 2004 and 2009, the Gulf States lost an estimated 39,000 hectares (approximately 96,400 acres) of estuarine wetlands, with the majority being converted to open-water habitat (Dahl and Stedman, 2013). Globally, the story is similar for oyster reefs and SAV beds, with high rates of habitat loss and degradation due to poor water quality and human disturbance (Handley et al., 2007; Waycott et al., 2009; Beck et al., 2011).

Figure 1. General schematic of the estuarine environment in the northern Gulf of Mexico, including key habitats and species. Also shown is the life history pattern of some species, which includes recruitment to the estuarine system as larvae and moving offshore as adults.



Source: Some elements on diagram courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (https://ian.umces.edu/symbols/).

Increased federal and state efforts in the past few decades in the Gulf Coast have focused on the restoration and protection of these important estuarine habitats. For example, numerous regional and state-wide restoration and management plans have highlighted coastal habitat restoration and protection as a key focus (e.g., Gulf Coast Ecosystem Restoration Task Force, 2011; DWH NRDA Trustees, 2016; Gulf Coast Ecosystem Restoration Council, 2016; CPRA, 2017; FWC and FLDEP, 2018). In addition, restoration work in the region is underway. The federal Coastal Wetlands Planning, Protection and Restoration Act has authorized over 200 projects in Louisiana since its enactment in 1990 (www.lacoast.gov). Recent environmental disasters have provided over $15 billion in funds primarily focused on natural resource restoration in the Gulf of Mexico through the Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act; the Natural Resource Damage Assessment; and the Gulf Environmental Benefit Fund.

Implementing effective coastal habitat restoration and protection projects will remain a management priority in the northern Gulf of Mexico for many years to come. These projects often include a goal of supporting a diverse assemblage of nekton species, including species that have cultural, recreational, or commercial importance. While there are many project-level assessments of outcomes (e.g., Rozas and Minello, 2001; Scyphers et al., 2011; Armitage et al., 2014; La Peyre et al., 2014), there is no comprehensive resource currently available that has analyzed the key habitat characteristics that define nekton use, how nekton use varies spatially and temporally, and environmental factors that affect nekton use of estuarine habitats in the Gulf of Mexico. Without this comprehensive understanding of nekton use of key habitats across locations and habitats, natural resource managers and restoration practitioners in the northern Gulf of Mexico region are lacking a key tool to assist in their efforts of designing, implementing, and monitoring effective coastal restoration and protection efforts in the decades to come.

To address this need, a systematic literature review, data compilation, and meta-analysis were conducted to evaluate nekton use of estuarine habitats in the northern Gulf of Mexico. This meta-analysis, which compiled data from a diversity of habitats, studies, and areas in the Gulf of Mexico, provides the opportunity to statistically summarize findings from across comparable studies (Vetter et al., 2013). This approach also provides the ability to address a broad scope of questions and application of results. The key findings of the meta-analysis are summarized in this guidebook, with the objective to provide natural resource managers and restoration practitioners with information that is useful in planning, implementing, and evaluating estuarine habitat restoration and protection efforts in the northern Gulf of Mexico. This guidebook also (1) provides a companion comprehensive database on nekton use in the northern Gulf of Mexico from studies reported in the scientific and grey literature, and (2) presents the meta-analytical approach that can be applied to aggregate nekton data from different studies and sampling gear types to understand key research questions.

1.2 Purpose of the Guidebook

The purpose of this guidebook and companion database is to provide information on habitat-specific nekton use and recovery to help natural resource managers and restoration practitioners plan, implement, and evaluate habitat restoration and protection projects. This includes providing information that could aid in:

- Communicating expected benefits of restoration and protection projects
- Setting conservation and restoration goals

- Designing projects to maximize benefits for important resources
- Identifying important components of the project to monitor
- Determining if projects are on track for success, or in need of corrective actions or adaptive management.

This guidebook focuses on the four common habitat types found in the estuarine environment of the northern Gulf of Mexico: marsh, oyster reef, SAV, and open-water NVB. The first three habitat types are also a focus of restoration and protection efforts in the region. More studies and research have focused on marsh habitat compared to the other three habitats. Thus, more information is presented in this guidebook for marsh habitat compared to the other types. Given the importance of these other habitats to nekton use, this is noted as a data gap for future research (see Section 7.4).

1.3 Overview of the Guidebook

This guidebook presents analytical methods, results, and discussion focused on understanding nekton use in northern Gulf of Mexico estuarine habitats, and is organized as follows:

- Chapter 1, this chapter, provides an overview of the importance of estuarine habitats, the purpose of the guidebook, and how the remaining guidebook is organized
- Chapter 2 provides an overview of the analytical methods for data compilation and meta-analysis (with supplemental information in the appendices)
- Chapter 3 discusses nekton use of marsh and adjacent open-water habitat, including a summary of species assemblages, how nekton use varies spatially and temporally, environmental variables that affect nekton use, and nekton recovery following marsh restoration
- Chapter 4 discusses nekton use of oyster reef habitat, including a summary of species assemblages; how nekton use varies seasonally; and nekton recovery following oyster reef restoration
- Chapter 5 discusses nekton use of SAV habitat, including a summary of species assemblages; how nekton use varies seasonally; and nekton recovery following SAV restoration
- Chapter 6 provides a comparison of nekton use across the four habitat types, including nekton use and nekton composition
- Chapter 7 provides a discussion on key findings and additional considerations for monitoring and future research
- Chapter 8 presents other sources of information on the importance of estuarine habitats, other regional/national compilations of nekton use, gear correction reviews, and monitoring and evaluation guidelines
- The final section provides the list of references cited in this guidebook.

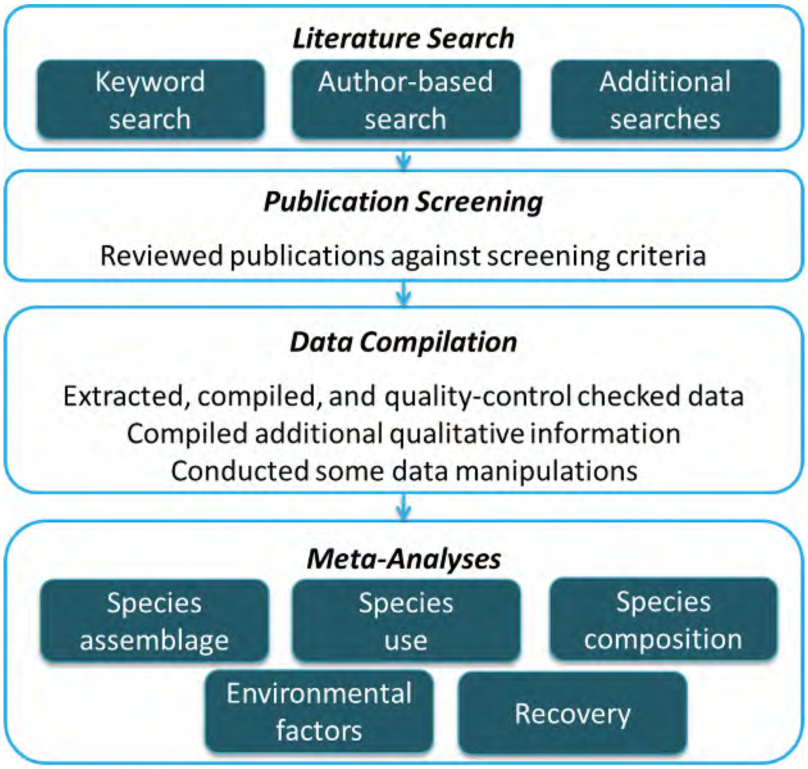
This guidebook also consists of an accompanying database and three appendices that provide:

- Information on the data compilation process (Appendix A)
- An overview of the accompanying database (Appendix B)
- Information on the analytical methods (Appendix C).

2. Methods

A systematic literature search, data compilation, and meta-analysis were conducted to support the evaluation of nekton use of restored and reference estuarine habitats in the northern Gulf of Mexico. For the purposes of this guidebook, restored sites were classified as habitats that were either created or enhanced; and reference sites were classified as natural habitats that were minimally impaired and unrestored. An overview of the general approach is provided in Figure 2 and summarized in the sections below, with additional information in Appendices A–C.

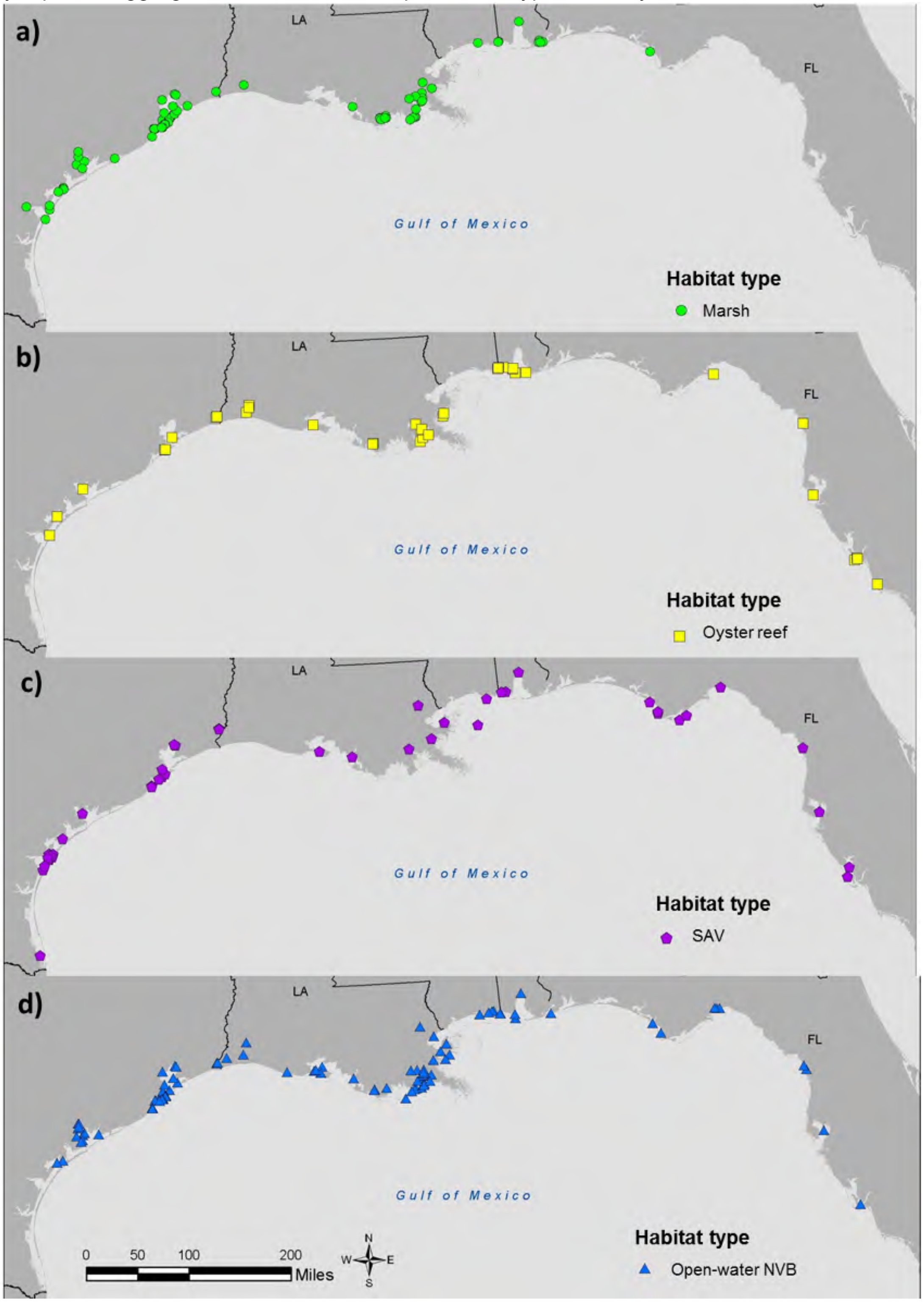
Figure 2. General overview of the methodological approach. Specific details on the data compilation and resulting database are found in Appendices A and B; and details on the analyses are detailed in Appendix C.



2.1 Literature Search, Publication Screening, and Data Compilation

Recognizing the wealth of information already collected by previous and ongoing studies in the northern Gulf of Mexico, this project aimed to leverage this existing work and develop a comprehensive database with information on nekton use of estuarine habitats in the region. To accomplish this, an extensive literature search was first conducted to identify nekton density and abundance data reported in the scientific and grey (e.g., theses, dissertations, reports) literature from studies conducted in the northern Gulf of Mexico. The literature search consisted of a keyword search, an author-based search, and supplemental searches. Using a standard set of screening criteria, identified publications were screened to determine if they contained relevant information on nekton use of estuarine habitats (i.e., marsh, mangrove, oyster reef, SAV, and open-water NVB) in the northern Gulf of Mexico. For the papers that passed the screening criteria, nekton data and associated metadata were extracted and compiled into an electronic database. A 100% quality control check was performed to verify correct data entry. A total of 841 publications were identified from the literature search, of which 119 publications were compiled into the comprehensive database (Figure 3). See Appendix A for more information on the literature search, publication screening, and data compilation methods. See Appendix B for more information on the database.

Figure 3. Location of study sites included in the nekton database, separated by studies conducted in a) marsh, b) oyster reef, c) SAV, and d) open-water NVB habitat. At a particular study site, sampling may be conducted at multiple locations and over multiple seasons. Map excludes study sites that only reported aggregated data across multiple habitat types, salinity zones, or seasons.



2.2 Data Analyses

Following data compilation, a series of analyses were conducted on the compiled dataset to evaluate nekton use across and within four estuarine habitats in the northern Gulf of Mexico, including marsh, oyster reef, SAV, and open-water NVB. Most of the analyses were based on a meta-analytical approach, but some more general data summaries were also conducted. Below, Section 2.2.1 provides a general description of the meta-analytical method, Section 2.2.2 provides an overview of each analysis that was conducted, and Section 2.2.3 provides a summary of the analyses and where they are presented in the guidebook.

2.2.1 General Description of the Meta-Analytical Method

Meta-analysis is a statistical method for combining results from two or more separate studies into a single analysis (Higgins and Green, 2011), and provides the opportunity to find a common pattern if one exists. For example, if a literature search on blue crab densities in marshes yields 15 studies with different results, a meta-analysis might be used to estimate an average density across all the studies or investigate whether other variables explain the variability among these studies. Hence, a meta-analysis may be able to demonstrate if there is a tendency for an intervention, such as marsh restoration, to have a positive effect on an ecosystem. Contrary to site-specific studies, this method allows for identifying commonalities over many locations or time periods.

Meta-analyses are performed using the summarized results reported in individual studies. These include quantitative measures of the magnitude of the parameter of interest, called the effect size, and a measure of its variability, usually the standard error (SE) of the effect size. SEs are important as they are a measure of the precision of the associated effect size and are used in developing weights that capture the quality of the studies. The most precise effect sizes (i.e., those with the lowest SEs) have the highest weights and the least precise have the lowest weights. Then, effect sizes and weights are used to calculate a grand weighted average over all studies or to identify variables that can explain differences among the findings.

In this guidebook, meta-analyses were used to evaluate common patterns in nekton use of habitats, effects of environmental variables on nekton densities, and nekton recovery following restoration.

2.2.2 Overview of the Data Analyses

To support the development of this guidebook, a series of data analyses were conducted with the following objectives:

- Summarize species assemblages within each of the four estuarine habitat types, including marsh, oyster reef, SAV, and open-water NVB
- Understand general patterns of nekton use across and within the four estuarine habitat types
- Understand the effects of key environmental factors on nekton use within marsh and adjacent open-water NVB habitat
- Evaluate recovery of nekton following marsh restoration
- Understand how nekton composition varies across the four estuarine habitat types.

A general overview of each analysis is provided below, with additional information in Appendix C and Hollweg et al. (2019a, 2019b).

2.2.2.1 Summary of Species Assemblages within Estuarine Habitats

This analysis was conducted to summarize species assemblages within marsh, oyster reef, and SAV habitats. To accomplish this, species-level density data from both restored and reference sites reported in the nekton database were aggregated across studies to determine the total density range and relative density values across seasons (i.e., spring, summer, fall, and winter) and salinity zone (i.e., saline, brackish, intermediate, and fresh) for each estuarine habitat type. Seasons were defined as spring (March–May), summer (June–August), fall (September–November), and winter (December–February). Vegetation type (i.e., saline, brackish, intermediate, and fresh; discussed further in Section 3.1) was used as a proxy for salinity zone as it represents average environmental conditions over time rather than a single salinity measurement at a location. Vegetation type was assigned based on the vegetation community at the site, as reported in the paper, following the classification scheme outlined in Visser et al. (1998, 2000, 2002), Enwright et al. (2014), and Sasser et al. (2014). If the vegetation community was not reported, the project location was cross-referenced with available vegetation maps, including the vegetation layers displayed in the Coastwide Reference Monitoring System online viewer (http://lacoast.gov/crms2/home.aspx), and state-specific maps for Louisiana (Sasser et al., 2014) and Texas (Enwright et al., 2014). The results of this analysis are provided in Sections 3.2 (marsh), 4.2 (oyster reef), and 5.2 (SAV).

2.2.2.2 Nekton Use of Estuarine Habitats

This meta-analysis was conducted to understand general patterns of nekton use across and within the four estuarine habitat types (i.e., marsh, oyster reef, SAV, and open-water NVB). Using both restored and reference site data from the database, density values were aggregated across studies to estimate mean densities and SEs for selected taxa within a given habitat (i.e., combination of habitat type and vegetation type) and season (Table 1). These habitat-season combinations were selected based on data availability. These analyses were conducted for total nekton (sum of crustacean and fish species), total crustaceans, total fish, and 50 fish and crustacean taxa. Of the close to 300 species in the database, these 50 taxa were selected due to their high densities, high sample numbers, and/or commercial/recreational importance.

Since sampling gear types vary in their ability to capture target organisms, and their capture ability may differ across different habitat types (Rozas and Minello, 1997), a critical component of this meta-analysis involved correcting density values for gear efficiency before performing the meta-analysis. To accomplish this, habitat-specific gear correction factors were developed for the different gear types included in the database using information from the scientific literature. These correction factors were then applied to the specific density values to calculate a gear-corrected density value. This correction allowed for density values to be standardized and compared across studies. See Appendix C and Hollweg et al. (2019b) for more information on the gear-correction methods and the meta-analytical methods.

Table 1. Habitat-season combinations included in the meta-analysis.

Habitat (and landscape)	Vegetation type[e]	Season[f]	Guidebook section
Marsh edge[a] Marsh interior[b] Open-water NVB near[c] Open-water NVB far[d]	Saline	Spring Fall	Section 3.3.1
Marsh edge and interior	Saline Brackish Intermediate	Spring Fall	Section 3.3.2
Marsh edge and interior	Saline	Spring Summer Fall Winter	Section 3.3.3
Oyster reef	Saline	Spring Fall	Section 4.3
SAV	Saline	Spring Fall	Section 5.3
Marsh edge and interior Oyster SAV Open-water NVB near and far	Saline	Spring Fall	Section 6.1

a. Marsh edge: Located on the vegetated surface < 5 m from the marsh shoreline (i.e., the interface between open-water and emergent vegetation).
b. Marsh interior: Located on the vegetated surface ≥ 5 m inland from the marsh shoreline.
c. Open-water NVB near: Located in the open water < 5 m from the marsh shoreline.
d. Open-water NVB far: Located in the open water ≥ 5 m from the marsh shoreline.
e. Vegetation type (as classified by Visser et al., 1998, 2000, 2002; Sasser et al., 2014; and Enwright et al., 2015; discussed in Section 3.1) was used as a proxy for salinity zone as it represents average environmental conditions over time rather than a single salinity measurement at a location.
f. Season: Spring = March–May, summer = June–August, fall = September–November, winter = December–February.

2.2.2.3 Environmental Factors that Affect Nekton Use

Two sets of meta-analyses were conducted to understand the effects of key environmental factors on nekton use within marsh and adjacent open-water NVB habitat. One analysis looked at the interplay of salinity and temperature on density and the other used distance from the marsh edge as a predictor of taxon density. These meta-analyses were performed on total nekton, total crustaceans, total fish, and selected species for marsh and open-water NVB in the saline zone in fall and spring. Species were selected based on data availability during that specific habitat-season combination. Similar to the other meta-analyses, the approach used density values corrected for gear type. Section 3.4 presents the results of this meta-analysis. See Appendix C for more information on the meta-analytical methods.

2.2.2.4 Nekton Recovery Following Marsh Restoration

This meta-analysis was conducted to evaluate nekton recovery following marsh restoration in the northern Gulf of Mexico. Due to data availability, the meta-analysis focused on two common marsh restoration techniques, including (1) the creation of large-scale marsh that consisted of establishing marsh in open-water or fragmented habitat, and (2) the construction of marsh terraces using onsite subtidal sediment or offsite dredged material.

For this analysis, nekton densities at restored marshes were compared to densities at paired reference marshes for selected taxa. Hence, only studies that included a paired reference marsh were used. Each restored and reference data pair was from the same study, and collected during the same time period using the same gear type. To compare restored and reference site densities, the percentage of the restored site density to that of the reference site density was estimated using the following equation:

$$\%\ of\ reference = \frac{Restored\ Mean\ Density}{Reference\ Mean\ Density}\ x\ 100\%.$$

A value less than 100% indicates the restored site density is less than the reference site density, and a value greater than 100% indicates the restored site density is greater than the reference site density.

Two sets of analyses were performed to assess recovery. The first analysis binned restored site data into two groups, either classified as an "early" time period (equal to or less than five years following restoration) or a "late" time period (greater than five years following restoration). A five-year threshold was used because existing literature suggests that aboveground biomass at restored sites generally recovers within two to five years following restoration (Ebbets et al., 2019; Craft et al., 2002, 2003; Strange et al., 2002). The second analysis investigated recovery trends over time based on the age of the restored site. See Appendix C and Hollweg et al. (2019a) for more information on the meta-analysis methods.

2.2.2.5 Nekton Composition of Estuarine Habitats

This analysis was conducted to understand how nekton composition varies across the four estuarine habitat types. Using mean density values estimated by the meta-analyses (discussed in Section 2.2.2.2), relative densities were calculated at the family-level for each habitat in the saline zone during the spring and fall. Analyses were separated between crustacean and fish, and proportional densities of each crustacean and fish family relative to the summed total density for that group of species within each habitat were calculated. Section 6.2 presents the results of this analysis.

2.2.3 Summary of the Data Analyses

Table 2 provides a summary of the data analyses and where the results are reported in the guidebook.

Table 2. Summary of analyses by habitat and location of results in this guidebook.

	Habitats			
Analyses	Marsh and adjacent open-water habitat	Oyster reef	SAV	Comparison across habitats
Species assemblages	Section 3.2	Section 4.2	Section 5.2	–
Nekton use	Section 3.3	Section 4.3	Section 5.3	Section 6.1
Environmental factors	Section 3.4	–	–	–
Nekton recovery	Section 3.5 (meta-analysis and literature)	Section 4.4 (literature only)	Section 5.4 (literature only)	–
Nekton composition	–	–	–	Section 6.2

3. Nekton Use of Marsh and Adjacent Open-Water Habitat

This chapter provides an overview of nekton use of marsh and adjacent open-water habitat (Figure 4); and how nekton use varies spatially, temporally, by environmental conditions, and following restoration. The chapter is organized as follows:

- Section 3.1 presents an overview of marsh habitat in the Gulf of Mexico
- Section 3.2 presents a summary of species assemblages within marsh habitat by season and salinity zone
- Section 3.3 presents nekton use by:
  - Landscape position (marsh edge/interior and adjacent open-water NVB near/far) within the saline zone during the spring and fall
  - Salinity zone (saline, brackish, and intermediate) within marsh habitat during the spring and fall
  - Season (spring, summer, fall, and winter) within marsh habitat in the saline zone
- Section 3.4 discusses how local environmental factors affect nekton use in marsh and adjacent open-water NVB habitats within the saline zone
- Section 3.5 presents trajectories of nekton recovery following marsh restoration and the factors that may affect recovery rates.

3.1 Overview of Marsh Habitat

The northern Gulf of Mexico is home to a network of saline to freshwater marshes that contain close to 40% of all the coastal wetlands in the contiguous United States (Dahl and Stedman, 2013). The dominant emergent vegetation of the marsh system is driven by long-term salinity trends, and is typically classified into four vegetation types following the classification scheme outlined in Visser et al. (1998, 2000, 2002), Sasser et al. (2014), and Enwright et al. (2015), including:

- Saline marsh – dominated by *Spartina alterniflora*, *Distichlis spicata*, or *Avicennia germinans*
- Brackish marsh – dominated by *Spartina patens*
- Intermediate marsh – dominated by *Leptochloa fusca*, *Panicum virgatum*, *Paspalum vaginatum*, *Phragmites australis*, or *Schoenoplectus americanus*
- Fresh marsh – dominated by *Panicum hemitomon*, *Sagittaria lancifolia*, *Eleocharis baldwinii*, or *Cladium jamaicense*.

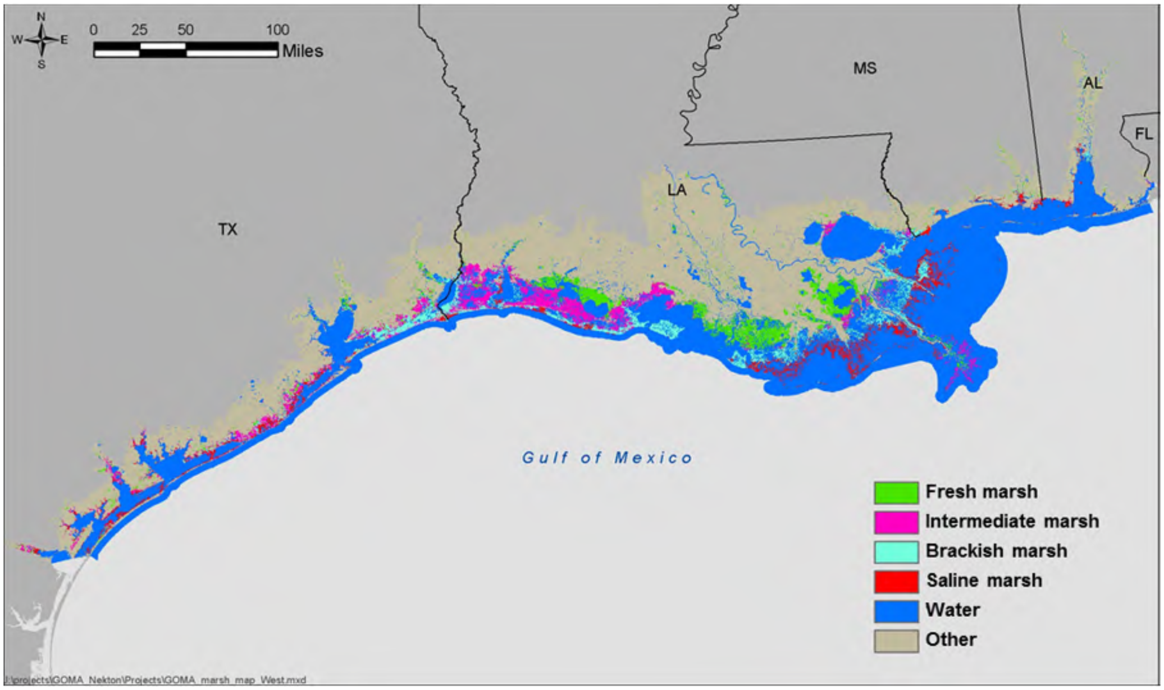
Figure 4. Marsh and adjacent open-water habitat along Florida's Gulf Coast.

Source: www.istockphoto.com.

Coastal marsh systems from Corpus Christi Bay, TX, to Perdido Bay, AL, have been delineated using this classification system (Enwright et al., 2015; Figure 5). Currently, this delineation has not been performed in Florida, but other spatial datasets are available with information on wetland distribution, including the U.S. Fish and Wildlife Service's (USFWS's) National Wetlands Inventory (USFWS, 2019; Figure 6). These vegetation maps reflect the most recent data available; as coastal land is being lost and isohalines are shifting, they may not reflect the vegetation type of past years or decades. In this guidebook, vegetation type (following the classification scheme of Visser et al., 1998, 2000, 2002; Sasser et al., 2014; and Enwright et al., 2015) was used as a proxy for salinity zone in the estuarine system of the northern Gulf of Mexico.

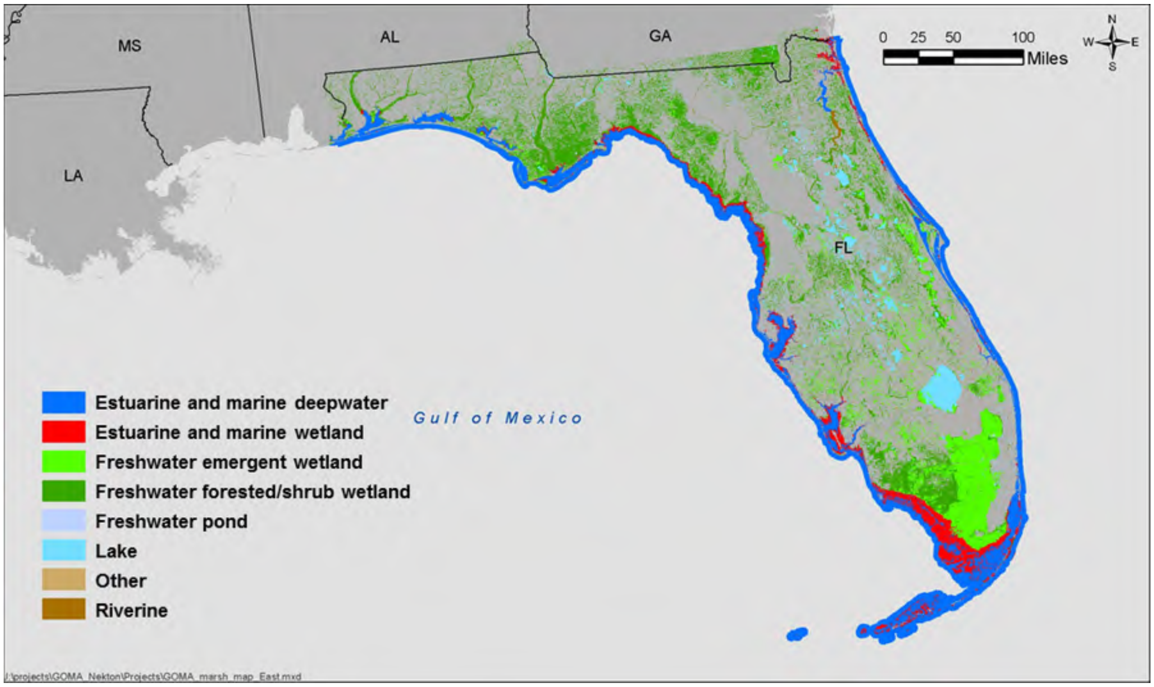
Coastal marshes of the northern Gulf of Mexico are experiencing extensive land loss due to a variety of factors, including the engineering of the Mississippi River, storms, subsidence, relative sea level rise, construction of canals for oil and gas development, and urban and rural development (Boesch et al., 1994; Day et al., 2000, 2007; Dahl and Stedman, 2013). Between 2004 and 2009, the Gulf States lost an estimated 39,000 hectares (approximately 96,400 acres) of saltwater wetlands, with the majority being converted to open-water habitat (Dahl and Stedman, 2013). Although prevalent along all five Gulf States, land loss is greatest in Louisiana (Dahl and Stedman, 2013), with an average annual loss rate of 4,290 hectares (approximately 10,600 acres) between 1985 and 2010 (Couvillion et al., 2011).

Figure 5. Vegetation types from Corpus Christi Bay, TX, to Perdido Bay, AL.



Source: Data layers from Enwright et al. (2015).

Figure 6. Wetland types in Florida based on USFWS's National Wetlands Inventory.



Source: Data from USFWS' National Wetlands Inventory (USFWS, 2019).

To combat this land loss, recent state and federal efforts have focused on marsh restoration. Common types of marsh restoration used in the northern Gulf of Mexico include large-scale marsh creation with dredged material, thin-layer placement of dredged material to increase marsh elevation, and the construction of marsh terraces (Figure 7). Building sediment diversions is another restoration approach, which redirects sediment- and nutrient-rich freshwater from rivers to coastal bays to reestablish the deltaic processes to, in turn, increase the sustainability of the marsh system and build land (CPRA, 2017; Louisiana Trustee Implementation Group, 2018).

Figure 7. Examples of large-scale marsh creation (left) and marsh terraces (right) in the northern Gulf of Mexico.

Source: www.lacoast.gov (left) and www.bing.com/maps (right).

3.2 Summary of Species Assemblages

Marsh habitats within the Gulf of Mexico support numerous fish and crustacean species, from small prey species to larger predators. Some of these species use the marsh during their full life history, such as grass shrimp, mud crabs, killifish, and gobies. Others, however, are transient and only use these vegetated habitats during part of their life history, typically as larvae and juveniles before moving offshore as adults. Commercially and/or recreationally important species that can be found in the marsh habitat include blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), pink shrimp (*Farfantepenaeus duorarum*), striped mullet (*Mugil cephalus*), southern flounder (*Paralichthys lethostigma*), spotted seatrout (*Cynoscion nebulosus*), and red drum (*Sciaenops ocellatus*), to name a few. Based on data compiled in the companion database, Table 3 provides an overview of species assemblage within marsh habitat (including both edge and interior), by season and salinity zone.

3.3 Nekton Use

Nekton use of marsh habitat varies both spatially and temporally, governed by several factors including habitat characteristics, tidal regimes, salinity regimes, and general life history requirements of a species. Below, information is presented on nekton use (total mean density, and densities and relative abundances of select taxa) of the marsh and adjacent open-water habitat in the northern Gulf of Mexico, including by landscape position (Section 3.3.1), salinity zone (Section 3.3.2), and season (Section 3.3.3). Key findings of the meta-analysis are highlighted, with additional information from the scientific literature. For a more in-depth look at how environmental variables affect nekton use within marsh and adjacent open-water NVB habitats, see Section 3.4.

Table 3. Relative density of crustacean and fish species in marsh habitat (edge and interior) by season and salinity zone. Density range (# of individuals per m^2, as reported in the records) and total number of records are also provided. Species sorted by total number of records, in descending order. ● = High relative density (76–100% of observed season or vegetation type maximum), ◖ = Medium relative density (25–75.9% of observed maximum), ○ = Low relative density (1–24.9% of observed maximum), ⦸ = Not present (< 1% of observed maximum), – = No data. Commercial and recreational designations do not necessarily apply across all Gulf States.

Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season				Relative density by salinity zone				Density range (# of ind./m^2)	Total # of records
				Spring	Summer	Fall	Winter	Saline	Brackish	Intermediate	Fresh		
Crustaceans													
Callinectes sapidus	Blue crab	T	C, R	○	◖	●	◖	●	◖	○	●	0–103.6	226
Farfantepenaeus aztecus	Brown shrimp	T	C, R	●	●	◖	○	●	◖	⦸	–	0–28.0	194
Palaemonetes pugio	Daggerblade grass shrimp	R		◖	●	◖	◖	●	◖	○	–	0–238.2	190
Litopenaeus setiferus	White shrimp	T	C, R	○	◖	●	○	●	◖	○	–	0–64.2	152
Palaemonetes intermedius	Brackish grass shrimp	R		◖	○	●	◖	●	◖	○	–	0–29.6	113
Palaemonetes vulgaris	Marsh grass shrimp	R		○	○	●	○	●	●	◖	–	0–34.0	91
Clibanarius vittatus	Thinstripe hermit	R		●	●	●	○	●	⦸	⦸	–	0–8.0	69
Sesarma reticulatum	Heavy marsh crab, purple marsh crab	R		●	○	◖	–	●	○	○	–	0–25.4	68
Farfantepenaeus duorarum	Pink shrimp	T	C	○	◖	●	⦸	●	◖	⦸	–	0–13.6	67
Rhithropanopeus harrisii	Harris mud crab, estuarine mud crab	R		◖	◖	●	–	○	○	●	–	0–43.4	59
Dyspanopeus texanus	Gulf grassflat crab	R		○	○	●	–	●	◖	○	–	0–12.7	55
Uca longisignalis	Gulf marsh fiddler	R		◖	○	●	–	●	○	○	–	0–29.4	52
Alpheus heterochaelis	Bigclaw snapping shrimp	R		○	◖	●	◖	●	⦸	⦸	–	0–9.3	39
Panopeus herbstii	Atlantic mud crab	R		●	●	◖	○	●	◖	⦸	–	0–0.8	38
Uca spp.	Fiddler crabs	R		●	○	◖	○	●	◖	○	○	0–11.6	33
Eurypanopeus depressus	Flatback mud crab	R		○	●	◖	⦸	●	○	⦸	–	0–9.2	32
Armases cinereum	Squareback marsh crab	R		●	●	◖	–	●	⦸	⦸	–	0–3.9	28
Hippolyte zostericola	Zostera shrimp	T		○	–	●	–	●	–	–	–	0–41.0	22
Palaemonetes paludosus	Riverine grass shrimp	R		●	○	○	●	⦸	⦸	●	○	0–43.6	22
Xanthidae spp.	Mud crabs	R		◖	⦸	●	–	⦸	○	●	–	0–42.1	19
Menippe mercenaria	Florida stone crab	T	C, R	◖	●	◖	⦸	●	⦸	–	–	0–0.1	11

Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season				Relative density by salinity zone				Density range (# of ind./m^2)	Total # of records
				Spring	Summer	Fall	Winter	Saline	Brackish	Intermediate	Fresh		
Petrolisthes armatus	Green porcelain crab	R		◖	◖	◖	●	●	–	–	–	0–0.3	10
Tozeuma carolinense	Arrow shrimp	T		○	–	●	–	●	–	–	–	0–35.9	10
Uca pugnax	Atlantic marsh fiddler	R		–	◖	●	–	◖	●	◖	–	0–1.3	10
Eurypanopeus turgidus	Ridgeback mud crab	R		●	–	⊘	–	●	–	–	–	0–0.8	8
Libinia dubia	Longnose spider crab	R		●	◖	●	●	●	–	–	–	0–0.2	8
Macrobrachium ohione	Ohio shrimp	R		○	○	●	–	–	–	●	○	0.1–12.6	7
Petrolisthes galathinus	Banded porcelain crab	R		–	–	●	–	●	–	–	–	0–0.2	6
Uca minax	Redjointed fiddler, red–joint fiddler	R		–	●	○	–	●	⊘	–	–	0–0.7	6
Uca rapax	Mudflat fiddler	R		–	◖	●	–	●	⊘	–	–	0–0.1	6
Menippe adina	Gulf stone crab	T	C, R	◖	–	●	–	●	–	○	–	0–0.2	5
Eurypanopeus abbreviatus	Lobate mud crab	R		–	●	●	–	●	⊘	–	–	0–0.2	4
Callinectes similis	Lesser blue crab	T		●	–	–	–	●	–	–	–	0–1.9	3
Latreutes parvulus	Sargassum shrimp	T		–	–	●	–	●	–	–	–	0–0.1	3
Panopeus simpsoni	Oystershell mud crab	R		◖	◖	●	–	●	–	–	–	0.8–2.5	3
Pinnixa chaetopterana	Tube pea crab	R		–	–	●	–	●	–	–	–	0–0.1	2
Taphromysis bowmani	–	R		●	–	–	–	–	–	●	–	1.4–41.1	2
Fish													
Fundulus grandis	Gulf killifish	R		●	●	●	○	●	◖	●	●	0–4.7	136
Menidia beryllina	Inland silverside	R		●	●	◖	⊘	◖	○	◖	●	0–7.3	136
Mugil cephalus	Striped mullet	T	C, R	●	●	◖	○	◖	◖	●	○	0–2.6	133
Anchoa mitchilli	Bay anchovy	T	C (minor)	●	●	◖	⊘	○	●	⊘	○	0–21.3	132
Cyprinodon variegatus	Sheepshead minnow	R		●	◖	●	○	○	○	◖	●	0–22.7	129
Gobiosoma bosc	Naked goby	R		○	◖	●	○	◖	●	○	–	0–41.1	125
Lagodon rhomboides	Pinfish	T	R	●	○	○	○	●	○	○	–	0–12.0	114
Ctenogobius boleosoma	Darter goby	R		●	○	◖	⊘	●	○	○	○	0–24.5	103
Brevoortia patronus	Gulf menhaden	T	C	◖	●	⊘	○	○	●	●	–	0–164.7	98
Leiostomus xanthurus	Spot	T	C, R	●	○	○	●	●	◖	○	⊘	0–2.9	97
Cynoscion nebulosus	Spotted seatrout	T	C, R	○	●	◖	○	●	◖	⊘	–	0–1.3	80
Symphurus plagiusa	Blackcheek tonguefish	T		○	○	●	⊘	◖	●	◖	–	0–2.7	80

Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season				Relative density by salinity zone				Density range (# of ind./m^2)	Total # of records
				Spring	Summer	Fall	Winter	Saline	Brackish	Intermediate	Fresh		
Lucania parva	Rainwater killifish	R		◖	◖	●	◖	○	◖	●	◖	0–11.9	79
Myrophis punctatus	Speckled worm eel	T		◖	◖	●	⦸	○	○	●	○	0–2.5	78
Paralichthys lethostigma	Southern flounder	T	C, R	●	◖	◖	⦸	●	●	⦸	⦸	0–0.5	75
Micropogonias undulatus	Atlantic croaker	T	C, R	○	○	◖	●	◖	●	○	⦸	0–0.3	72
Adinia xenica	Diamond killifish	R		◖	○	●	–	●	●	◖	–	0–6.8	61
Fundulus pulvereus	Bayou killifish	R		◖	○	●	○	○	●	◖	–	0–7.5	59
Syngnathus scovelli	Gulf pipefish	T		◖	◖	●	–	◖	●	●	–	0–1.7	59
Microgobius gulosus	Clown goby	R		○	○	●	⦸	◖	◖	●	–	0–1.0	48
Sciaenops ocellatus	Red drum	T	C, R	○	○	●	◖	●	●	⦸	–	0–1.0	48
Fundulus similis	Longnose killifish	R		●	●	●	●	●	⦸	○	–	0–1.2	46
Citharichthys spilopterus	Bay whiff	T		●	◖	◖	⦸	○	⦸	○	●	0–0.2	43
Gambusia affinis	Western mosquitofish	R		○	○	○	●	○	○	●	◖	0–6.4	35
Gobiesox strumosus	Skilletfish	R		●	○	○	⦸	●	●	⦸	–	0–5.8	35
Elops saurus	Ladyfish	T		○	●	⦸	⦸	◖	●	●	⦸	0–0.1	33
Opsanus beta	Gulf toadfish	R		◖	●	◖	⦸	●	⦸	⦸	–	0–0.2	33
Bairdiella chrysoura	Silver perch	T	C	◖	●	–	–	◖	●	–	–	0–4.0	32
Poecilia latipinna	Sailfin molly	R		○	–	●	◖	◖	●	◖	–	0–8.6	32
Syngnathus louisianae	Chain pipefish	T		◖	◖	●	–	◖	●	–	–	0–0.5	28
Orthopristis chrysoptera	Pigfish	R		●	⦸	⦸	⦸	●	⦸	–	–	0–0.4	26
Sphoeroides parvus	Least puffer	T		◖	⦸	●	–	●	⦸	⦸	–	0–0.3	26
Ariopsis felis	Hardhead catfish	T	C, R	◖	⦸	●	–	●	●	◖	–	0–0.2	24
Gobiosoma robustum	Code goby	R		◖	–	●	–	◖	⦸	●	–	0–1.2	24
Achirus lineatus	Lined sole	T		⦸	●	◖	⦸	●	⦸	–	–	0–0.1	22
Microgobius thalassinus	Green goby	R		⦸	⦸	●	⦸	●	⦸	⦸	–	0–0.2	22
Membras martinica	Rough silverside	R		●	⦸	⦸	⦸	●	⦸	○	⦸	0–0.6	21
Dormitator maculatus	Fat sleeper	T		◖	●	◖	–	⦸	●	⦸	◖	0–0.1	19
Fundulus jenkinsi	Saltmarsh topminnow	R		●	◖	◖	–	○	○	●	–	0–2.3	17
Heterandria formosa	Least killifish	R		●	○	○	◖	–	–	●	○	0–35.1	17
Archosargus probatocephalus	Sheepshead	T	C, R	●	○	⦸	–	◖	●	–	–	0–0.3	16

Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season				Relative density by salinity zone				Density range (# of ind./m²)	Total # of records
				Spring	Sum-mer	Fall	Winter	Saline	Brack-ish	Inter-mediate	Fresh		
Eucinostomus argenteus	Spotfin mojarra	T		⦸	⦸	●	–	●	⦸	–	–	0–0.4	14
Syngnathus floridae	Dusky pipefish	T		◖	–	●	–	◖	●	⦸	–	0–0.2	13
Cynoscion arenarius	Sand seatrout	T	C, R	⦸	–	●	–	⦸	●	⦸	–	0–0.1	12
Bathygobius soporator	Frillfin goby	R		●	–	○	–	●	⦸	–	–	0–2.0	11
Pogonias cromis	Black drum	T	C, R	⦸	●	⦸	⦸	●	–	–	–	< 0.1	11
Anguilla rostrata	American eel	T		●	–	–	●	●	⦸	○	–	0–0.1	10
Lepomis microlophus	Redear sunfish	R	R	◖	–	●	⦸	–	–	●	–	0–0.7	10
Strongylura marina	Atlantic needlefish	T		●	–	⦸	–	◖	●	⦸	⦸	0–0.2	9
Fundulus chrysotus	Golden topminnow	R		●	⦸	–	●	–	–	●	⦸	0–0.2	8
Lepomis macrochirus	Bluegill	R	R	●	⦸	–	◖	–	–	●	⦸	0–0.4	8
Ctenogobius shufeldti	Freshwater goby	R		◖	●	○	–	–	–	●	●	0.1–1.5	7
Hyporhamphus unifasciatus	Halfbeak, silverstripe halfbeak	T		⦸	●	–	–	⦸	●	–	–	0–0.1	6
Lepomis punctatus	Spotted sunfish	R		●	–	–	◖	–	–	●	–	0–0.1	6
Stellifer lanceolatus	Star drum	T		⦸	●	–	–	⦸	●	–	–	0–0.1	6
Chaetodipterus faber	Atlantic spadefish	T	R	●	⦸	–	–	●	–	–	–	0–0.1	5
Micropterus salmoides	Largemouth bass	R	R	●	–	–	–	–	–	●	–	0–0.1	5
Astroscopus y-graecum	Electric stargazers	T		–	●	–	–	⦸	●	–	–	0–0.1	4
Dorosoma cepedianum	Gizzard shad	T	C (minor)	⦸	●	–	–	–	–	–	●	0–0.1	4
Gobionellus oceanicus	Highfin goby, sharptail goby	R		–	⦸	●	–	–	–	–	●	0–0.2	4
Ictalurus furcatus	Blue catfish	T	C, R	●	–	–	–	⦸	●	–	–	0–0.1	4
Lepomis cyanellus	Green sunfish	R		●	⦸	–	–	⦸	–	●	–	0–0.9	4
Mugil curema	White mullet	T		●	–	–	–	●	–	–	–	0.3–2.6	4
Atractosteus spatula	Alligator gar	T	R	●	–	–	–	⦸	●	●	–	0–0.1	3
Gobiomorus dormitor	Bigmouth sleeper	R		●	–	–	–	●	⦸	⦸	–	0–0.1	3
Conodon nobilis	Barred grunt	T		–	●	–	–	–	⦸	●	–	0–0.3	2
Lepomis megalotis	–	R	–	●	–	–	–	–	–	●	–	0–0.1	2
Oligoplites saurus	Leatherjack	T		–	●	–	–	⦸	●	–	–	0–0.3	2
Stephanolepis hispida	Planehead filefish	T		–	–	●	–	●	–	–	–	0–0.1	2

3.3.1 Landscape Position

In the Gulf of Mexico, the marsh landscape is constantly changing, on both daily and longer timescales. The marsh system includes a matrix of emergent vegetation that is interspersed with ponds, channels, and open-water habitat (Figure 8). As shown in Figure 9, the marsh landscape can be classified into four general areas: (1) the **marsh interior** that is the inner marsh consisting of emergent vegetation with small ponds and channels, (2) the **marsh edge** that is typically fragmented and adjacent to open-water habitat, (3) the **open-water NVB near** habitat that is alongside the marsh edge, and (4) the **open-water NVB far** habitat that is away from the marsh edge and opens up to the larger bays. Nekton are typically able to use the marsh platform during high tides; and then move to ponds, channels, and open-water habitat when the tide lowers (Figure 9).

Figure 8. Marsh landscape along the Louisiana-Texas border.

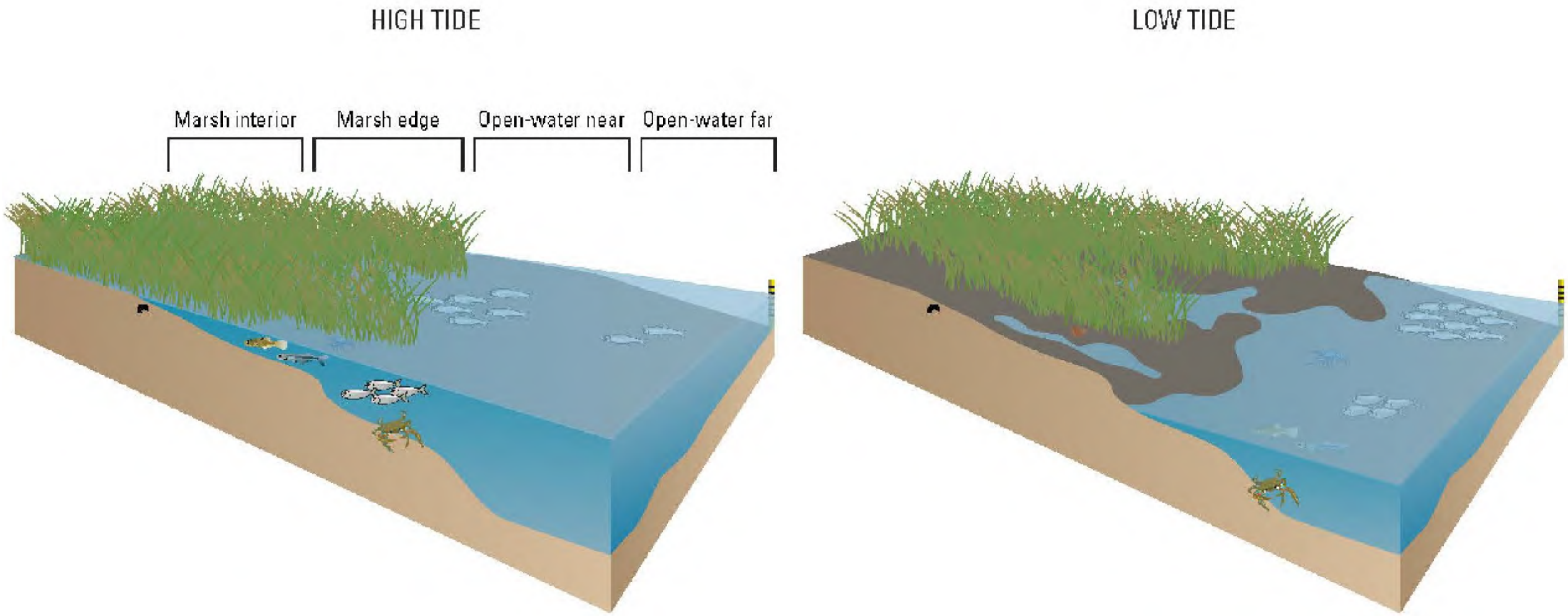
Source: www.istockphoto.com.

Below, key findings of the meta-analysis examining nekton use and distribution across the marsh landscape (marsh edge/interior and open-water NVB near/far habitats) are provided, with additional information from the scientific literature. As discussed in Section 2.2.2.2, the meta-analysis was limited to studies conducted in the saline zone during the spring and fall. For the purposes of this guidebook, the marsh edge was classified as the vegetated surface < 5 m from the marsh shoreline (i.e., the interface between open-water and emergent vegetation), the marsh interior was classified as the vegetated surface ≥ 5 m inland from the marsh shoreline, the open-water NVB near habitat was classified as the open water < 5 m from the marsh shoreline, and the open-water NVB far habitat was classified as the open water ≥ 5 m from the marsh shoreline.

Key finding: Within the saline zone during spring and fall, the marsh edge supports higher total nekton densities compared to marsh interior or open-water NVB habitats. This trend was primarily driven by densities of many crustacean species, whereas density patterns of fish species were more variable across taxa.

In the saline zone, total nekton density was highest in marsh edge habitat, followed by marsh interior habitat, and was lowest in open-water NVB habitat, with a similar pattern observed during both the spring and fall (Figure 10). This trend was driven primarily by total crustacean density, which was more than an order-of-magnitude higher density in marsh edge habitat than open-water NVB far habitat, and higher than both open-water NVB near and marsh interior habitats (Figure 10). Total fish density showed no consistent trend across season, being somewhat higher in open-water NVB near habitat during the spring and relatively comparable across zones in the fall (Figure 10).

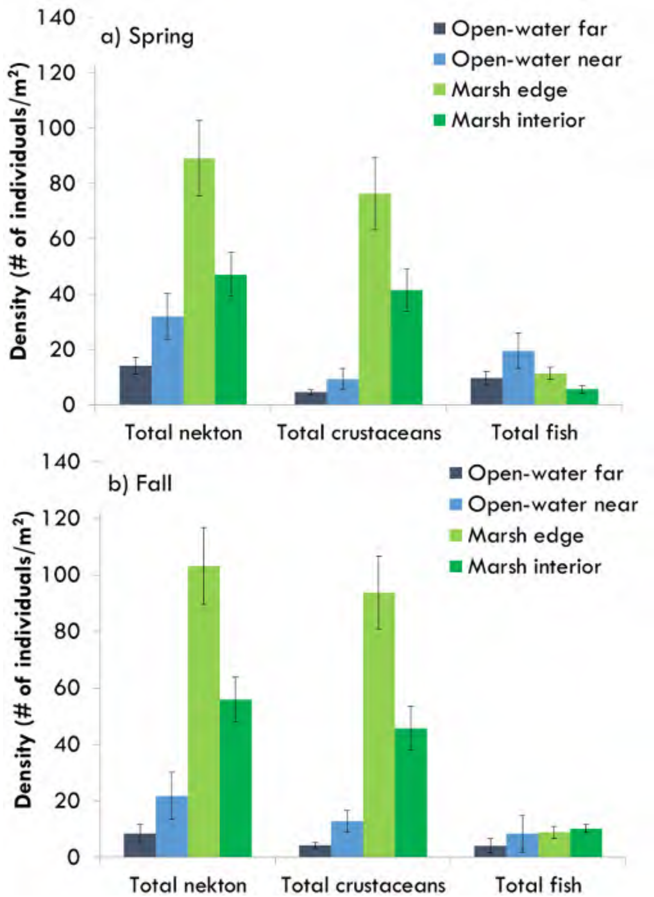
Figure 9. Illustration of the marsh landscape.



Source: Some elements on diagram courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (https://ian.umces.edu/symbols/).

Most crustacean species exhibited relatively higher densities on the marsh edge than in the marsh interior and open-water NVB habitats, including blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), pink shrimp (*Farfantepenaeus duorarum*), white shrimp (*Litopenaeus setiferus*, fall), and daggerblade grass shrimp (*Palaemonetes pugio*) (Figure 11). Density patterns of fish species, on the other hand, were more variable across taxa (Figure 12). Whereas some fish species, such as darter goby (*Ctenogobius boleosoma*), had relatively higher densities at the marsh edge compared to marsh interior or open-water NVB habitats, other species had relatively higher densities in the marsh interior than the other two habitat zones, including sheepshead minnow (*Cyprinodon variegatus*) and Gulf killifish (*Fundulus grandis*). Moreover, bay anchovy (*Anchoa mitchilli*) and Gulf menhaden (*Brevoortia patronus*, spring only) had relatively higher densities in open-water NVB than marsh, with higher densities near the marsh edge than farther away. See Table S1 for the complete list of taxa densities by landscape position. See Section 3.4.2 for more information on nekton use by landscape position.

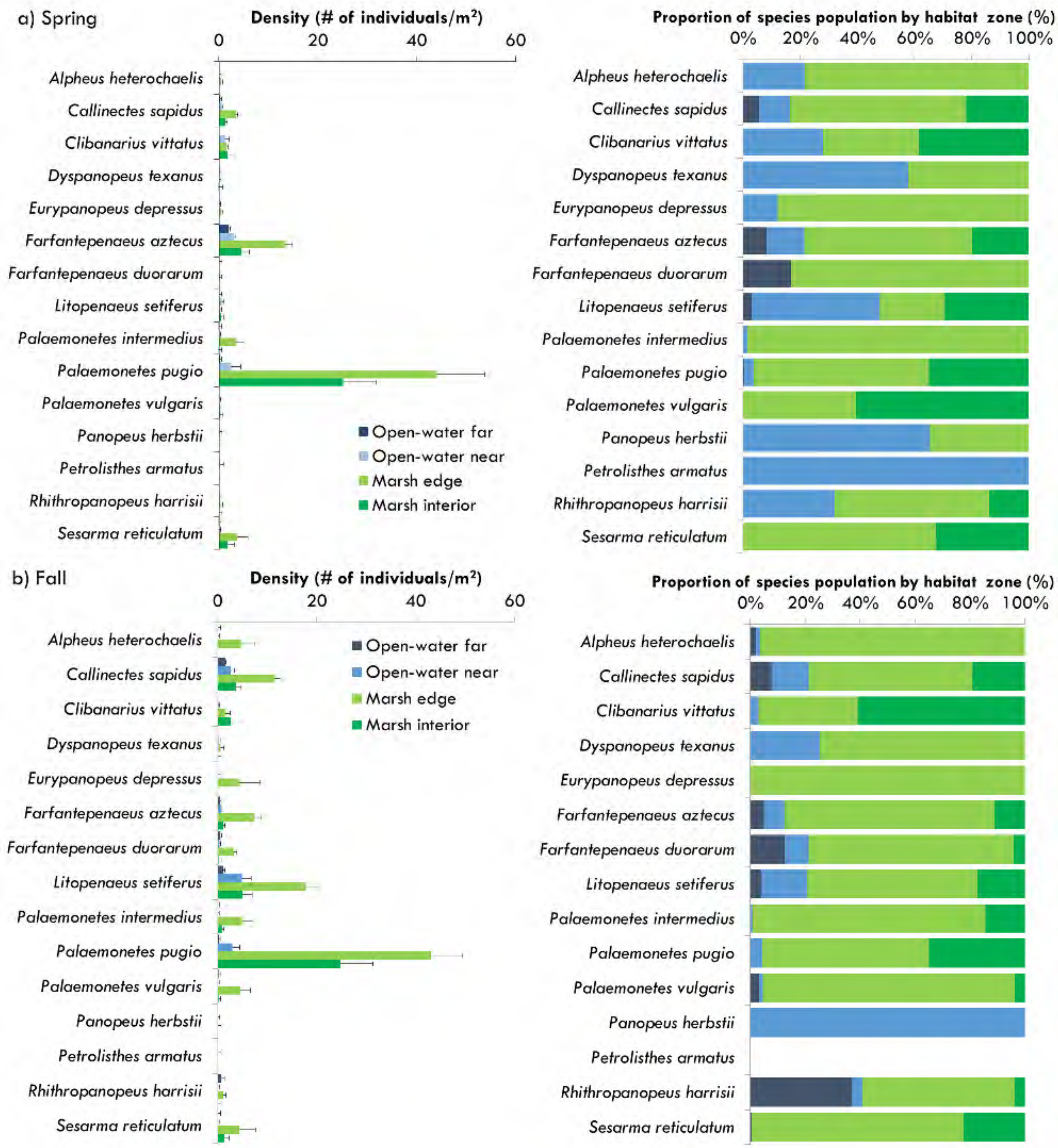
Figure 10. Estimated mean density (# of individuals per m^2 ± 1 SE) of total nekton (sum of crustacean and fish species), total crustaceans, and total fish in open-water NVB ("near" and "far") and marsh ("edge" and "interior") habitats during the a) spring and b) fall. This analysis was limited to sampling conducted in the saline zone.



Source: Figures adapted from Hollweg et al. (2019b).

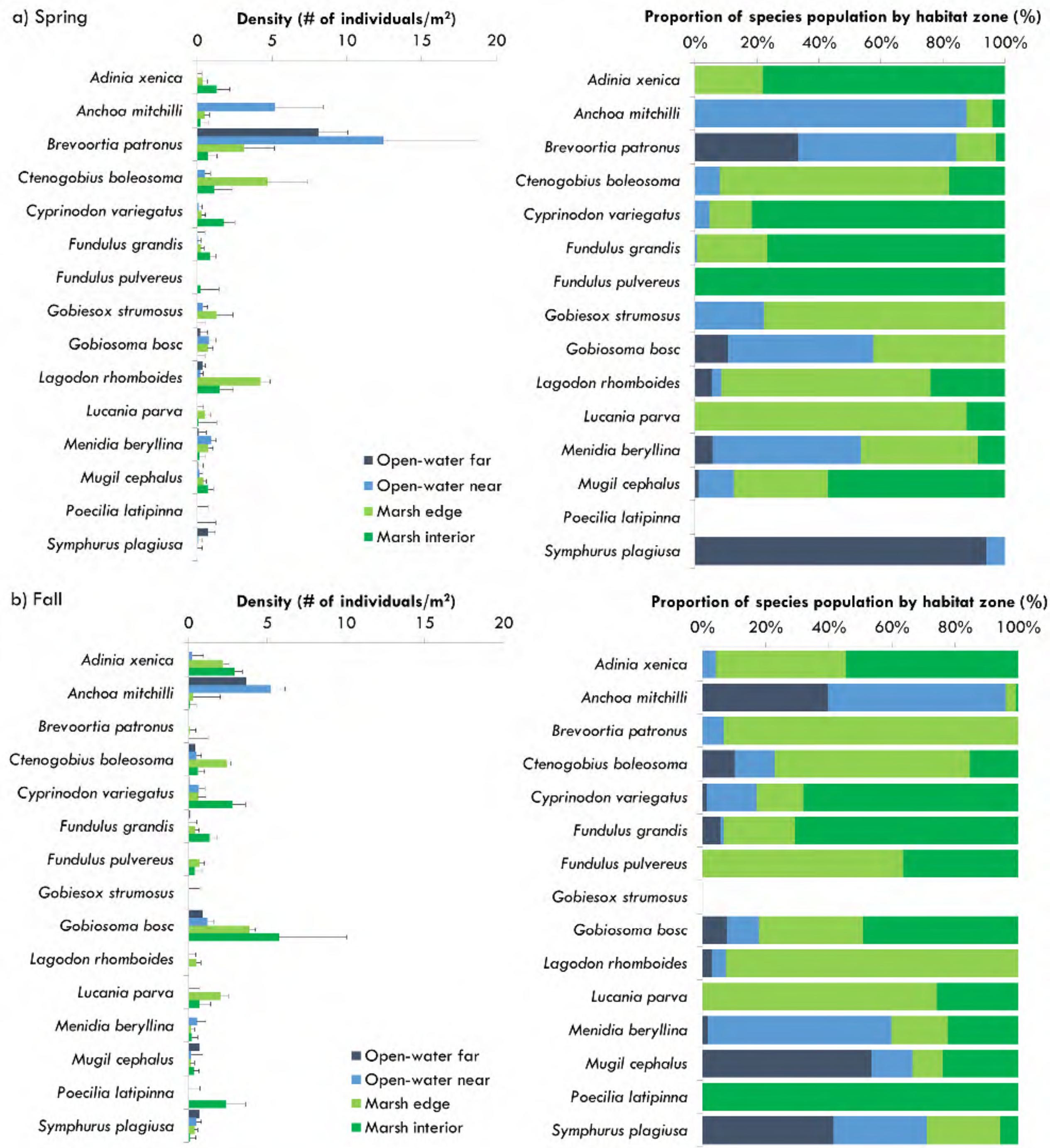
Findings of this meta-analysis are also supported by multiple site-specific studies (many of which were included in this meta-analysis) in the northern Gulf of Mexico (e.g., Baltz et al., 1993; Peterson and Turner, 1994; Minello and Rozas, 2002; Minello et al., 2008). For example, in Galveston Bay, TX, densities of brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), and blue crab (*Callinectes sapidus*) were highest at the marsh edge (on the marsh surface 1 m from the water's edge) and declined rapidly 10 m from the edge into the vegetation (Minello and Rozas, 2002). A similar decline was observed for the same species based on samples collected at 1, 5, 15, 25, and 50 m from the marsh edge into the open water (Minello et al., 2008). These findings are also generally supported by regional and global analyses (Minello, 1999; Minello et al., 2003).

Figure 11. Estimated mean density (# of individuals per m^2 ± 1 SE) and proportion of species population by habitat zone (%) of individual crustacean species in open-water NVB ("near" and "far") and marsh ("edge" and "interior") habitats in the saline zone during the a) spring and b) fall. Of the 50 taxa analyzed, this figure displays the 15 most-abundant crustacean species observed within this habitat-season combination. The proportion of species population by habitat zone (%) was calculated by dividing the species' mean density within one habitat zone by the sum of the species' densities across all four habitat zones. Estimated mean density values for all 50 taxa are presented in Table S1.



Source: Figures adapted from Hollweg et al. (2019b).

Figure 12. Estimated mean density (# of individuals per m^2 ± 1 SE) and proportion of species population by habitat zone (%) of individual fish species in open-water NVB ("near" and "far") and marsh ("edge" and "interior") habitats in the saline zone during the a) spring and b) fall. Of the 50 taxa analyzed, this figure displays the 15 most-abundant fish species observed within this habitat-season combination. The proportion of species population by habitat zone (%) was calculated by dividing the species' mean density within one habitat zone by the sum of the species' densities across all four habitat zones. Estimated mean density values for all 50 taxa are presented in Table S1.



Source: Figures adapted from Hollweg et al. (2019b).

Key finding: The saline marsh edge supports many transient species, including those that are commercially and recreationally important.

Many of the nekton that exhibit higher densities in the saline marsh edge compared to marsh interior and open-water NVB are transient species that support Gulf of Mexico commercial and recreational fisheries, including blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), pink shrimp (*Farfantepenaeus duorarum*), white shrimp (*Litopenaeus setiferus*, fall), and spotted seatrout (*Cynoscion nebulosus*, fall) (Figure 11 and Figure 12, Table S1). However, some resident species also exhibit higher densities in the saline marsh edge, including grass shrimp (*Palaemonetes pugio*), darter goby (*Ctenogobius boleosoma*), and rainwater killifish (*Lucania parva*) (Figure 11 and Figure 12, Table S1), but this trend is not consistent across all taxa. Some resident species were more abundant in the marsh interior, including sheepshead minnow (*Cyprinodon variegatus*), gulf killifish (*Fundulus grandis*), and sailfin molly (*Poecilia latipinna*, fall) (Figure 11 and Figure 12, Table S1).

Additional considerations: Nekton density patterns across the landscape are related to biotic and abiotic factors, including prey availability, refuge, site accessibility, and site hydrology/elevation.

Prey availability. Marsh habitat is known to serve as a key food source for many estuarine species (Boesch and Turner, 1984; Minello and Zimmerman, 1991; Deegan et al., 2000; Zimmerman et al., 2000). Benthic infauna, important prey species for many fish and crustaceans, have been found to be most abundant at the marsh edge (Minello et al., 1994; Whaley and Minello, 2002). A significant positive relationship has also been observed between crustacean density and infauna density (Minello and Zimmerman, 1992).

Refuge. Due to its inherent structure, marsh vegetation provides fish and crustacean species protection from larger predators (Boesch and Turner, 1984; Minello and Zimmerman, 1991; Deegan et al., 2000; Zimmerman et al., 2000). Lower mortality rates have been measured in vegetated habitats than unstructured habitats (e.g., Minello and Zimmerman, 1991; Zimmerman et al., 2000; Minello et al., 2003). Smaller resident species may move to interior marsh sites to seek refuge from predators (such as larger transient species) during high tides (Peterson and Turner, 1994).

Site accessibility. Transient species may prefer to occupy edge habitats so they can quickly exit the marsh during low tides (Kneib and Wagner, 1994; Peterson and Turner, 1994; Kneib, 1997).

Site hydrology and elevation. The marsh hydroperiod is known to affect nekton use of salt marsh habitat (Rozas, 1995). Several field and modeling studies point to marsh elevation and flooding patterns as important indicators of their value for and use by nekton (e.g., Rozas and Reed, 1993; Kneib and Wagner, 1994; Rozas and Zimmerman, 2000; Roth et al., 2008; Minello et al., 2012; Baker et al., 2013; Rozas and Minello, 2015). In the northern Gulf of Mexico, in particular, low marsh elevations allow for the direct use of the marsh platform by nekton over a relatively long time period compared to East Coast marshes (Zimmerman et al., 2000).

Additional considerations: Nekton density patterns across the landscape may differ across the region.

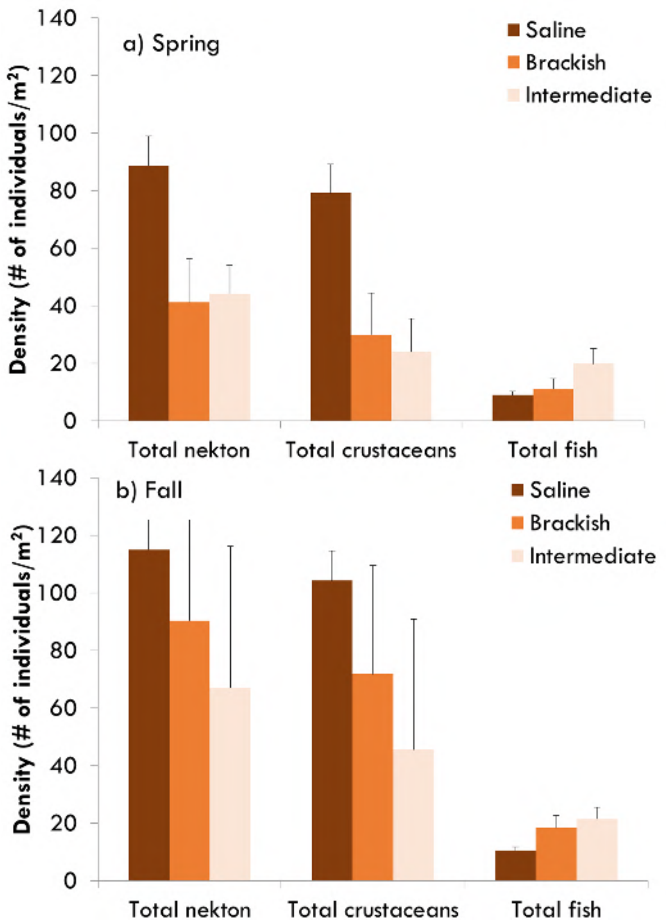
Recent studies have suggested that the trend of higher nekton densities at the marsh edge is not necessarily consistent across marsh systems in the northern Gulf of Mexico (Rozas et al., 2012; Rozas and Minello, 2015). Rozas and Minello (2015) found that nekton patterns in Barataria Bay marsh systems appeared to differ from those of Galveston Bay, with densities of white shrimp

(*Litopenaeus setiferus*), brown shrimp (*Farfantepenaeus aztecus*), and blue crab (*Callinectes sapidus*) not always highest at the marsh edge within the Barataria Bay system. Explanations for these potential differences include marsh elevation and slope, which influence flooding patterns of the marsh surface (Rozas and Minello, 2015).

3.3.2 Salinity Zone

As discussed in Section 3.1, salinity has a strong influence on the vegetative composition of the marsh. In addition, salinity is also known to affect nekton use and distribution within an estuarine system. Key factors that drive these patterns are physiological tolerances of the species (e.g., osmoregulation); as well as the distribution of prey, predators, and competitors in the system (e.g., Werner et al., 1983; McIvor and Odum, 1988; Lima and Dill, 1990; Dunson and Travis, 1991; Schmidt-Nielsen, 1997). Below, key findings of the meta-analysis examining nekton use and distribution across salinity zones are provided, with additional information from the scientific literature. As discussed in Section 2.2.2.2, the meta-analysis was limited to studies conducted on the marsh platform (edge and interior) during the spring and fall.

Figure 13. Estimated mean density (# of individuals per m^2 ± 1 SE) of total nekton (sum of crustacean and fish species), total crustaceans, and total fish in saline, brackish, and intermediate marshes during the a) spring and b) fall. For comparison, this analysis was limited to sampling conducted on the marsh platform (edge and interior).



Source: Figures adapted from Hollweg et al. (2019b).

Key finding: During the spring and fall, total nekton density was highest in the saline marsh zone compared to brackish and intermediate zones, primarily driven by total crustacean density.

Total nekton density was highest in the saline marsh zone compared to brackish and intermediate zones during both the spring and fall, primarily driven by total crustacean density (Figure 13). In contrast, total fish density had an inverse relationship with salinity, with higher densities observed in intermediate marsh compared to saline and brackish marshes (Figure 13).

Similar to the results of the meta-analysis, a site-specific study (which was included in the meta-analysis) in Barataria Bay, LA, found that for sampling conducted on the marsh platform, saline and brackish marshes supported higher total nekton densities than in the intermediate zone (Rozas and Minello, 2010). However, this pattern does not appear to remain constant when moving from the marsh to the open-water habitat of adjacent marsh ponds (e.g., Rozas and Minello, 2010; Hitch et al., 2011; Kang and King, 2013). For these sites, the authors observed differences in nekton use across habitats that were related to salinity as well as other habitat attributes, including SAV, dissolved oxygen, and hydrologic connectivity (Rozas and Minello, 2010; Hitch et al., 2011; Kang and King, 2013).

Key findings: Saline and brackish marshes support high densities of many commercially and recreationally important species.

Several commercially and recreationally important crustacean and fish species exhibited higher relative densities in saline and/or brackish marshes compared to intermediate zones (Figure 14 and Figure 15, Table S2), including blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), pink shrimp (*Farfantepenaeus duorarum*), white shrimp (*Litopenaeus setiferus*), sheepshead (*Archosargus probatocephalus*, spring), spotted seatrout (*Cynoscion nebulosus*, fall), spot (*Leiostomus xanthurus*, spring), southern flounder (*Paralichthys lethostigma*, spring), and red drum (*Sciaenops ocellatus*, fall). For example, blue crab (*Callinectes sapidus*) and penaeid shrimp make up a significant fraction of the commercial fishery landings in the Gulf of Mexico (Chesney et al., 2000; O'Connell et al., 2005; NMFS, 2018); and spotted seatrout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellatus*), and southern founder (*Paralichthys lethostigma*) are important targets of recreational fisheries (O'Connell et al., 2005; NMFS, 2018). These results provide further support for the notion that saline and brackish marshes in the northern Gulf of Mexico are vital habitats for many ecologically and commercially important species (Rozas and Minello, 2010). See Table S2 for the complete list of taxa densities by salinity zone.

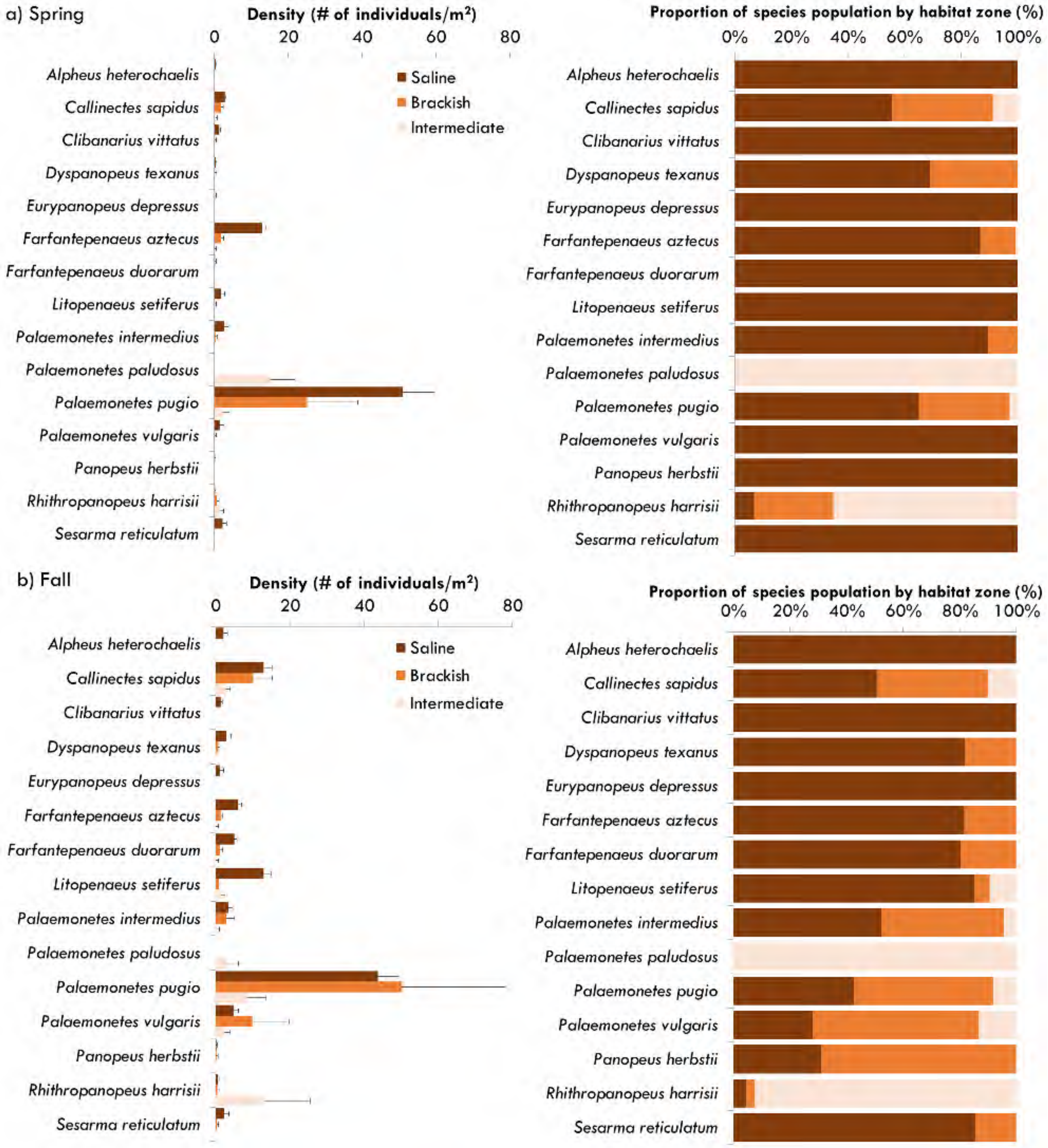
Additional considerations: The intermediate zone, while exhibiting lower nekton densities overall, should not be dismissed for its importance to coastal fisheries. Reasons include life history requirements of some species, the large area of the intermediate zone, and the potential for changing environmental conditions.

Life history requirements of some species. Several fishery species use low-salinity zones in Gulf of Mexico estuaries during some portion of their life cycle (e.g., Felley, 1987; Rozas and Minello, 2010). For example, Gulf menhaden (*Brevoortia patronus*), the dominant species contributing to commercial landings in the Gulf of Mexico and serving an important ecological role as prey for many other species (Chesney et al., 2000; O'Connell et al., 2005; VanderKooy and Smith, 2015; NMFS, 2018), exhibited high densities in the intermediate zone during the spring (Figure 15). A relationship between salinity and size has also been observed in estuaries, with some transient species moving to higher-salinity waters as they mature (e.g., Gunter, 1961; Rogers et al., 1984; Able et al., 2001; Upchurch and Wenner, 2008).

Large area of the intermediate zone. While overall densities of some species may be lower, the large area of intermediate marsh in the northern Gulf of Mexico (~ 28% of the total marsh area from Corpus Christi Bay, TX, to Perdido Bay, AL; Enwright et al., 2015) makes it a significant contributor to fisheries production in the region (Mace and Rozas, 2017).

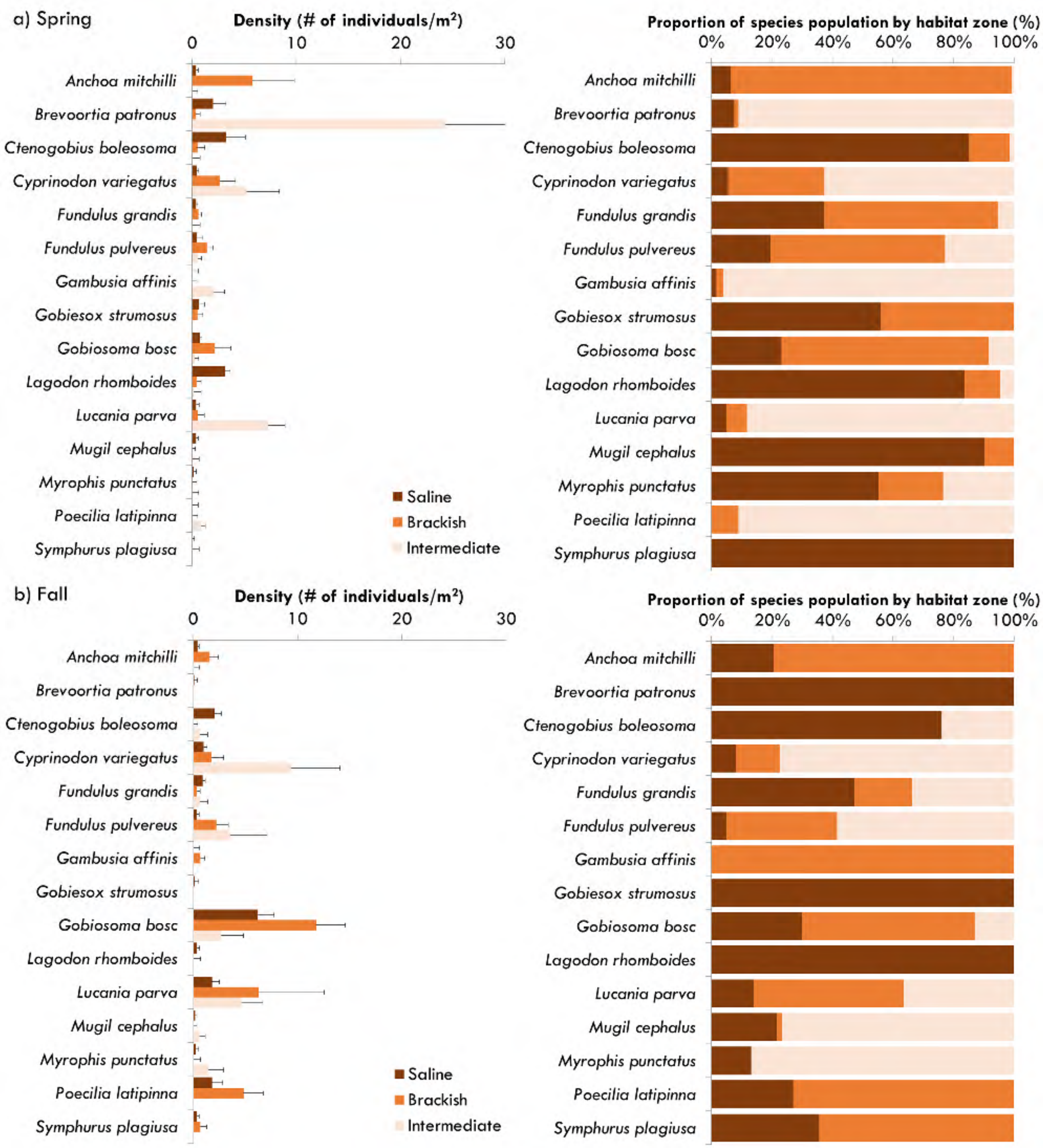
Potential for changing environmental conditions. In drought years when the estuarine isohalines shift inland, these intermediate zones may serve as important habitat to fishery species that favor more saline conditions (Mace and Rozas, 2017).

Figure 14. Estimated mean density (# of individuals per m^2 ± 1 SE) and proportion of species population by habitat zone (%) of individual crustacean species in saline, brackish, and intermediate marshes during the a) spring and b) fall. Of the 50 taxa analyzed, this figure displays the 15 most-abundant crustacean species observed within this habitat-season combination. The proportion of species population by habitat zone (%) was calculated by dividing the species' mean density within one habitat zone by the sum of the species' densities across all three habitat zones. For comparison, this analysis was limited to sampling conducted on the marsh platform (edge and interior). Estimated mean density values for all 50 taxa are presented in Table S2.



Source: Figures adapted from Hollweg et al. (2019b).

Figure 15. Estimated mean density (# of individuals per m^2 ± 1 SE) and proportion of species population by habitat zone (%) of individual fish species in saline, brackish, and intermediate marshes during the a) spring and b) fall. Of the 50 taxa analyzed, this figure displays the 15 most-abundant fish species observed within this habitat-season combination. The proportion of species population by habitat zone (%) was calculated by dividing the species' mean density within one habitat zone by the sum of the species' densities across all three habitat zones. For comparison, this analysis was limited to sampling conducted on the marsh platform (edge and interior). Estimated mean density values for all 50 taxa are presented in Table S2.



Source: Figures adapted from Hollweg et al. (2019b).

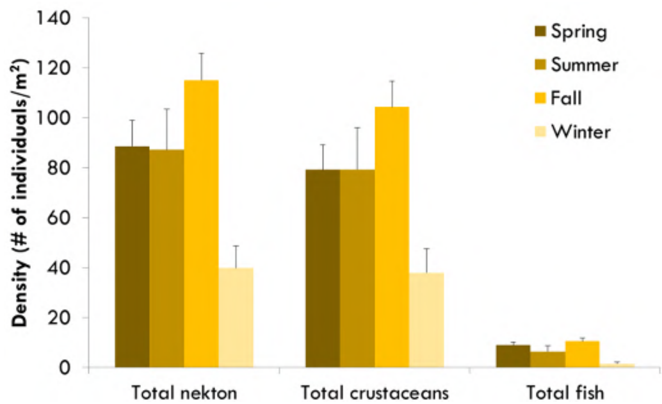
3.3.3 Season

The season is also a key determinant of nekton densities in the estuarine zone, driven by changes in overall system productivity and a species' life history cycle (e.g., reproduction, recruitment, migration). Below, key findings of the meta-analysis examining nekton use across seasons are provided, with additional information from the scientific literature. As discussed in Section 2.2.2.2, the meta-analysis was limited to studies conducted on the marsh platform (edge and interior) in the saline zone.

Key finding: Within the saline zone, total nekton densities in marsh habitat were highest during the spring, summer, and fall. However, seasonal trends varied by species.

Within the saline zone, total nekton density, total crustacean density, and total fish density in marsh habitat were relatively higher during the spring, summer, and fall, and decreased during the winter (Figure 16). While some species showed a strong seasonal trend, others had relatively similar densities throughout the year (Figure 17). See Table S3 for a complete list of taxa densities by season.

Figure 16. Estimated mean density (# of individuals per m^2 ± 1 SE) of total nekton (sum of crustacean and fish species), total crustaceans, and total fish in saline marshes during the spring, summer, fall, and winter. For comparison, this analysis was limited to sampling conducted on the marsh platform (edge and interior).

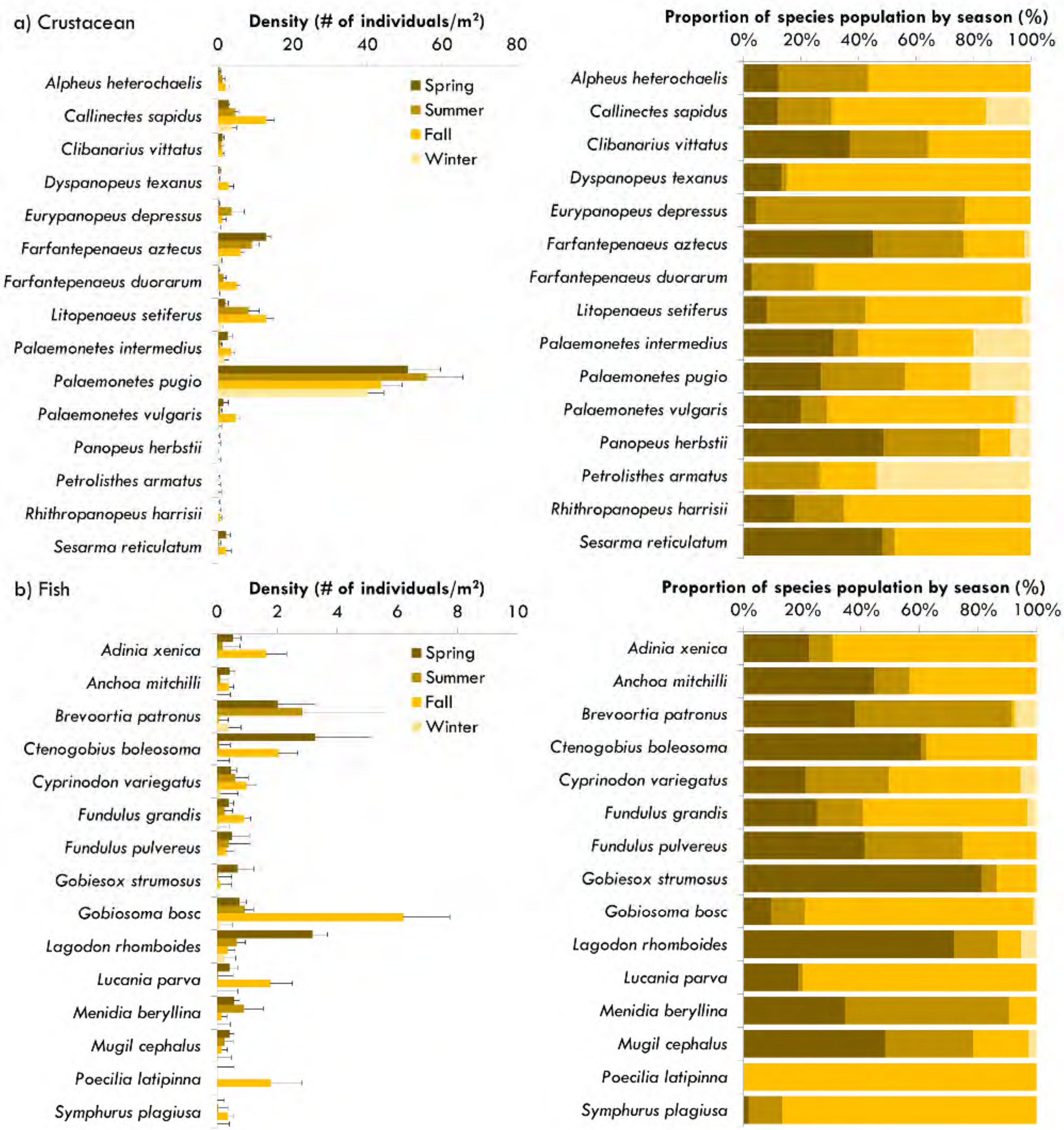


Source: Figures adapted from Hollweg et al. (2019b).

Key-finding: Seasonal trends reflect species-specific life history patterns.

In saline marshes, seasonal patterns of nekton abundance reflect species-specific life history patterns. Several fish and crustacean species peaked in abundance during the spring and fall months, which is indicative of the seasonal recruitment to that habitat. Pinfish (*Lagodon rhomboides*), for example, migrate offshore to spawn in the late fall and winter, with first-year juveniles migrating to estuaries in the spring and summer (Muncy, 1984; Pattillo et al., 1997). Other species that have similar life history patterns (i.e., spring recruitment) include brown shrimp (*Farfantepenaeus aztecus*), Gulf menhaden (*Brevoortia patronus*), and spot (*Leiostomus xanthurus*), to name a few (Pattillo et al., 1997). For these species, peaks in densities were observed during the spring and summer months (Figure 17, Table S3). Several transient species also recruit to estuaries in the late summer and fall, and then migrate to deeper waters as adults, including pink shrimp (*Farfantepenaeus duorarum*), white shrimp (*Litopenaeus setiferus*), spotted seatrout (*Cynoscion nebulosus*), and red drum (*Sciaenops ocellatus*) (Pattillo et al., 1997). For these species, peaks in densities were observed during the summer and fall months (Figure 17, Table S3). Similar trends in seasonal abundance were documented over an 11-year study in a salt marsh in Galveston Island, TX, by Rozas et al. (2007).

Figure 17. Estimated mean density (# of individuals per m² ± 1 SE) and proportion of species population by season (%) of individual a) crustacean and b) fish species in saline marshes during the spring, summer, fall, and winter. Of the 50 taxa analyzed, this figure displays the 15 most-abundant fish species and 15 most-abundant crustacean species observed within this habitat-season combination. The proportion of species population by season (%) was calculated by dividing the species' mean density during one season by the sum of the species' densities across all four seasons. For comparison, this analysis was limited to sampling conducted on the marsh platform (edge and interior). Estimated mean density values for all 50 taxa are presented in Table S3.



Source: Figures adapted from Hollweg et al. (2019b).

3.4 Environmental Factors that Affect Nekton Use of Marsh and Open-Water NVB Habitats

Salinity and temperature are important factors affecting nekton density and diversity. Salinity directly affects the physiology and growth of nekton species (Able and Palmer, 1988). Salinity can also have indirect effects through impacts on the type of marsh vegetation present (Rountree and Able, 2007). Temperature also has direct physiological and growth effects (O'Connor et al., 2009), and its variability is closely related to seasonal oscillations. Another important factor on nekton density and composition is the location across the open-water marsh landscape (Minello et al., 2008). As presented in the sections above, there are clear differences in nekton density and composition across salinity zones and seasons, and moving from adjacent open-water NVB habitat to the marsh edge and into the marsh interior. In this section, further analyses of the relationships between nekton density and salinity, temperature, and location along the open-water marsh landscape are presented. Other factors such as site conditions (e.g., hydro-period, elevation) and habitat conditions (e.g., vegetation, soil, water quality), among others, may also affect nekton use of estuarine habitats (see Section 7.2); however, these variables were not included in the meta-analyses.

First, Section 3.4.1 examines how densities of total nekton, total crustaceans, total fish, and selected species vary with salinity and temperature. This section also addresses whether there are non-additive (i.e., interactive) effects of salinity and temperature on nekton density and, if so, their magnitude and nature. Second, Section 3.4.2 presents a more sensitive analysis of nekton density through the open-water marsh landscape. To do that, rather than grouping the density data into different distance intervals across the landscape (as conducted in Section 3.3.1), nekton density was regressed against the distance from the marsh edge where the nekton were collected. To facilitate data interpretation, the analysis examined (1) changes in density from the marsh edge into the marsh interior, and (2) changes in density from the marsh edge into the open water.

3.4.1 Salinity and Temperature

Both through direct and indirect processes, salinity and temperature are major factors affecting the density and composition of nekton in coastal systems. In the Gulf of Mexico, salinity varies spatially from inland tidal riverine headwaters to open Gulf waters. Salinity also varies temporally, following intense and prolonged rain periods, and seasonally as a result of increased river discharge in the spring (Lartigue et al., 2003). Spatial (from warmer inland reaches to the colder, open ocean) and temporal (seasonal) variability also exists for water temperature (Osland et al., 2017). The extent of spatial and temporal variability can be large for both salinity and temperature, even across small areas or short time periods. Furthermore, changes in salinity and temperature can interact with one another and lead to large and complex impacts on coastal nekton populations.

Much work has been done on single and interactive effects of salinity and temperature on nekton communities. The sections above examined how the density of total nekton, crustaceans, and fish, as well as several individual species, varies across distinct salinity zones (Section 3.3.2) and seasons (Section 3.3.3). The results corroborate the importance of these factors on the nekton community, and show trends regarding the distribution of nekton across salinity zones and seasons. Below, further analyses are presented that examine the interactive effects of temperature and salinity on total nekton, total crustacean, and total fish densities; and also for densities of selected species. Key findings of the meta-analysis are highlighted, with additional information from the scientific literature. As discussed in Section 2.2.2.3, the meta-analysis was limited to studies conducted on the marsh platform (edge and interior) and open-water NVB in the saline zone during the spring and fall.

Key finding: Complex, interactive effects of temperature and salinity often exist for the total communities of nekton, crustacean, and fish; and also for selected species.

There is a statistically significant interactive effect of temperature and salinity on total nekton density, total fish density, and total crustacean density for marshes in both seasons and for open-water NVB in fall (Table 4, Figures 18–21). For individual species, there was more variability in whether there was an interactive effect of temperature and salinity on density. In marsh in the spring, the density of five out of the seven species examined showed an interactive impact of temperature and salinity (Table 4, Figure 18). In marsh in the fall, the density of three out of the four species examined showed an interactive impact of temperature and salinity (Table 4, Figure 19). In open-water NVB in the spring, the density of two out of the seven species examined showed an interactive impact of temperature and salinity (Table 4, Figure 20). For open-water NVB in the fall, the density of two out of the four species examined showed an interactive impact of temperature and salinity (Table 4, Figure 21). Together, these results demonstrate that one factor, temperature or salinity, often influences how density responds to the other factor; thus, both factors should be considered when addressing coastal nekton communities.

Key finding: Despite the common occurrence of temperature and salinity effects on nekton density, the exact nature and extent of the effects varied widely across taxa, marsh landscape, and seasons.

There was substantial variation regarding the exact relationships between temperature, salinity, and density for the various taxonomic groupings considered, both when comparing taxa within the same habitat in the marsh landscape (marsh or NVB) and season (spring or fall), or when comparing habitats and seasons for a specific taxon (Table 4, Figures 18–21). In some instances, the interaction between temperature and salinity was positive, in others the interaction was negative, and for the remainder there was no interaction, implying that the effects of temperature and salinity were strictly additive (Table 4, Figures 18–21). These results show that the exact nature and strength of the association between nekton density, temperature, and salinity varies with taxon, habitat, and season. Some of this variation is likely due to true variability among taxa, habitats, or seasons, but it is important to keep in mind that some might be due to the availability and quality of the data on which these analyses were based. Further research into whether there are other environmental variables of importance should be considered.

Comparison of results with existing literature

Numerous studies have addressed the single and combined effects of temperature and salinity on nekton species, including density, prey-predator dynamics, growth, reproduction, and other physiological processes (Valiela, 2015). However, most of these studies have focused on fewer species or communities than encompassed here. The results of this meta-analysis corroborate the importance of temperature and salinity for nekton species. In addition, these results show the prevalence of interactive effects between temperature and salinity on nekton density at all taxon levels. Such effects have been reported in several studies, and the results of this meta-analysis provide further support.

Table 4. The effect of salinity and temperature, and their interaction on taxon density for selected nekton taxa. The statistical models used the square-root transformation of density to obtain approximate normality in order to perform hypothesis testing. If the interaction term was non-significant, a no interaction model was run with only the main effects of salinity (S) and temperature (T). Significant positive and negative relationships are indicated, respectively, by “+” and “-” symbols. Non-significant relationships are indicated by “NS.”

			Interaction model			No interaction model	
Taxon	Habitat type	Season	S	T	S x T	S	T
Total nekton	Marsh	Spring	+	+	+		
		Fall	+	+	+		
	Open-water NVB	Spring	NS	NS	NS	NS	–
		Fall	–	–	+		
Total crustaceans	Marsh	Spring	+	+	–		
		Fall	+	+	–		
	Open-water NVB	Spring	–	–	+		
		Fall	–	–	+		
Callinectes sapidus	Marsh	Spring	NS	NS	NS	+	–
		Fall	NS	NS	NS	–	NS
	Open-water NVB	Spring	–	–	+		
		Fall	–	–	+		
Farfantepenaeus aztecus	Marsh	Spring	+	+	–		
	Open-water NVB	Spring	–	–	+		
Litopenaeus setiferus	Marsh	Fall	–	–	+		
	Open-water NVB	Fall	–	–	+		
Palaemonetes pugio	Marsh	Spring	+	+	–		
		Fall	+	+	–		
	Open-water NVB	Spring	NS	NS	NS	–	–
		Fall	NS	NS	NS	NS	NS
Total fish	Marsh	Spring	+	+	–		
		Fall	+	+	–		
	Open-water NVB	Spring	NS	NS	NS	+	NS
		Fall	–	–	+		
Anchoa mitchilli	Marsh	Spring	NS	NS	NS	NS	NS
		Fall	+	+	–		
	Open-water NVB	Spring	NS	NS	NS	+	NS
		Fall	NS	NS	NS	–	NS
Brevoortia patronus	Marsh	Spring	–	–	+		
	Open-water NVB	Spring	NS	NS	NS	NS	NS
Lagodon rhomboides	Marsh	Spring	+	+	–		
	Open-water NVB	Spring	NS	NS	NS	+	–
Mugil cephalus	Marsh	Spring	+	+	–		
	Open-water NVB	Spring	NS	NS	NS	NS	NS

Figure 18. Contour plots for back-transformed density (# of individuals per m^2) for marshes in the spring against temperature (T) and salinity (S). Significant explanatory variables (α = 0.10) are listed in the upper corner of the plots.

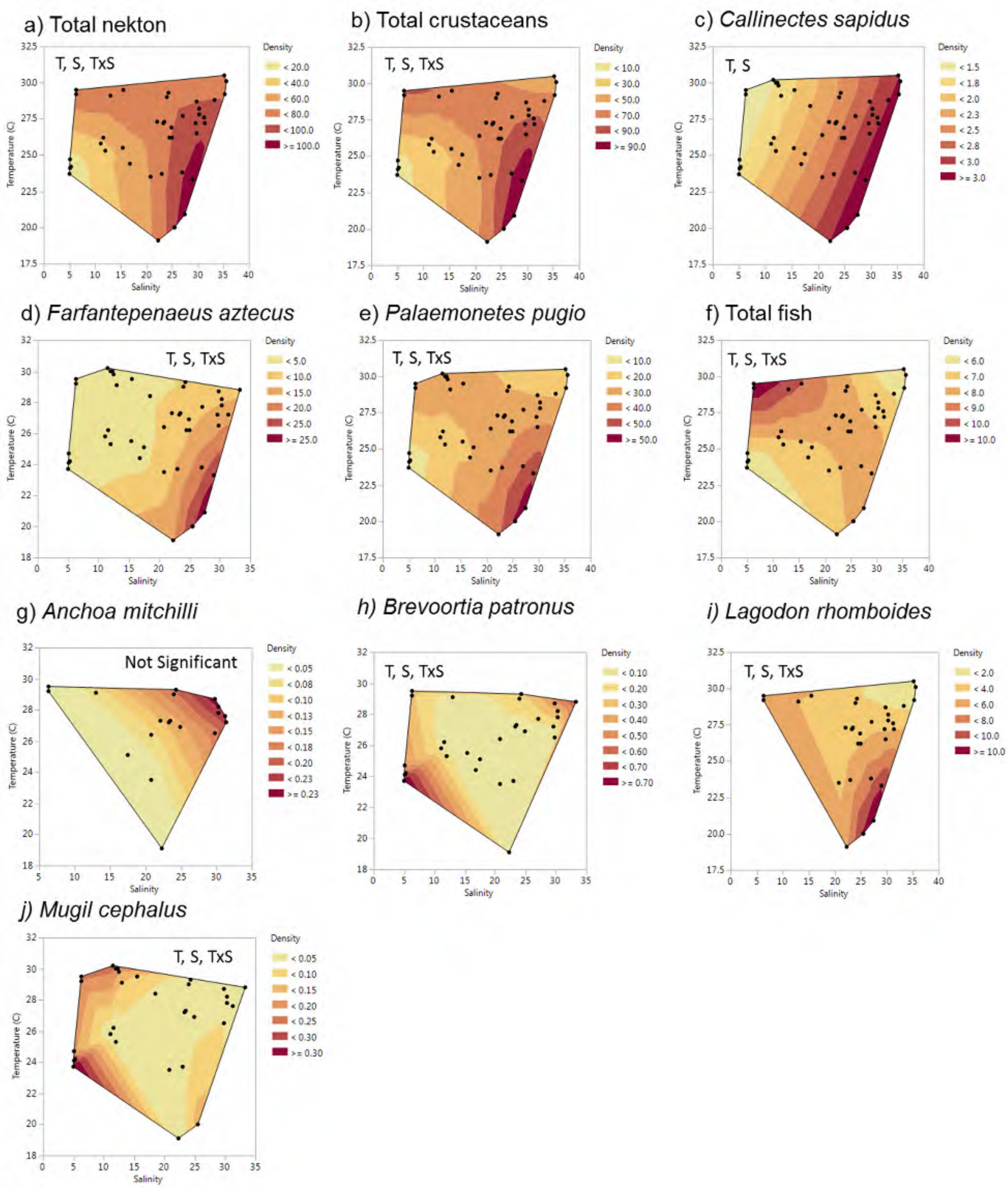


Figure 19. Contour plots for back-transformed density (# of individuals per m²) for marshes in the fall against temperature (T) and salinity (S). Significant explanatory variables (α = 0.10) are listed in the upper corner of the plots.

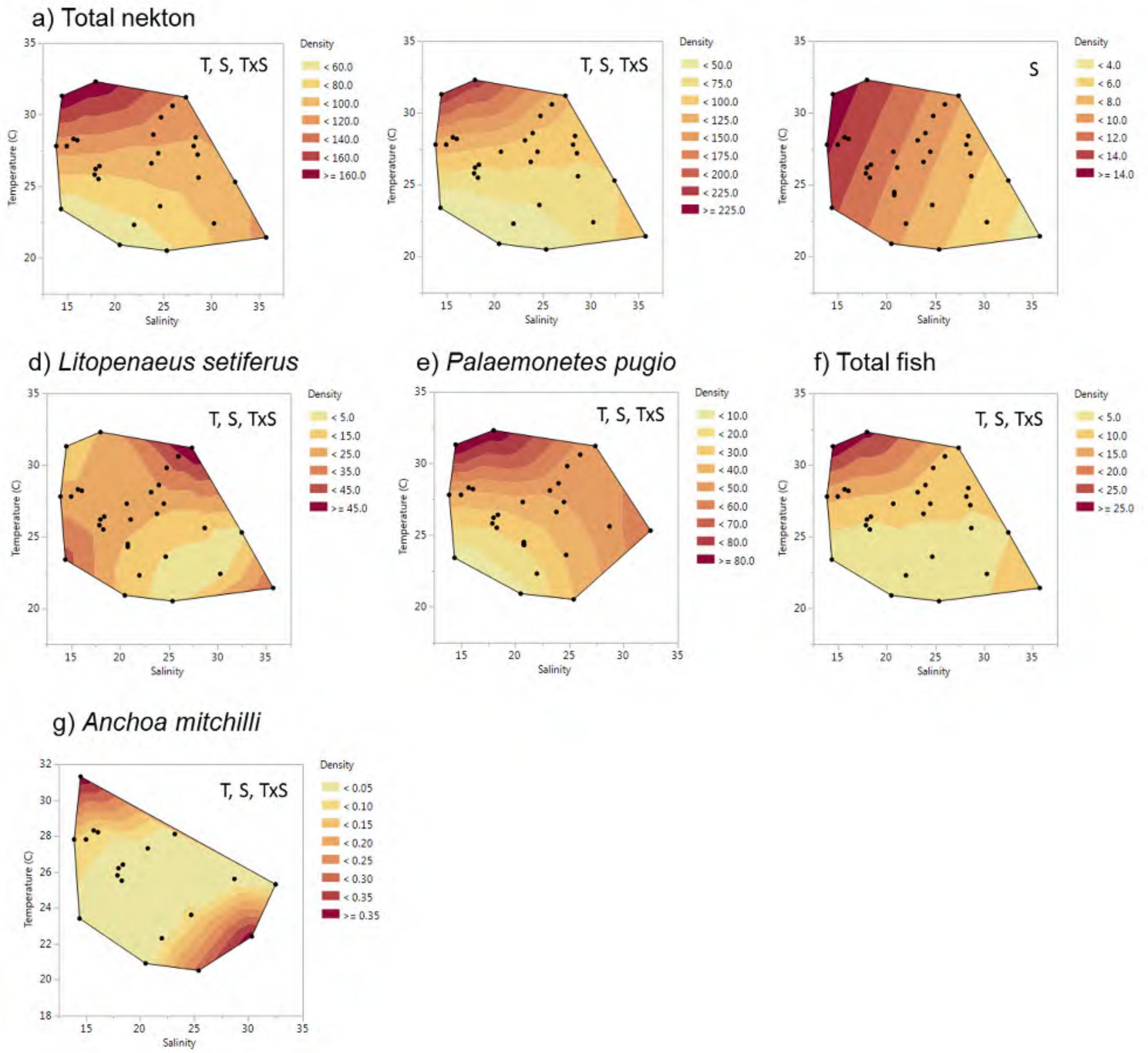


Figure 20. Contour plots for back-transformed density (# of individuals per m^2) for open-water NVB in the spring against temperature (T) and salinity (S). Significant explanatory variables (α = 0.10) are listed in the upper corner of the plots.

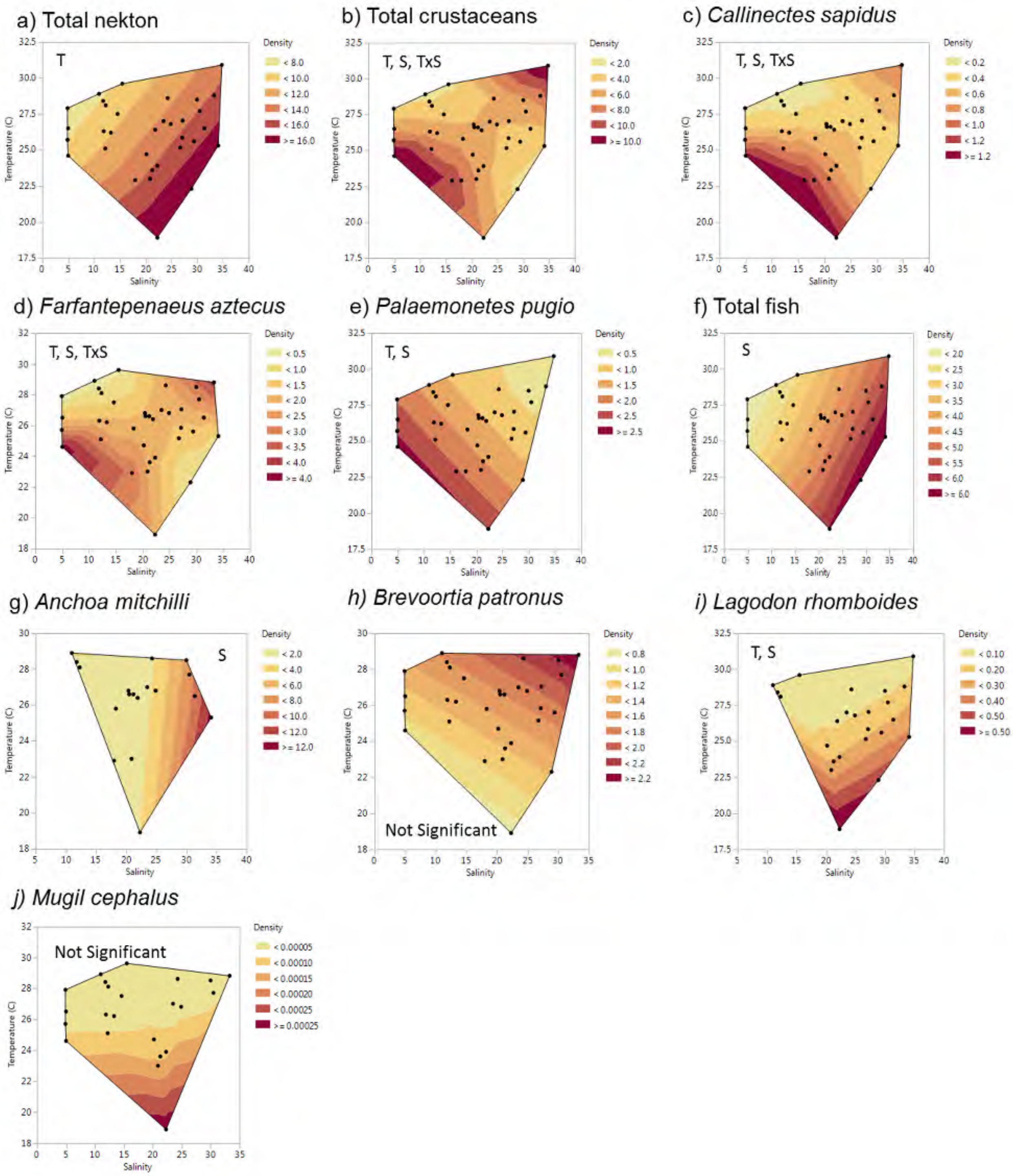
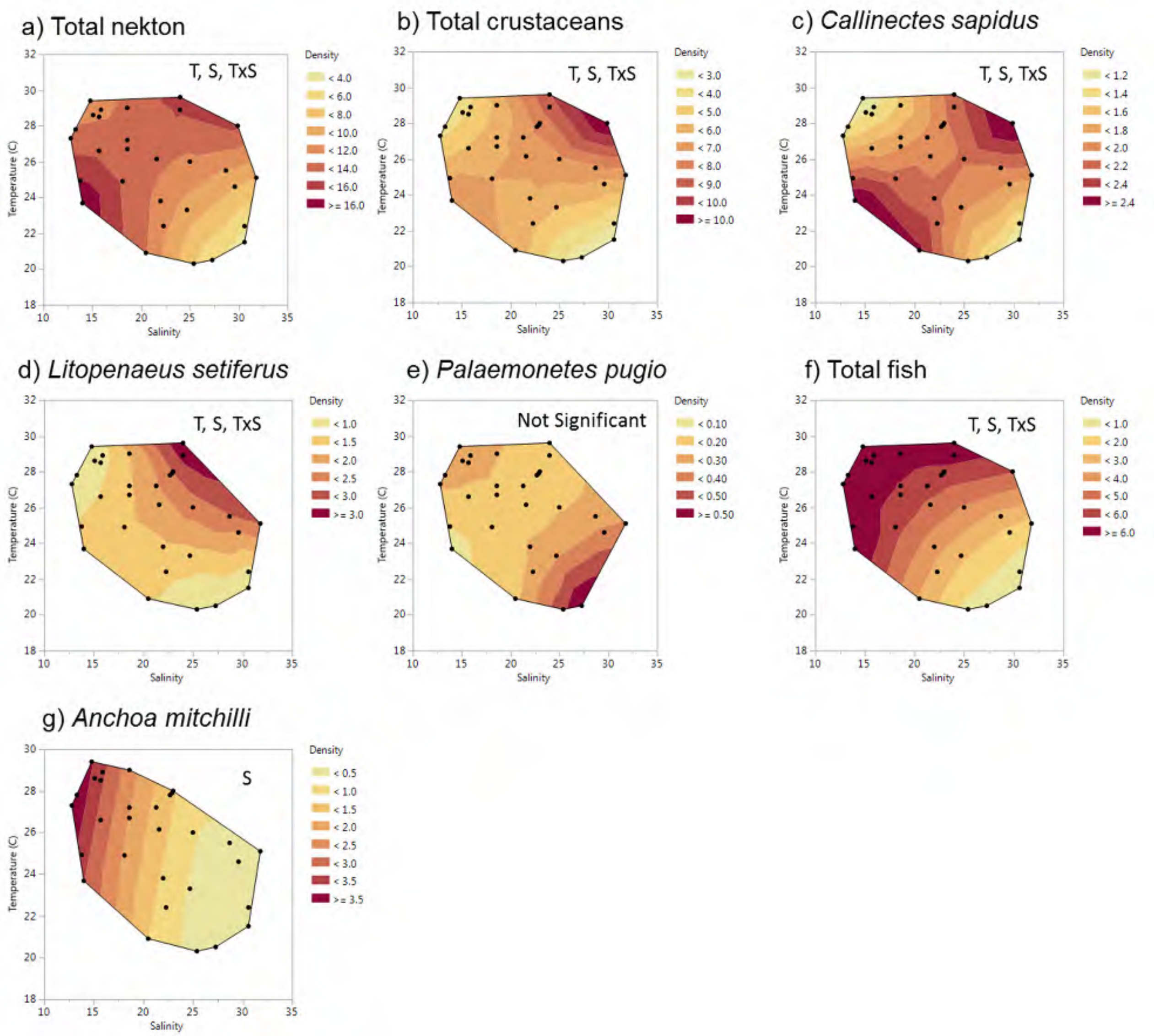


Figure 21. Contour plots for back-transformed density (# of individuals per m^2) for open-water NVB in the fall against temperature (T) and salinity (S). Significant explanatory variables (α = 0.10) are listed in the upper corner of the plots.



3.4.2 Distance to Marsh Edge

Moving from adjacent open-water NVB habitats to marshes, environmental, physical, and structural gradients exist running from the marsh edge and into the marsh interior. These gradients offer differing habitat complexity, water movement, and accessibility, influencing available resources and refugia. As discussed in Section 3.3.1, the marsh edge, in particular, is an area of high biological activity providing resources from both open-water and the marsh platform. The marsh interior is also rich in structure and resources, but may be less accessible to some nekton species. There has been substantial research on nekton distribution along the open water-marsh landscape (Baltz et al., 1993; Minello and Rozas, 2002; Minello et al., 2008). This section expands on the analyses done in Section 3.3.1 by studying the relationship of distance (m) from the marsh edge and density for selected taxa. Key findings of the meta-analysis are highlighted, with additional information from the scientific literature. As discussed in Section 2.2.2.3, the meta-analysis was limited to studies conducted on the marsh platform (edge and interior) and open-water NVB in the saline zone during the spring and fall.

Key finding: Moving from the marsh edge toward the interior of the marsh, total crustacean density tends to decrease, but total fish density tends to increase.

In the spring and fall, total crustacean density trended lower as distance from the marsh edge into the marsh interior increased (Figure 22 and Figure 23). An opposing trend was observed for total fish density, with values becoming higher farther into the marsh interior (Figure 22 and Figure 23).

Since total crustacean density and total fish density showed opposite trends with distance from the marsh edge into its interior during both the spring and fall, the net outcome for total nekton density depends on the magnitude of total crustacean and fish trends relative to each other. During the spring, the two trends cancel each other out (i.e., no trend was observed in total nekton density from the marsh edge farther into its interior) (Figure 22). However, in the fall, the decreasing trend with total crustacean density overrides the increasing trend with total fish density, and thus total nekton density also decreases farther into the marsh interior (Figure 23).

Key finding: Moving from the marsh edge out onto open-water NVB habitat, total crustacean density and total fish density both decrease.

There was a consistent trend observed during both the spring and fall toward decreasing total crustacean density and total fish density, with increasing distance from the marsh edge out onto open-water NVB habitat (Figure 24 and Figure 25). Not surprising, total nekton density decreased as the distance from the marsh edge into open-water NVB habitat increased; this was seen during both the spring and fall (Figure 24 and Figure 25).

Key finding: Trends found with total crustacean density along the open-water marsh landscape were apparent for individual crustacean species.

All individual crustacean species examined in the spring showed a decreasing trend of density similar to that observed for total crustaceans as distance from the marsh edge to the interior increased (Figure 22); two out of the three crustacean species examined in the fall showed a similar pattern (Figure 23). Regarding densities from the marsh edge onto open-water NVB, decreasing trends in spring and fall were observed for two of the three crustacean species examined (Figure 24 and Figure 25).

Key finding: Trends found with total fish density along the open-water marsh landscape were often not apparent for individual fish species.

Only one of three fish species examined in the spring, and none in the fall showed an increasing trend of density when moving from the marsh edge to the interior (Figure 22 and Figure 23). Regarding densities from the marsh edge onto open-water NVB, no significant trend was observed in any of the four fish species examined in the spring (Figure 24), albeit a decreasing trend was observed for the one species examined in the fall (Figure 25).

Comparison to earlier meta-analysis

Overall, the results obtained for nekton density based on this regression approach are comparable with the results obtained when grouping the density data in different distance intervals along the open-water marsh landscape (Section 3.3.1). The only discrepancies appear with the results for total fish density and total nekton density along marshes in the spring. The relative differences in total fish density and total nekton density between "marsh edge" and "marsh interior" for the spring (Figure 10; Section 3.3.1) do not visually correspond with the regression-based results for total fish density and total nekton density from the marsh edge farther into the marsh interior in the spring (Figure 22). These discrepancies may be explained by the different nature of the analyses. As the regression analysis required paired values of density and distance from the marsh edge, only a subset of the data was used in this analysis, compared to the full dataset that was used in the earlier analysis. In addition, the regression analysis is based on weighted values, where mean values with lower uncertainty, as indicated by their variance, contributed more weight to the regression. Thus, discrepancies are possible between the two types of analyses.

Comparison of these results with existing literature

The results of this meta-analysis confirm some trends reported previously in the literature. Total crustacean density, as well as the density of several crustacean species, have been found to be highest at the marsh edge and decrease farther into the marsh and out onto open-water NVB habitat (e.g., Minello and Rozas, 2002; Minello et al., 2008). The meta-analysis result that total fish density decreases with farther distance from the marsh edge onto open-water NVB habitat can be inferred from past studies (Baltz et al., 1993; McDonald et al., 2016), but observations of increases in density with farther distance from the marsh edge into the marsh are less-documented. This suggests that, unlike crustaceans, the total fish community along the open-water marsh landscape does not peak in abundance at the marsh edge but may do so farther into the marsh. The higher mobility of fish and the capacity to access resources farther into the marsh, in comparison to crustaceans, may be the reasons for these differences.

Despite these overall trends in total fish density along the open-water marsh landscape, distributions of the individual fish species examined do not frequently follow these trends. Indeed, the results demonstrate large variability in the density of individual species regardless of the location along the open-water marsh landscape, which often results in the lack of a discernible association between species density and location along the landscape. Some of this variability may be due to differences in sampling, including the timing of sampling in relation to water levels, tides, and adjacent land elevation or flooding. It is clear that substantial variability exists for individual fish species in regard to their distribution along the open-water marsh landscape. However, it is also clear that, despite such variability, the trends reported here for the total fish community (total fish density) likely exist for a substantial number of species that live in the open-water marsh landscape but have not been examined in this guidebook.

Figure 22. The relationship between distance to marsh edge (m) and density (# of individuals per m²) of total nekton, total crustaceans, total fish, and selected fish and crustacean species in saline marsh habitat in the spring. An increase in distance from the marsh edge represents sampling sites farther into the marsh interior.

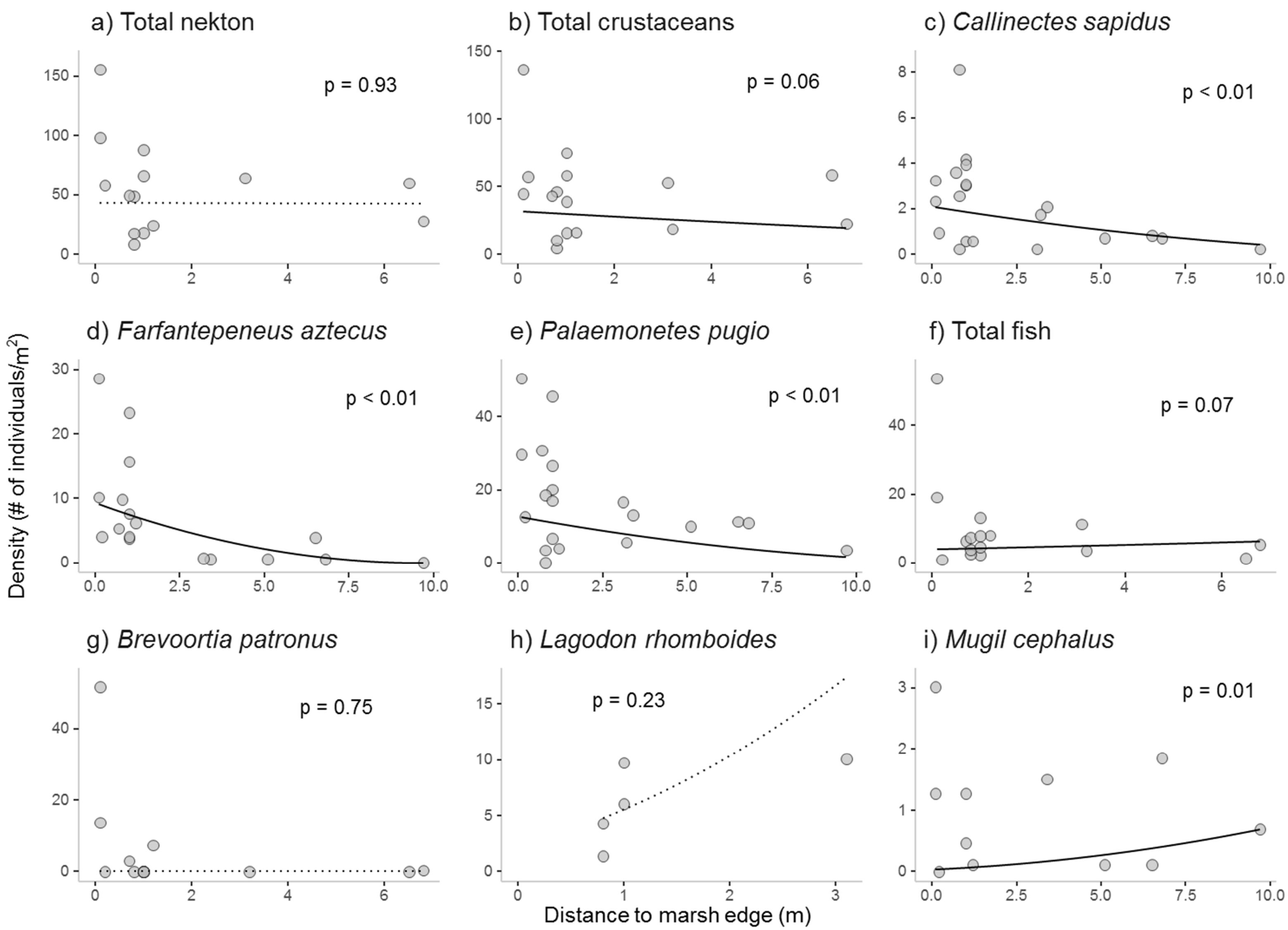


Figure 23. The relationship between distance to marsh edge (m) and density (# of individuals per m²) of total nekton, total crustaceans, total fish, and selected fish and crustacean species in saline marsh habitat in the fall. An increase in distance from the marsh edge represents sampling sites farther into the marsh interior.

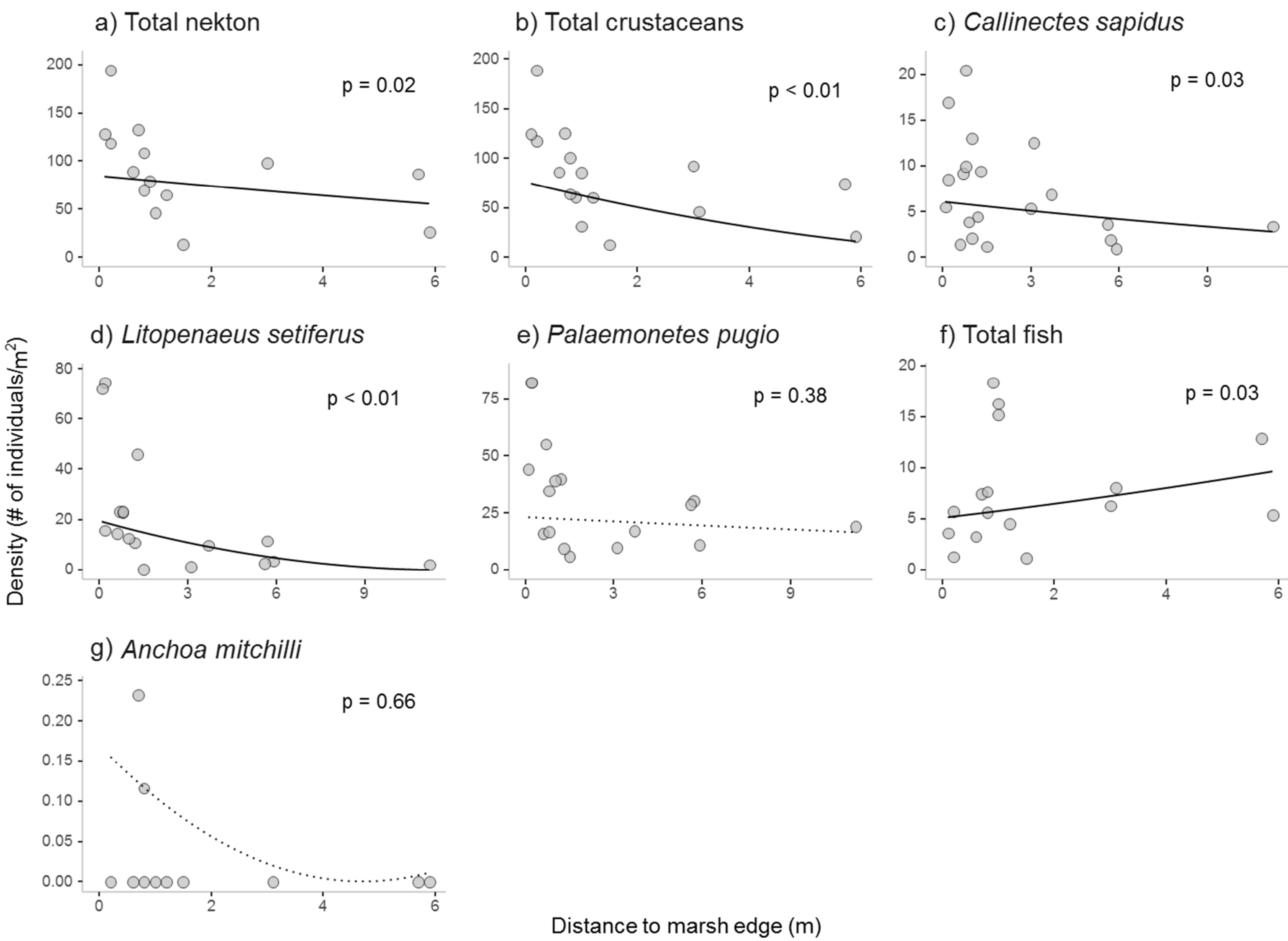


Figure 24. The relationship between distance to marsh edge (m) and density (# of individuals per m²) of total nekton, total crustaceans, total fish, and selected fish and crustacean species in saline open-water NVB habitat in the spring. An increase in distance from the marsh edge represents sampling sites farther out onto open-water NVB habitat.

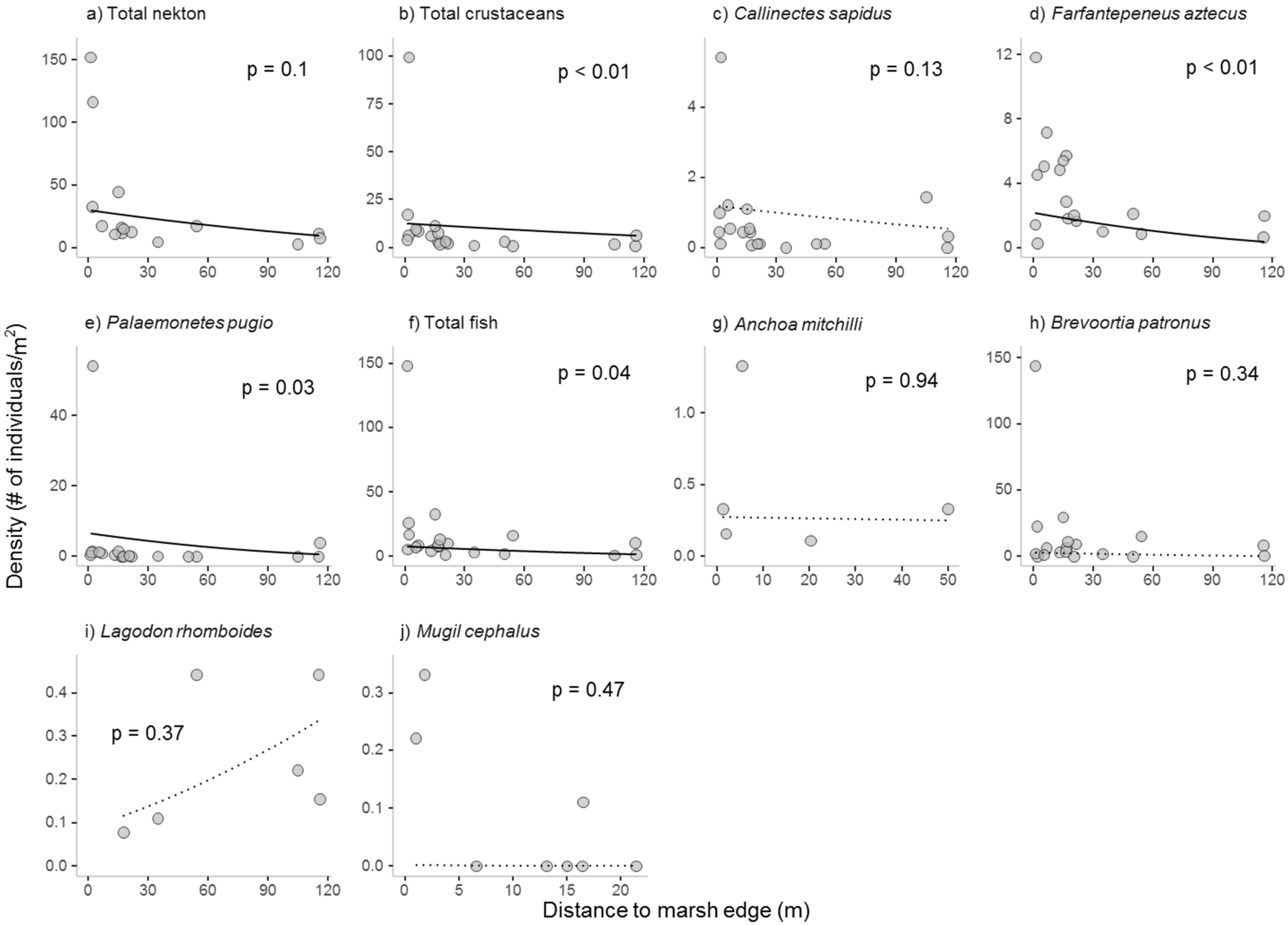
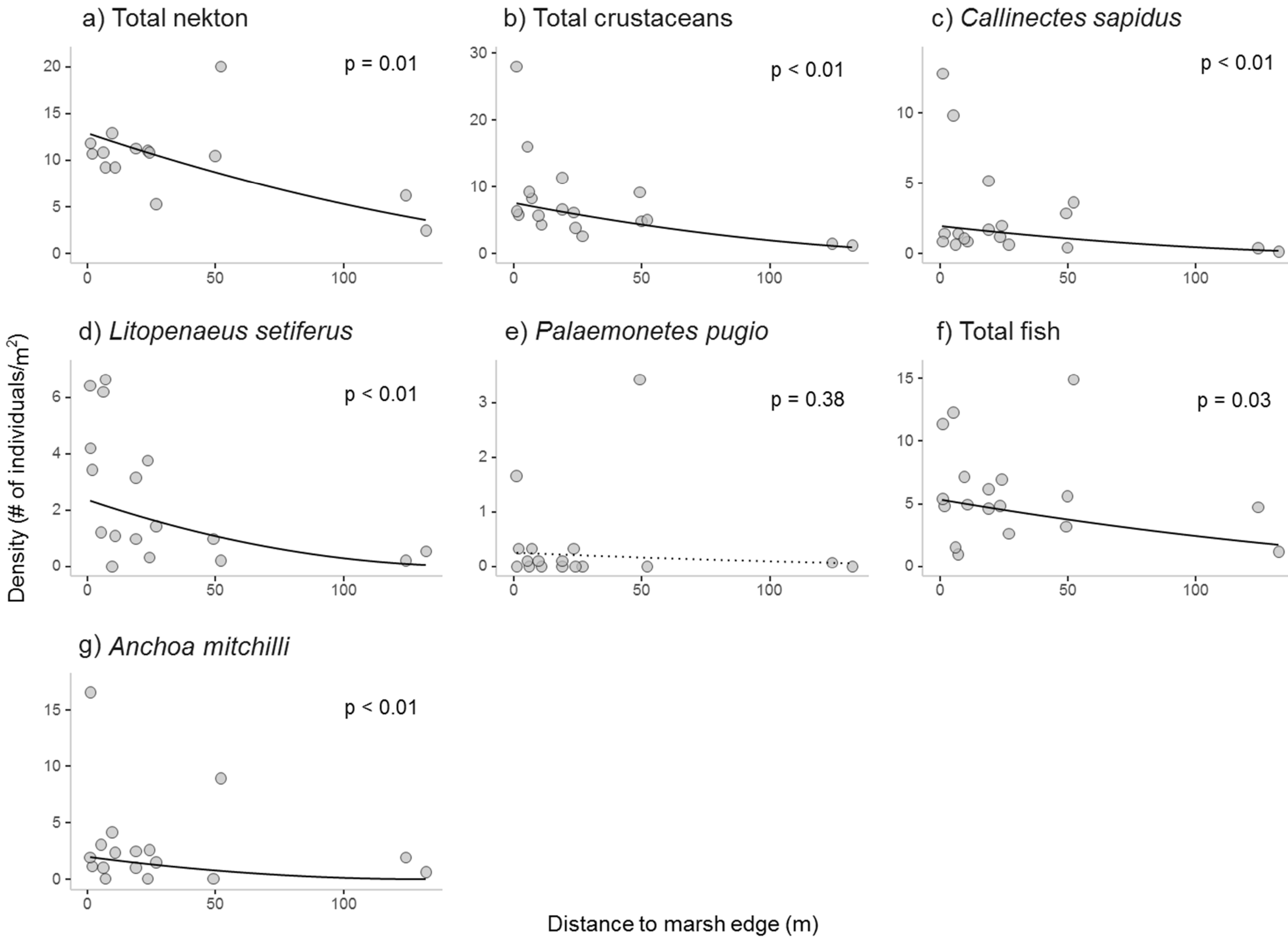


Figure 25. The relationship between distance to marsh edge (m) and density (# of individuals per m²) of total nekton, total crustaceans, total fish, and selected fish and crustacean species in saline open-water NVB habitat in the fall. An increase in distance from the marsh edge represents sampling sites farther out onto open-water NVB habitat.



3.5 Nekton Recovery Following Marsh Restoration

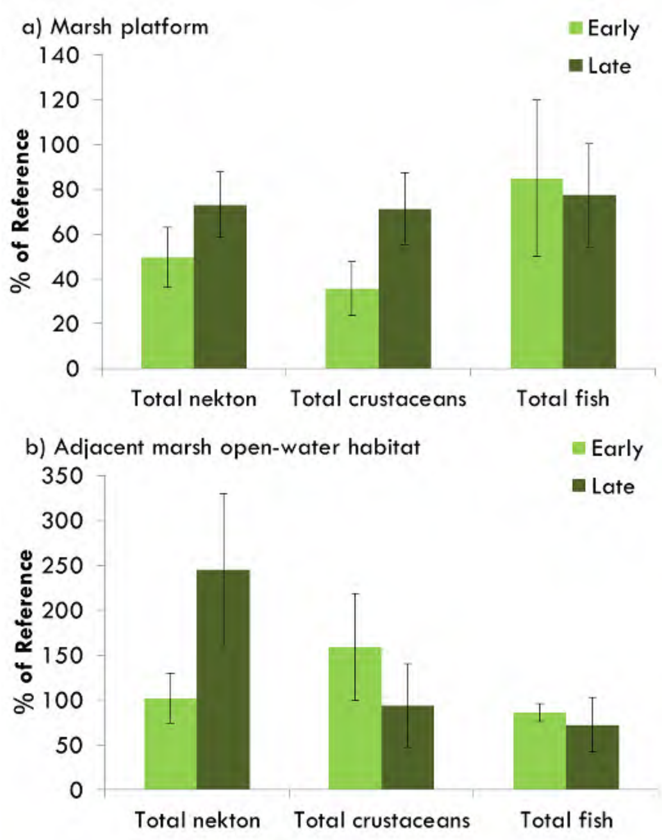
Over the past few decades, increased federal and state efforts have focused on coastal marsh restoration in the Gulf of Mexico (see Section 3.1 for an overview). For many (if not all) of these efforts, one of the primary goals is to create marsh habitat that supports faunal (e.g., fish, crustacean, bird, wildlife) use and productivity similar to natural sites. However, questions related to the relative function of restored habitats to natural habitats remain (Streever, 2000; Zedler, 2000; Callaway, 2005), such as habitat provisioning for fish and crustaceans. This section discusses nekton use and recovery trajectories of marsh habitat following restoration in the northern Gulf of Mexico, and factors that may affect nekton recovery.

3.5.1 Nekton Recovery

Key finding: Total nekton densities at restored marsh sites were generally lower than densities measured at reference marsh sites. This trend was only observed for studies conducted on the marsh platform, and not in the adjacent marsh open-water habitat.

Meta-analysis of studies conducted on the marsh platform. For studies conducted on the marsh platform, mean total nekton and crustacean densities at restored marsh sites were generally lower than reference marsh sites (Figure 26a). During the first five years following restoration, mean total nekton density in restored marshes was approximately 50 ± 14% (mean ± SE) of reference marsh densities; in the subsequent years following restoration (age of restored sites: 6 to 30 years), densities of nekton in restored marshes were approximately 73 ± 15% of reference marsh densities. Because crustaceans accounted for the majority of total nekton abundance (e.g., Figure 16), overall trends in nekton densities generally mirrored those of crustacean densities. Mean densities of fish species also tended to be somewhat lower in restored marshes than in reference marshes, but relative densities were highly variable during both the initial five-year period (85 ± 35%) and in subsequent years (77 ± 23%).

Figure 26. Mean percent of restored habitat densities compared to reference habitat densities (± 1 SE) of total nekton, total crustaceans, and total fish across paired reference and restored sites sampled on the a) marsh platform and b) adjacent marsh open-water habitat (NVB, SAV) for early (age of restored site = 2–5 years) and late (age of restored site > 5 years) time periods. The 100% line indicates equal densities at restored sites to reference sites. Less than 100% indicates lower densities at restored sites compared to reference sites.



Source: Figures adapted from Hollweg et al. (2019a).

Meta-analysis of studies conducted in adjacent marsh open-water habitat. When looking at nekton sampled in open-water habitat adjacent to the marsh edge (including NVB and SAV), no consistent pattern in nekton densities was observed over time (Figure 26b). Total nekton densities in open-water habitat adjacent to restored sites were similar to paired reference sites during the initial five years following restoration (102 ± 28%), and greater than reference sites during later periods (245 ± 85%). Mean densities of crustaceans in open-water habitat adjacent to restored sites were highly variable and showed a decreasing trend from the early to the late periods relative to reference sites. Total fish densities in open-water habitat were similar to results from the marsh platform, with mean densities at restored sites 86 ± 10% of reference locations during the early period, and 72 ± 31% of reference locations during the late period, with high variability across studies.

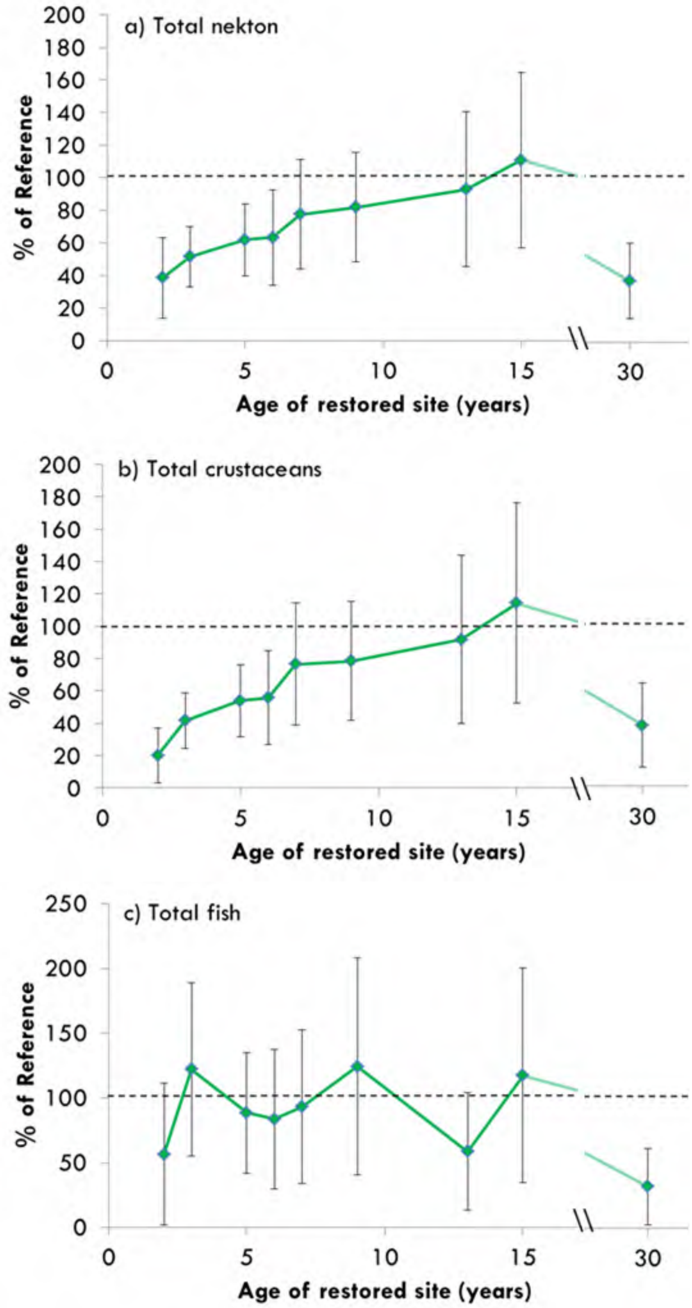
Supporting scientific literature. Several studies, all of which were sampled on the marsh platform and included in the meta-analysis, reported lower fish and/or crustacean densities in restored marshes compared to reference sites (e.g., Minello and Zimmerman, 1992; Minello and Webb, 1997; Rozas and Minello, 2001; Zeug et al., 2007). However, these findings were not necessarily consistent across species or seasons. Other studies in the Gulf of Mexico (many of which were included in the meta-analysis) found comparable nekton densities between restored and reference marsh sites (e.g., Thom et al., 2004; La Peyre et al., 2007; Rozas and Minello, 2007; Llewellyn and La Peyre, 2011; La Peyre and Gordon, 2012). Notably, all of these studies were conducted in open-water habitat adjacent to the marsh edge, with the exception of Rozas and Minello (2007). This finding is consistent with the meta-analysis results, which did not find a clear trend in nekton use of restored and reference sites when sampling was conducted in adjacent marsh open-water habitat.

Key finding: Total nekton densities and total crustacean densities measured on the marsh platform at restored sites showed a general recovery trend, with restored site densities lower than reference sites during the first decade following restoration and approaching reference values in later years.

Meta-analysis of studies conducted on the marsh platform. A general increasing trend of total nekton densities at restored sites toward reference values was observed over the 15 years following restoration, with mean densities at restored sites comparable to paired reference locations by approximately year 13 (Figure 27a). Because crustaceans accounted for the majority of total nekton abundance, overall trends in nekton densities generally mirrored those of crustacean densities (Figure 27b). A similar pattern was not observed for fish, with densities relatively comparable between reference and restored sites soon after restoration (Figure 27c).

Supporting scientific literature. While the results of the meta-analysis showed a general recovery trend in total nekton and crustacean mean densities at restored sites to reference values over the first 15 years following restoration, 2 site-specific studies (the former included in the meta-analysis) that measured nekton densities at a series of restored marshes of different ages in the northern Gulf of Mexico found no clear trend in nekton densities over time (Minello and Webb, 1997; Minello, 2000). For example, although Minello and Webb (1997) found significantly lower densities for many commercially important crustacean species in created marshes of different ages (3–15 years) compared to natural marshes, they did not observe a relationship between nekton densities and marsh age. Minello (2000) measured lower nekton densities at a four-month-old created marsh compared to two older created marshes (five and nine years), but this younger marsh reached similar densities to its older counterparts within one year. The author, however, concluded that all three created marshes were functioning at lower levels than natural marshes (Minello, 2000).

Figure 27. Percent of restored habitat densities compared to reference habitat densities for a) total nekton, b) total crustaceans, and c) total fish shown by age of restored sites (i.e., years since restoration) across paired reference and restored sites in marsh habitats. All sampling was conducted on the marsh platform.



Source: Figures adapted from Hollweg et al. (2019a).

Additional considerations: Nekton density is only one measure of equivalency of restored marsh habitats to reference sites. When evaluating recovery of restoration efforts, other metrics should also be considered.

While the meta-analysis used density as a comparison between restored and reference sites, it is important to note that this is only one measure of equivalency of restored marsh habitats. Due to the highly mobile nature of nekton, newly created marshes – following the development of the physical structure – are able to attract fish and crustaceans in the first few years after restoration (e.g., Minello and Zimmerman, 1992; Minello and Webb, 1997). However, there is likely a delay in the ecosystem support for these species, as other functions recover more slowly (as discussed more below). Other measures of functional equivalency have been suggested as important indicators of overall ecosystem fisheries support when comparing restored and reference marshes, including growth, mortality, community composition, condition, and food web structure (Minello and Webb, 1997; Callaway et al., 2001; La Peyre et al., 2007; Rozas and Minello, 2009; Llewellyn and La Peyre, 2011). Thus, it is important to consider additional metrics of functional equivalence when assessing the comparative function of restored and reference sites, as density only tells one piece of the story.

3.5.2 Factors that May Affect Nekton Recovery

Additional considerations: Reasons for the slow recovery of nekton following restoration may be attributed to several abiotic and biotic factors, including differences in the physical structure and/or the slow development of biological components of the restored habitat.

Site hydrology. The marsh hydroperiod is known to affect nekton use of salt marsh habitat (Rozas, 1995), and differences between restored and reference sites have also been attributed to differences in elevation and flooding (Minello and Webb, 1997).

Amount of marsh edge. Another important physical feature of restored marshes is the amount of marsh edge at a site. Marsh terraces are hypothesized to support high fisheries populations (Rozas et al., 2005; Rozas and Minello, 2007) because they have a high marsh-edge-to-area ratio, and nekton densities have been observed to be highest at this transition between marsh and open water (Baltz et al., 1993; Peterson and Turner, 1994; Minello and Rozas, 2002; Minello et al., 2008; Rozas and Minello, 2015; this study).

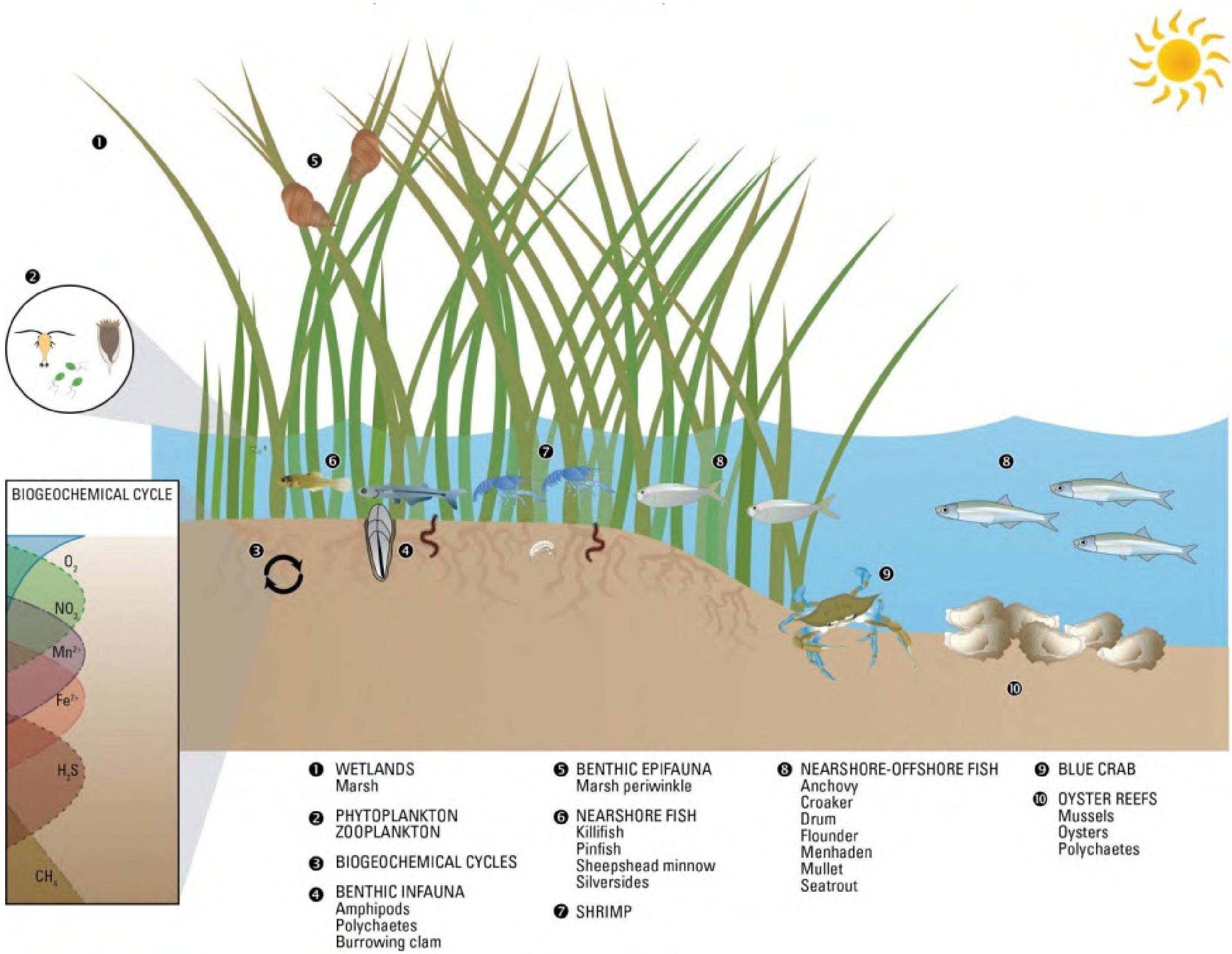
Development of marsh structure and function. The marsh habitat is a complex ecosystem, home to a vast array of species from primary producers to top predators, and a site of unique biogeochemical processes (Figure 28). Although vegetation may be present within two to five years post-restoration (Broome et al., 1986; LaSalle et al., 1991; Craft et al., 1999, 2002; Strange et al., 2002; Edwards and Proffitt, 2003; Armitage et al., 2014; Ebbets et al., 2019), organic matter and infauna, which collectively form the base of the marsh food web, recover on longer timescales (e.g., Sacco et al., 1994; Craft, 2000). General recovery trajectories, described below, include:

- **Vegetation development.** Across a range of marsh creation projects, vegetative structure (e.g., aboveground biomass and percent cover) reaches levels similar to reference marshes on a relatively short timeframe, with recovery typically occurring between two and five years (Broome et al., 1986; LaSalle et al., 1991; Craft et al., 1999, 2002; Strange et al., 2002; Edwards and Proffitt, 2003; Armitage et al., 2014; Ebbets et al., 2019).
- **Soil development.** Several studies have documented delayed development of soil organic matter compared to reference site conditions (e.g., Lindau and Hossner, 1981; Craft et al., 1988a, 1988b, 2002, 2003; Craft, 2000; Edwards and Proffitt, 2003; Zeug et al., 2007), with

soil organic content still not recovering to levels of a natural marsh 30 years post-restoration (Zeug et al., 2007). Because emergent marsh vegetation is likely the principal source of organic matter to soils (Craft et al., 1988a, 1988b; Broome et al., 2000) and many marsh creation projects often use dredged material that is low in organic matter content (Broome et al., 2000; Streever, 2000), soil organic matter at a restored site would be expected to accumulate slowly over time, following the establishment of vegetation.

- **Colonization by infauna.** Density of infauna has also been observed to recover slowly compared to reference site conditions (LaSalle et al., 1991; Moy and Levin, 1991; Sacco et al., 1994; Levin et al., 1996), with equivalency observed between 8 and 15 years (Craft et al., 1999, 2003). The slow rate of benthic infauna recovery has been attributed to the slow development of organic matter content (Moy and Levin, 1991; Sacco et al., 1994; Broome et al., 2000), with relationships observed between infauna densities and macroorganic matter content (Minello and Zimmerman, 1992; Craft, 2000), and soil organic matter content (Broome et al., 2000; Craft, 2000). At a restored site, Minello and Zimmerman (1992) attributed the lower abundance of decapod densities to the lower abundance of benthic infauna, supported by their finding of a significant positive relationship between decapod density and infauna density.

Figure 28. Schematic of the marsh system, highlighting common species and biogeochemical processes.



Source: Some elements on diagram courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (https://ian.umces.edu/symbols/).

4. Nekton Use of Oyster Reef Habitat

This chapter provides an overview of nekton use of oyster reef habitat, and how nekton use varies temporally and following restoration. The chapter is organized as follows:

- Section 4.1 presents an overview of oyster reef habitat in the Gulf of Mexico
- Section 4.2 presents a summary of species assemblages within oyster reef habitat by season
- Section 4.3 presents nekton use by season (spring and fall) within the saline zone
- Section 4.4 presents a summary of nekton recovery following oyster reef restoration.

4.1 Overview of Oyster Reef Habitat

Reefs built by the eastern oyster (*Crassostrea virginica*; Figure 29) create unique three-dimensional habitat within coastal environments; within the Gulf of Mexico estuaries, they represent the only reef-building organisms. Due to their unique habitat, oyster reefs have been identified as essential fish habitat and support a diverse assemblage of fish and crustacean species (e.g., Wells, 1961; Coen et al., 1999; Coen and Grizzle, 2007). The reported decline in oyster reefs (Beck et al., 2011; zu Ermgassen et al., 2012) is likely to have broad consequences on fisheries through lost production (zu Ermgassen et al., 2015).

Figure 29. Oyster-barnacle clusters along the shoreline.

Source: www.istockphoto.com.

In the Gulf of Mexico, oyster reefs can be found within the intertidal zone fringing along marsh shorelines or mudflats, and subtidally within the shallow estuarine system. Oyster reefs are typically most abundant in semi-enclosed water bodies, with water depths less than 12 m and salinities between 15 and 30 ppt (VanderKooy, 2012). Higher-salinity areas may limit oyster growth due to disease (such as dermo, caused by the protistan parasite *Perkinsus marinus*) and predation by oyster drills (VanderKooy, 2012), while lower-salinity areas can cause oyster death from osmotic stress (Cake, 1983). Other environmental factors that also affect oyster growth and survival include temperature, dissolved oxygen, and turbidity, among others (Cake, 1983; VanderKooy, 2012).

In recent decades, significant efforts to conserve and restore oyster reefs have been justified based on their role as ecosystem engineers, including their contributions to water quality improvements, shoreline protection, and habitat creation for commercially and recreationally important fisheries (Coen et al., 2007; Grabowski and Peterson, 2007; Grabowski et al., 2012). Efforts to restore oyster reefs include the provision of hard-bottom habitat using materials such as shell, limestone, or bio-engineered structures to provide substrate for the settlement of oyster larvae; and the use of reefs along marsh edges as living shorelines (Figure 30).

Figure 30. Examples of large-scale oyster cultch placement (left) and living shorelines (right) in the Gulf of Mexico.

Source: https://www.habitat.noaa.gov/storymap/dwh/index.html.

4.2 Summary of Species Assemblages

Oyster reefs within the Gulf of Mexico support a diverse assemblage of fish and crustacean species, from small prey species to larger predators. Many of the species that use oyster reef habitat are year-round residents, including mud crabs, porcelain crabs, snapping shrimp, grass shrimp, gobies, blennies, and toadfish. Commercially and/or recreationally important species that can also be found in the oyster reef habitat include blue crab (*Callinectes sapidus*), stone crab (*Menippe* spp.), and pinfish (*Lagodon rhomboides*), to name a few. Based on data compiled in the companion database, Table 5 provides an overview of species assemblage within oyster reef habitat by season.

4.3 Nekton Use

Nekton use of oyster reef habitat varies both spatially and temporally, governed by several factors including structural characteristics, salinity regimes, and general life history requirements of a species. Below, information is presented on nekton use (total mean density and densities of select taxa) of oyster reef habitat in the northern Gulf of Mexico. Key findings of the meta-analysis are highlighted, with additional information from the scientific literature. As discussed in Section 2.2.2.2, the meta-analysis was limited to studies conducted in the saline zone during the spring and fall.

Table 5. Relative density of crustacean and fish species in oyster reef habitat in the saline zone by season. Density range (# of individuals per m^2, as reported in the records) and total number of records are also provided. Species sorted by total number of records, in descending order. ● = High relative density (76–100% of observed season maximum), ◖ = Medium relative density (25–75.9% of observed maximum), ○ = Low relative density (1–24.9% of observed maximum), ⦸ = Not present (< 1% of observed maximum), – = No data. Commercial and recreational designations do not necessarily apply across all Gulf States.

Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season: Spring	Summer	Fall	Winter	Density range (# of ind./m^2)	Total number of records
Crustaceans									
Callinectes sapidus	Blue crab	T	C, R	○	●	◖	○	0–69.7	68
Eurypanopeus depressus	Flatback mud crab	R		○	◖	●	○	0–173.5	60
Alpheus heterochaelis	Bigclaw snapping shrimp	R		◖	●	◖	◖	0–50.5	56
Petrolisthes armatus	Green porcelain crab	R		○	●	⦸	◖	0–204.5	52
Menippe adina	Gulf stone crab	T	C, R	⦸	●	●	⦸	0–9.1	48
Palaemonetes pugio	Daggerblade grass shrimp	R		◖	●	○	○	0–525.2	48
Clibanarius vittatus	Thinstripe hermit	R		◖	◖	●	○	0–4.5	45
Panopeus herbstii	Atlantic mud crab	R		●	◖	◖	◖	0–840.9	43
Armases cinereum	Squareback marsh crab	R		⦸	○	●	◖	0–55.5	36
Pachygrapsus transversus	Mottled shore crab	R		⦸	●	⦸	⦸	0–15.2	36
Petrolisthes politus	Redback porcelain crab	R		○	⦸	●	○	0–7.6	36
Uca spp.	Fiddler crabs	R		⦸	⦸	●	◖	0–2.5	33
Farfantepenaeus aztecus	Brown shrimp	T	C, R	●	◖	○	⦸	0–18.2	18
Litopenaeus setiferus	White shrimp	T	C, R	⦸	◖	●	⦸	0–32.0	14
Panopeus simpsoni	Oystershell mud crab	R		○	●	◖	–	0.9–28.6	12
Rhithropanopeus harrisii	Harris mud crab, estuarine mud crab	R		⦸	●	⦸	–	0–84.0	7
Menippe mercenaria	Florida stone crab	T	C, R	–	●	–	●	0–2.6	6
Farfantepenaeus duorarum	Pink shrimp	T	C	○	◖	●	○	0–1.0	5
Xanthidae spp.	Mud crabs	R		–	●	–	–	0–1.4	5
Micropanope sculptipes	Sculptured mud crab	R		–	–	●	–	0–0.2	4
Dyspanopeus texanus	Gulf grassflat crab	R		○	●	–	–	0–1.1	3
Palaemonetes intermedius	Brackish grass shrimp	R		◖	●	–	–	< 0.1	3
Eurypanopeus turgidus	Ridgeback mud crab	R		◖	–	●	–	6.1–14.2	2

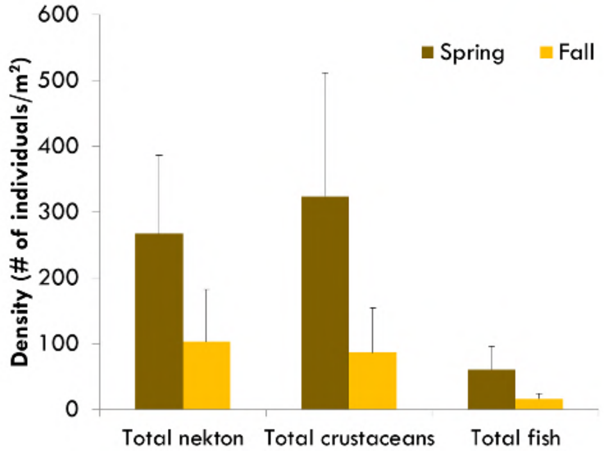
Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season				Density range (# of ind./m²)	Total number of records
				Spring	Summer	Fall	Winter		
Hippolyte zostericola	Zostera shrimp	T		○	●	–	–	< 0.1–0.3	2
Macrocoeloma trispinosum	Spongy decorator crab	R		●	⊘	–	–	< 0.1	2
Pachygrapsus gracilis	Dark shore crab	R		◐	–	●	–	< 0.1–0.2	2
Palaemonetes vulgaris	Marsh grass shrimp	R		–	⊘	–	●	0–0.3	2
Periclimenes americanus	American grass shrimp	R		●	⊘	–	–	< 0.1	2
Processa bermudensis	Bermuda night shrimp	T		●	⊘	–	–	< 0.1	2
Tozeuma carolinense	Arrow shrimp	T		⊘	–	●	–	0–0.7	2
Upogebia affinis	Coastal mud shrimp	R		●	◐	–	–	0.2–0.7	2
Pagurus pollicaris	Flatclaw hermit, gray hermit crab	R		–	–	–	●	< 0.1	1
Gobiosoma bosc	Naked goby	R		○	●	●	○	0–102.8	62
Opsanus beta	Gulf toadfish	R		◐	●	◐	⊘	0–12.7	59
Fish									
Gobiesox strumosus	Skilletfish	R		⊘	●	◐	○	0–10.6	57
Ctenogobius boleosoma	Darter goby	R		●	◐	◐	⊘	0–21.8	54
Chasmodes bosquianus	Striped blenny	R		◐	●	◐	⊘	0–2.5	50
Myrophis punctatus	Speckled worm eel	T		◐	●	○	⊘	0–4.5	50
Fundulus grandis	Gulf killifish	R		●	⊘	⊘	⊘	0–2.5	40
Chasmodes longimaxilla	Stretchjaw blenny	R		⊘	●	⊘	⊘	0–2.5	36
Hypleurochilus geminatus	Crested blenny	R		⊘	●	⊘	⊘	0–5.1	36
Hypleurochilus multifilis	Featherduster blenny	R		◐	●	⊘	⊘	0–5.1	36
Lutjanus griseus	Gray snapper	T	C, R	●	◐	◐	–	0–0.7	16
Hypsoblennius ionthas	Freckled blenny	R		–	●	◐	–	0–18.2	13
Bairdiella chrysoura	Silver perch	T	C	●	⊘	◐	–	0–1.0	12
Lagodon rhomboides	Pinfish	T	R	◐	○	○	●	0–13.0	12
Anchoa mitchilli	Bay anchovy	T	C (minor)	⊘	●	◐	–	0–16.8	11
Archosargus probatocephalus	Sheepshead	T	C, R	–	○	●	–	< 0.1–1.9	11
Bathygobius soporator	Frillfin goby	R		◐	●	○	–	0–1.2	9
Eucinostomus argenteus	Spotfin mojarra	T		◐	⊘	●	–	0–0.6	9
Paralichthys lethostigma	Southern flounder	T	C, R	–	●	⊘	–	0–0.3	9

Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season				Density range (# of ind./m^2)	Total number of records
				Spring	Summer	Fall	Winter		
Chaetodipterus faber	Atlantic spadefish	T	R	–	●	●	–	0–2.6	8
Gobiosoma robustum	Code goby	R		●	–	◖	–	0–1.9	8
Hypsoblennius hentz	Feather blenny	R		–	●	○	–	0–4.5	7
Symphurus plagiusa	Blackcheek tonguefish	T		–	⦸	●	⦸	0–0.5	7
Bagre marinus	Gafftopsail catfish	T		–	–	●	–	0–0.3	6
Cyprinodon variegatus	Sheepshead minnow	R		–	–	●	●	0–0.4	6
Mugil cephalus	Striped mullet	T	C, R	⦸	●	⦸	–	0–0.2	6
Citharichthys spilopterus	Bay whiff	T		–	–	●	–	0–0.1	4
Menidia beryllina	Inland silverside	R		●	◖	⦸	–	0–7.0	4
Microgobius gulosus	Clown goby	R		–	–	●	–	0–0.4	4
Brevoortia patronus	Gulf menhaden	T	C	–	●	⦸	◖	0–0.1	3
Cynoscion nebulosus	Spotted seatrout	T	C, R	●	⦸	–	⦸	< 0.1	3
Leiostomus xanthurus	Spot	T	C, R	⦸	⦸	–	●	0–0.9	3
Microgobius thalassinus	Green goby	R		●	–	⦸	–	< 0.1	2
Micropogonias undulatus	Atlantic croaker	T	C, R	⦸	–	●	–	0–1.6	2
Erotelis smaragdus	Emerald sleeper	R		–	–	●	–	< 0.1	1
Lepomis cyanellus	Green sunfish	R		–	●	–	–	0.3	1
Orthopristis chrysoptera	Pigfish	R		●	–	–	–	0.7	1
Pomatomus saltatrix	Bluefish	T	C, R	–	●	–	–	0.4	1
Prionotus rubio	Blackfin searobin, blackwing searobin	T		●	–	–	–	< 0.1	1
Prionotus tribulus	Bighead searobin	T		–	–	–	●	< 0.1	1

Key finding: Within the saline zone, total nekton densities in oyster reef habitat were relatively higher during the spring than the fall. However, seasonal trends varied by species.

Within the saline zone, total nekton density, total crustacean density, and total fish density in oyster reef habitat were all substantially higher during the spring than the fall (Figure 31). The difference in total crustacean densities between the spring and fall was primarily driven by densities of Atlantic mud crab (*Panopeus herbstii*), although some other species also exhibited higher densities in the spring compared to the fall. For fish, darter goby (*Ctenogobius boleosoma*), pinfish (*Lagodon rhomboides*), and inland silverside (*Menidia beryllina*) made up the dominant catch and drove the observed differences between seasons. See Table S4 for the complete list of taxa densities by the spring and fall seasons.

Figure 31. Estimated mean density (# of individuals per m^2 ± 1 SE) of total nekton (sum of crustacean and fish species), total crustaceans, and total fish in oyster reef habitat during the spring and fall. For comparison, this analysis was limited to sampling conducted in the saline zone.



Source: Figures adapted from Hollweg et al. (2019b).

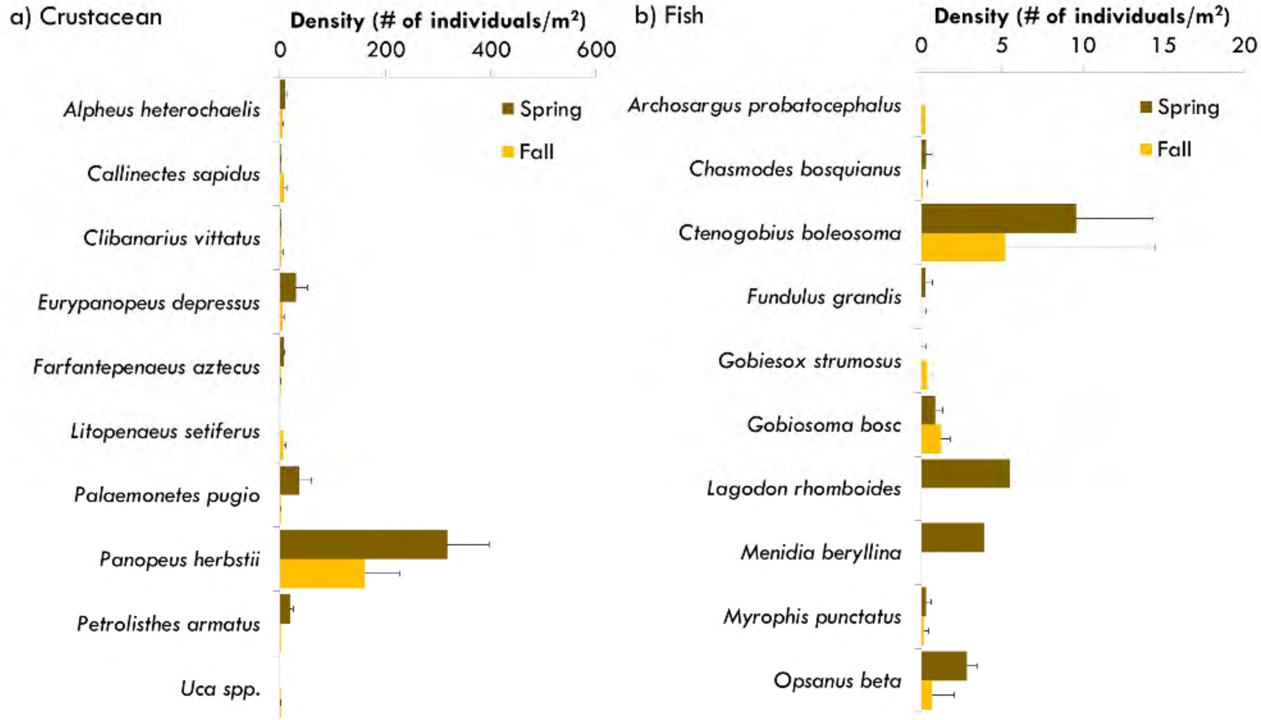
Key finding: Nekton using oyster reef habitat were dominated by year-round residents.

Species with the highest densities were typically resident species, including flatback mud crab (*Eurypanopeus depressus*), daggerblade grass shrimp (*Palaemonetes pugio*), Atlantic mud crab (*Panopeus herbstii*), green porcelain crab (*Petrolisthes armatus*), darter goby (*Ctenogobius boleosoma*), naked goby (*Gobiosoma bosc*), and Gulf toadfish (*Opsanus beta*) (Figure 32). Site-specific studies (many of which were included in this meta-analysis) also found oyster reef catch dominated by many of these same resident species (e.g., Glancy et al., 2003; Shervette and Gelwick, 2008; Robillard et al., 2010; Stunz et al., 2010). For example, Glancy et al. (2003) found that flatback mud crab (*Eurypanopeus depressus*), green porcelain crab (*Petrolisthes armatus*), and Atlantic mud crab (*Panopeus herbstii*) accounted for roughly 95% of the total abundance of crustaceans and occurred in at least 95% of all samples collected.

Key finding: Oyster reefs support commercially and recreationally important species.

Although at lower densities compared to other more abundant taxa, this meta-analysis documented the use of oyster reefs by commercially and recreationally important species, including blue crab (*Callinectes sapidus*), Gulf stone crab (*Menippe adina*), sheepshead (*Archosargus probatocephalus*), and pinfish (*Lagodon rhomboides*) (Figure 32; Table S4). In addition, other studies have documented additional commercially and recreationally important species using oyster reefs, including drum, seatrout, and flounder (e.g., Plunket and La Peyre, 2005; Robillard et al., 2010; Scyphers et al., 2011). For example, Scyphers et al. (2011) observed an increase in red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*), and flounder (*Paralichthys* sp.) on oyster breakwater reefs compared to control sites in Mobile Bay, AL. Many of these studies were not included in the meta-analysis, as these studies used gears (e.g., gill nets) targeting larger species, which are typically reported as catch-per-unit effort rather than density.

Figure 32. Estimated mean density (# of individuals per m^2 ± 1 SE) of individual a) crustacean and b) fish species in oyster reef habitat in the saline zone during the spring and fall. Of the 50 taxa analyzed, this figure displays the 10 most-abundant fish species and 10 most-abundant crustacean species observed within this habitat-season combination. Estimated mean density values for all 50 taxa are presented in Table S4.



Source: Figures adapted from Hollweg et al. (2019b).

4.4 Nekton Recovery Following Oyster Reef Restoration

Due to data limitations, a meta-analysis evaluating nekton recovery following oyster reef restoration was not conducted. However, site-specific studies from the scientific literature provide insights into the structural and functional development of this habitat following restoration in the northern Gulf of Mexico. A general summary of the literature is presented below.

Key takeaway of literature review: Faunal colonization is relatively rapid following oyster reef restoration, with nekton densities and assemblages matching reference reefs within a year or two following restoration. However, more studies are needed to determine if this trend is consistent across sites and over longer time periods.

Colonization by oysters. Oyster reef restoration projects in the Gulf of Mexico have shown successful recruitment and colonization of oysters within the first few years (Gregalis et al., 2008; Geraldi et al., 2009; La Peyre et al., 2014; Graham et al., 2017; De Santiago et al., 2019). For example, following the creation of small patch reefs in Sister (Caillou) Lake, LA, La Peyre et al. (2014) measured a total oyster density of over 1,000 oysters/m^2 at one year post-construction, the highest measured value over the three-year sampling period, with the density of market-sized oysters increasing through time (La Peyre et al., 2014). However, other created oyster reefs showed low oyster survival and reef sustainability over time (Scyphers et al., 2011; La Peyre et al., 2013a, 2013b) or highly variable oyster densities across sites (Gregalis et al., 2008), likely attributed to unfavorable bio-physical conditions.

Colonization by nekton and other fauna. Studies in the Gulf of Mexico and southeastern Atlantic Coast have documented rapid colonization of oyster reefs by resident and transient species (Meyer and Townsend, 2000; Peterson et al., 2003; Grabowski et al., 2005; Manley et al., 2010; Humphries et al., 2011; Rezek et al., 2017; De Santiago et al., 2019). For example, two years post-construction, created oyster reefs in North Carolina supported densities of numerous species of sessile and mobile fauna at equivalent or greater densities than adjacent natural reefs (Meyer and Townsend, 2000). Similarly, Luckenbach et al. (2005) observed similar total epifauna abundance on experimental and natural reefs in South Carolina three years post-construction. However, densities of some epifauna species did not converge with their natural counterpart until the year-seven sampling event (Luckenbach et al., 2005). In Texas, Rezek et al. (2017) observed a shift in a restored reef to a similar community composition as natural reefs within 12–15 months after restoration.

5. Nekton Use of SAV Habitat

This chapter provides an overview of nekton use of SAV habitat, and how nekton use varies temporally and following restoration. The chapter is organized as follows:

- Section 5.1 presents an overview of SAV habitat in the Gulf of Mexico
- Section 5.2 presents a summary of species assemblage within SAV habitat by season
- Section 5.3 presents nekton use by season (spring and fall) within the saline zone
- Section 5.4 presents a summary of nekton recovery following SAV restoration.

5.1 Overview of SAV Habitat

Figure 33. Seagrass beds in the Gulf of Mexico.

SAV is a general term used to describe plants that are rooted in aquatic environments and grow below the water's surface. SAV includes seagrass (Figure 33) as well as other types of aquatic plants and macroalgae. Of the six species of seagrass that can be found in the Gulf of Mexico (Handley et al., 2007), turtle grass (*Thalassia testudinum*), shoal grass (*Halodule wrightii*), and manatee grass (*Syringodium filiforme*) are the most common seagrasses found in higher-salinity waters; and wigeon grass (*Ruppia maritima*) is the most common seagrass found in lower-salinity waters. In addition, other aquatic plants may dominate SAV beds in lower-salinity waters, including coontail (*Ceratophyllum demersum*), hydrilla (*Hydrilla verticillata*), Eurasian watermilfoil (*Myriophyllum spicatum*), water nymph/guppy grass (*Najas guadalupensisis*), lesser pondweed (*Potamageton pusillus*), and wild celery (*Vallisneria americana*), among others (Merino et al., 2005; Carter et al., 2009; Hillmann et al., 2016; La Peyre et al., 2017).

SAV – and seagrass more specifically – has experienced significant habitat loss over the last half century. A report by the U.S. Geological Survey presented the status and trends of seagrass habitat in the northern Gulf of Mexico from 1940 to 2002 (Handley et al., 2007). Of the 14 estuarine systems studied, all experienced some declines in seagrass habitat (Handley et al., 2007). For example, Laguna Madre, TX, has experienced between 10% and 20% loss in seagrass habitat since 1965; Mississippi Sound has lost over 86% of seagrass habitat since 1969; and Tampa Bay, FL, has lost over 6,000 hectares (approximately 14,800 acres) of seagrass since the 1950s (Handley et al., 2007). The major threats to seagrass within these systems include reduced water quality from nutrient loading; increases in turbidity and/or stormwater runoff; dredging; boat propeller scars; and hydrologic modifications (Handley et al., 2007).

Due to the loss of seagrass from coastal systems, there has been an increased focus on restoring, conserving, and protecting these important habitats. Common restoration activities in the Gulf of Mexico include improving water quality, transplantation, backfilling of propeller scars, targeted nutrient addition (e.g., bird stakes), and protective measures (e.g., signage, buoys) (Figure 34).

Figure 34. Propeller scars damaging seagrass beds (left) and the use of bird stakes for seagrass restoration (right).

Source: https://floridakeys.noaa.gov/.

5.2 Summary of Species Assemblages

SAV habitat within the Gulf of Mexico support numerous fish and crustacean species, from small prey species to larger predators. Some of these species use this aquatic habitat during their full life history, such as grass shrimp, snapping shrimp, mud crabs, killifish, and gobies. Others, however, are transient and may only be found in SAV habitat during a period of their life history. Commercially and/or recreationally important species that can be found in SAV habitat include blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), pink shrimp (*Farfantepenaeus duorarum*), pinfish (*Lagodon rhomboides*), spot (*Leiostomus xanthurus*), and spotted seatrout (*Cynoscion nebulosus*), to name a few. Based on data compiled in the companion database, Table 6 provides an overview of species assemblage within SAV habitat, by season and salinity zone.

5.3 Nekton Use

Nekton use of SAV habitat varies both spatially and temporally, governed by several factors including vegetation characteristics, salinity regimes, and general life history requirements of a species. Below, information is presented on nekton use (total mean density and densities of select taxa) of SAV habitat in the northern Gulf of Mexico. Key findings of the meta-analysis are highlighted, with additional information from the scientific literature. As discussed in Section 2.2.2.2, the meta-analysis was limited to studies conducted in the saline zone during the spring and fall. The dominant vegetation for the majority of studies captured in the meta-analysis included two common seagrass species: turtle grass (*Thalassia testudinum*) and shoal grass (*Halodule wrightii*).

Table 6. Relative density of crustacean and fish species in SAV habitat by season and salinity zone. Density range (# of individuals per m^2, as reported in the records) and total number of records are also provided. Species sorted by total number of records, in descending order. ● = High relative density (76–100% of observed season or salinity zone maximum), ◖ = Medium relative density (25–75.9% of observed maximum), ○ = Low relative density (1–24.9% of observed maximum), ⦸ = Not present (< 1% of observed maximum), – = No data. Commercial and recreational designations do not necessarily apply across all Gulf States.

Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season: Spring	Summer	Fall	Winter	Relative density by salinity zone: Saline	Brackish	Intermediate	Fresh	Density range (# of ind./m^2)	Total number of records
Crustaceans													
Callinectes sapidus	Blue crab	T	C, R	◖	◖	●	○	●	●	●	●	0–41.4	125
Palaemonetes pugio	Daggerblade grass shrimp	R		●	◖	●	●	◖	●	◖	–	0–144.2	108
Farfantepenaeus aztecus	Brown shrimp	T	C, R	●	◖	◖	○	●	◖	○	–	0–34.0	67
Alpheus heterochaelis	Bigclaw snapping shrimp	R		○	◖	●	○	●	○	⦸	–	0–12.1	62
Farfantepenaeus duorarum	Pink shrimp	T	C	◖	◖	●	○	●	○	⦸	–	0–19.6	45
Palaemonetes intermedius	Brackish grass shrimp	R		●	◖	◖	–	●	⦸	◖	–	0–143.5	45
Hippolyte zostericola	Zostera shrimp	T		◖	◖	●	–	●	⦸	⦸	–	0–38.0	43
Palaemonetes vulgaris	Marsh grass shrimp	R		○	●	◖	–	●	⦸	◖	–	0–34.1	38
Dyspanopeus texanus	Gulf grassflat crab	R		◖	○	●	○	●	○	⦸	–	0–20.8	37
Litopenaeus setiferus	White shrimp	T	C, R	◖	○	●	–	◖	●	○	–	0–39.7	36
Tozeuma carolinense	Arrow shrimp	T		◖	○	●	○	●	⦸	⦸	–	0–14.1	29
Panopeus herbstii	Atlantic mud crab	R		●	●	●	◖	●	●	⦸	–	0–0.4	27
Rhithropanopeus harrisii	Harris mud crab, estuarine mud crab	R		○	○	●	–	○	○	●	–	0–42.4	19
Xanthidae spp.	Mud crabs	R		○	◖	●	○	○	◖	●	–	0–19.9	17
Clibanarius vittatus	Thinstripe hermit	R		◖	●	◖	–	●	⦸	⦸	–	0–1.8	12
Palaemonetes paludosus	Riverine grass shrimp	R		●	◖	◖	–	–	–	●	◖	0.1–15.7	11
Callinectes similis	Lesser blue crab	T		◖	–	●	–	●	–	–	–	0–8.0	9
Eurypanopeus turgidus	Ridgeback mud crab	R		●	◖	◖	–	●	⦸	⦸	–	0–0.4	9
Macrobrachium ohione	Ohio shrimp	R		○	○	●	–	–	–	●	○	0–16.5	8
Pagurus criniticornis	–	R		○	–	●	–	●	–	–	–	0.1–0.8	6

Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season				Relative density by salinity zone				Density range (# of ind./m^2)	Total number of records
				Spring	Sum-mer	Fall	Winter	Saline	Brack-ish	Inter-mediate	Fresh		
Eurypanopeus depressus	Flatback mud crab	R		⦸	●	⦸	–	●	–	–	–	0–0.2	4
Petrolisthes armatus	Green porcelain crab	R		⦸	●	⦸	–	●	–	–	–	< 0.1	3
Eurytium limosum	Broadback mud crab	R		⦸	●	–	–	●	–	–	–	< 0.1	2
Libinia dubia	Longnose spider crab	R		⦸	–	●	–	●	–	–	–	< 0.1	2
Macrocoeloma trispinosum	Spongy decorator crab	R		●	○	–	–	●	–	–	–	< 0.1–0.4	2
Periclimenes americanus	American grass shrimp	R		●	○	–	–	●	–	–	–	< 0.1–0.8	2
Processa bermudensis	Bermuda night shrimp	T		●	○	–	–	●	–	–	–	< 0.1–1.4	2
Upogebia affinis	Coastal mud shrimp	R		●	◖	–	–	●	–	–	–	< 0.1	2
Lepidophthalmus jamaicense	Estuarine ghost shrimp	R		–	–	●	–	●	–	–	–	0.1	1
Fish													
Lagodon rhomboides	Pinfish	T	R	●	○	○	○	●	⦸	○	–	0–47.4	144
Lucania parva	Rainwater killifish	R		◖	◖	◖	●	○	●	◖	◖	0–37.6	102
Gobiosoma robustum	Code goby	R		◖	◖	●	●	●	○	◖	–	0–42.0	99
Ctenogobius boleosoma	Darter goby	R		◖	◖	●	○	●	○	○	○	0–31.8	82
Cyprinodon variegatus	Sheepshead minnow	R		◖	●	◖	◖	○	◖	◖	●	0–17.6	60
Menidia beryllina	Inland silverside	R		◖	●	◖	○	○	●	⦸	○	0–7.6	49
Symphurus plagiusa	Blackcheek tonguefish	T		○	◖	●	⦸	●	○	⦸	–	0–8.4	43
Anchoa mitchilli	Bay anchovy	T	C (minor)	●	◖	◖	–	◖	◖	◖	●	0–1.8	36
Poecilia latipinna	Sailfin molly	R		◖	●	●	◖	○	●	–	–	0–83.2	36
Gobiosoma bosc	Naked goby	R		◖	●	●	●	●	○	●	–	0–6.8	35
Leiostomus xanthurus	Spot	T	C, R	●	○	○	○	●	●	◖	⦸	0–0.8	34
Syngnathus scovelli	Gulf pipefish	T		●	◖	●	–	●	○	●	–	0–1.8	33
Fundulus grandis	Gulf killifish	R		◖	◖	●	⦸	◖	●	⦸	◖	0–0.9	25
Cynoscion nebulosus	Spotted seatrout	T	C, R	◖	◖	●	–	●	○	⦸	–	0–0.5	24
Adinia xenica	Diamond killifish	R		○	●	◖	○	●	◖	⦸	–	0–0.7	21
Opsanus beta	Gulf toadfish	R		○	●	◖	–	●	⦸	⦸	–	0–0.2	21
Synodus foetens	Inshore lizardfish	T		●	⦸	○	○	●	⦸	⦸	–	< 0.1	21
Micropogonias undulatus	Atlantic croaker	T	C, R	○	⦸	○	●	◖	●	⦸	⦸	0–1.0	20

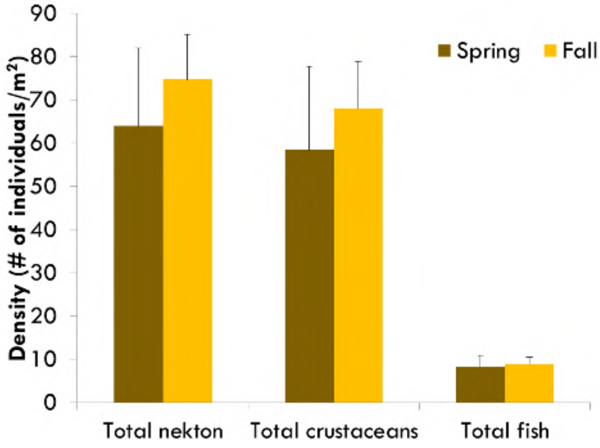
Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season				Relative density by salinity zone				Density range (# of ind./m^2)	Total number of records
				Spring	Summer	Fall	Winter	Saline	Brackish	Intermediate	Fresh		
Mugil cephalus	Striped mullet	T	C, R	○	○	●	○	○	●	●	○	0–3.2	19
Myrophis punctatus	Speckled worm eel	T		●	◖	◖	–	◖	◖	●	●	0–1.1	18
Brevoortia patronus	Gulf menhaden	T	C	●	–	○	–	○	○	●	–	0–105.1	17
Sciaenops ocellatus	Red drum	T	C, R	⦸	–	●	○	●	⦸	–	–	0–0.8	17
Microgobius gulosus	Clown goby	R		●	◖	◖	–	◖	◖	●	–	0–1.5	15
Fundulus similis	Longnose killifish	R		◖	●	⦸	○	●	⦸	–	–	0–0.7	12
Gerres cinereus	Yellowfin mojarra	T		⦸	●	◖	⦸	●	–	–	–	0–0.2	12
Paralichthys lethostigma	Southern flounder	T	C, R	●	⦸	–	◖	◖	⦸	–	●	0–0.1	11
Citharichthys spilopterus	Bay whiff	T		◖	–	–	●	◖	⦸	●	⦸	0–0.1	10
Bairdiella chrysoura	Silver perch	T	C	⦸	●	⦸	–	●	⦸	⦸	–	0–0.6	9
Eucinostomus argenteus	Spotfin mojarra	T		⦸	●	○	–	●	⦸	–	–	0–0.6	9
Heterandria formosa	Least killifish	R		●	○	⦸	–	–	–	●	○	0–3.7	9
Hippocampus zosterae	Dwarf seahorse, pygmy seahorse	T		○	⦸	●	◖	●	–	–	–	< 0.1	9
Orthopristis chrysoptera	Pigfish	R		●	●	–	–	●	⦸	–	–	0–0.2	8
Archosargus probatocephalus	Sheepshead	T	C, R	●	◖	–	–	●	⦸	–	–	0–0.7	7
Ariopsis felis	Hardhead catfish	T	C, R	⦸	●	⦸	–	●	⦸	⦸	–	< 0.1	7
Ctenogobius shufeldti	Freshwater goby	R		●	◖	○	–	–	–	●	◖	0.1–1.1	6
Dormitator maculatus	Fat sleeper	T		–	●	⦸	–	⦸	⦸	–	●	0–0.1	6
Fundulus pulvereus	Bayou killifish	R		–	●	○	–	◖	●	–	–	0–2.3	6
Gambusia affinis	Western mosquitofish	R		–	●	●	–	–	●	–	○	0.1–16.0	6
Lutjanus griseus	Gray snapper	T	C, R	⦸	●	○	–	●	–	–	–	< 0.1	6
Ophidion josephi	Crested cusk-eel	T		–	–	●	–	●	⦸	–	–	0–0.5	6
Pogonias cromis	Black drum	T	C, R	●	⦸	–	–	●	⦸	–	–	0–0.1	6
Dorosoma cepedianum	Gizzard shad	T	C (minor)	⦸	●	–	–	–	–	–	●	0–0.1	4
Evorthodus lyricus	Lyre goby	R		●	⦸	–	–	–	–	–	●	0–0.1	4
Gobionellus oceanicus	Highfin goby, sharptail goby	R		–	⦸	●	–	–	–	–	●	0–0.1	3
Syngnathus louisianae	Chain pipefish	T		–	–	●	–	●	⦸	–	–	0–0.1	3

Scientific name	Common name	Transient (T) or resident (R)	Commercial (C) or recreational (R)	Relative density by season: Spring	Sum-mer	Fall	Winter	Relative density by salinity zone: Saline	Brack-ish	Inter-mediate	Fresh	Density range (# of ind./m²)	Total number of records
Hyporhamphus unifasciatus	Halfbeak, silverstripe halfbeak	T		●	–	–	–	●	–	–	–	< 0.1	2
Lepisosteus oculatus	Spotted gar, shortnose gar	T	R	–	●	–	–	–	–	–	●	0–0.1	2
Lepomis macrochirus	Bluegill	R	R	–	●	–	–	–	–	–	●	0–0.1	2
Lobotes surinamensis	Tripletail, Atlantic tripletail	T	C	–	–	●	–	●	–	–	–	< 0.1	2
Micropterus punctulatus	Spotted bass	T	R	–	●	–	–	–	–	–	●	0–0.1	2
Ophichthus gomesii	Shrimp eel	T		●	–	–	–	●	–	–	–	< 0.1	2
Prionotus tribulus	Bighead searobin	T		●	–	–	–	●	–	–	–	< 0.1	2
Scartella cristata	Molly miller	R		–	–	●	–	●	–	–	–	< 0.1	2
Sphoeroides parvus	Least puffer	T		●	⊘	–	–	–	●	–	–	< 0.1	2
Eucinostomus melanopterus	Flagfin mojarra	T		–	–	●	–	●	–	–	–	0.3	1
Lepomis microlophus	Redear sunfish	R	R	–	–	●	–	–	–	●	–	0.3	1

Key finding: Within the saline zone, total nekton densities in SAV habitat were relatively similar across the spring and fall. However, seasonal trends were evident at the species level.

Within the saline zone, total nekton density, total crustacean density, and total fish density in SAV habitat were relatively similar during the spring and fall seasons (Figure 35). However, for a given taxa, densities were often variable across the two seasons (Figure 36). This was common for most transient species, such as brown shrimp (*Farfantepenaeus aztecus*), pink shrimp (*Farfantepenaeus duorarum*), white shrimp (*Litopenaeus setiferus*), Gulf menhaden (*Brevoortia patronus*), and pinfish (*Lagodon rhomboides*), but some resident species also displayed differences in densities between the two seasons (Figure 36). See Table S4 for the complete list of taxa densities by spring and fall.

Figure 35. Estimated mean density (# of individuals per m^2 ± 1 SE) of total nekton (sum of crustacean and fish species), total crustaceans, and total fish in SAV habitat during the spring and fall. For comparison, this analysis was limited to sampling conducted in the saline zone.

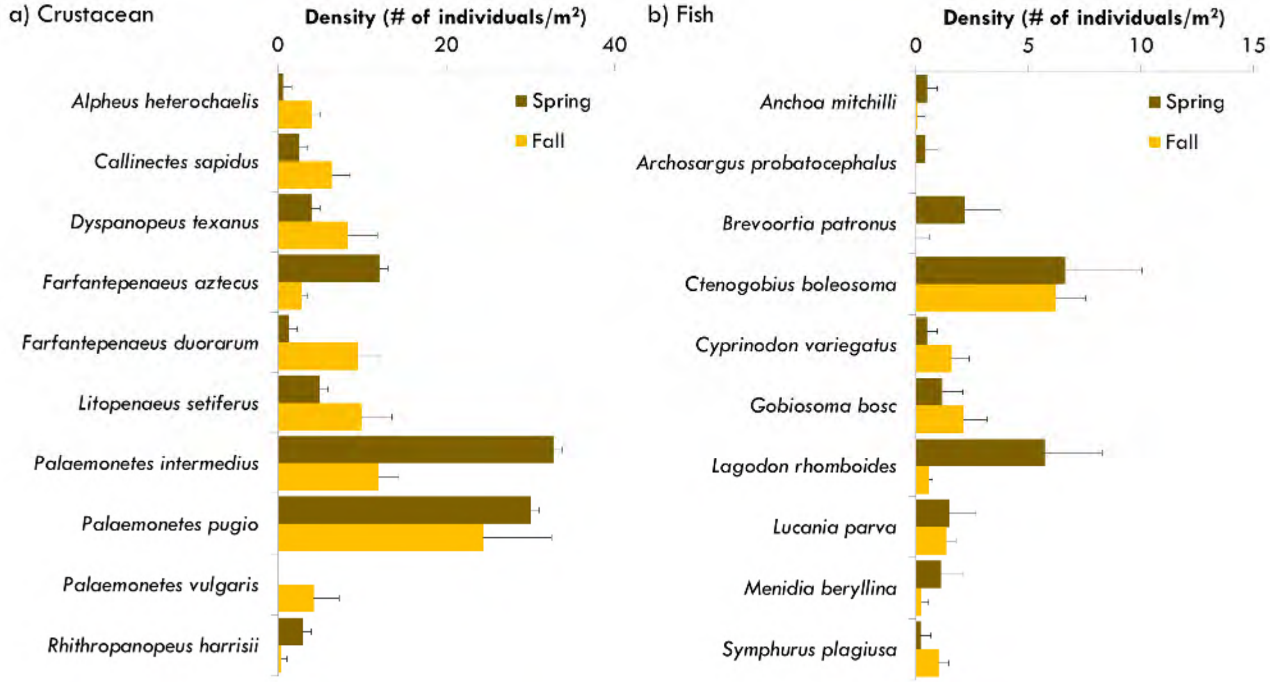


Source: Figures adapted from Hollweg et al. (2019b).

Key finding: Saline SAV habitat (primarily seagrass) supports many commercially and recreationally important species.

Commercially and recreationally important species observed in relatively high densities in saline SAV habitat included blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), pink shrimp (*Farfantepenaeus duorarum*), white shrimp (*Litopenaeus setiferus*), and pinfish (*Lagodon rhomboides*) (Figure 36). Other relatively less-abundant recreationally or commercial important species that were observed to use SAV habitat included sheepshead (*Archosargus probatocephalus*), spotted seatrout (*Cynoscion nebulosus*), spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias undulatus*), Southern flounder (*Paralichthys lethostigma*), black drum (*Pogonias cromis*), and red drum (*Sciaenops ocellatus*) (Table S4). Other studies have documented additional commercially and recreationally important species using SAV beds, such as snappers and groupers (e.g., Poulakis et al., 2003; Fodrie and Heck, 2011; De Angelo et al., 2014). For example, De Angelo et al. (2014) sampled fish assemblages using seines in seagrass beds along the Florida Gulf Coast, and observed relatively high abundances of economically important fish species including common snook (*Centropomus undecimalis*), gray snapper (*Lutjanus griseus*), lane snapper (*Lutjanus synagris*), and gag grouper (*Mycteroperca microlepis*), in addition to others that were found in this meta-analysis [e.g., sheepshead (*Archosargus probatocephalus*), spotted seatrout (*Cynoscion nebulosus*), pinfish (*Lagodon rhomboides*), spot (*Leiostomus xanthurus*), black drum (*Pogonias cromis*), and red drum (*Sciaenops ocellatus*)]. These specific studies were not included in the meta-analysis, as they did not fall within the specific habitat-season combinations analyzed (e.g., data were not separated by season).

Figure 36. Estimated mean density (# of individuals per m^2 ± 1 SE) of individual a) crustacean and b) fish species in SAV habitat in the saline zone during the spring and fall. Of the 50 taxa analyzed, this figure displays the 10 most-abundant fish species and 10 most-abundant crustacean species observed within this habitat-season combination. Estimated mean density values for all 50 taxa are presented in Table S4.



Source: Figures adapted from Hollweg et al. (2019b).

Additional considerations: Within SAV habitat, variations in nekton density are related to biotic and abiotic factors, including SAV cover/biomass, vegetation composition, and environmental conditions.

Many studies from the scientific literature have documented biotic and abiotic factors that affect nekton densities within SAV habitat (e.g., Scott, 1998; Kanouse et al., 2006; King and Sheridan, 2006; La Peyre and Gordon, 2012). For example, in Galveston Bay, TX, Scott (1998) found that SAV cover was the most important variable explaining variations in total fish and decapod density; additional variables that explained portions of variability included temperature, salinity, and water depth. In another study in Galveston Bay, TX, King and Sheridan (2006) observed variations in nekton density related to month and/or seagrass vegetation type for most-dominant nekton species. In a study of brackish marsh ponds in Louisiana, Kanouse et al. (2006) found a positive relationship between SAV and nekton biomass. La Peyre and Gordon (2012) found that salinity and SAV biomass were the dominant habitat variables influencing species assemblages.

5.4 Nekton Recovery Following SAV Restoration

Due to data limitations, a meta-analysis evaluating nekton recovery following SAV restoration was not conducted. However, site-specific studies from the scientific literature provide insights into the structural and functional development of this habitat following restoration in the northern Gulf of Mexico. A general summary of the literature is presented below. As most SAV restoration efforts are targeted on seagrass habitats, the studies presented below were primarily focused on this particular habitat type.

Key takeaway of literature review: Nekton colonization is relatively rapid following seagrass restoration, with densities similar to natural beds within five years. However, more studies are needed to determine if this trend is consistent across sites and longer time periods.

Structural development. Seagrass restoration projects via planting techniques in the Gulf of Mexico showed relatively quick development of vegetative structure, typically recovering within two–six years (Fonseca et al., 1996a; Sheridan, 2004; Bell et al., 2014). In some cases, studies observed an initial lag followed by a more rapid increase in seagrass cover (Fonseca et al., 1996a; Bell et al., 2014). However, restoration success was often variable, with survival of planting units low in some plots (Fonseca et al., 1996a; Sheridan et al., 1998; Bell et al., 2008).

Colonization by nekton. Colonization of seagrass by fish, shrimp, and crabs occurred on a similar timeframe as the development of the structured habitat, with densities similar to natural beds within two–five years (Fonseca et al., 1996b; Sheridan, 2004).

Colonization by benthic infauna. Bell et al. (1993) observed similar densities of annelids two–four years after restoration in Tampa Bay, FL. However, a study by Sheridan (2004) suggests that the development of infauna is slower at some sites, with densities of dominant benthic infauna not reaching equivalency to natural seagrass beds after eight years in Corpus Christi, TX.

6. Comparison of Nekton Use across Habitats

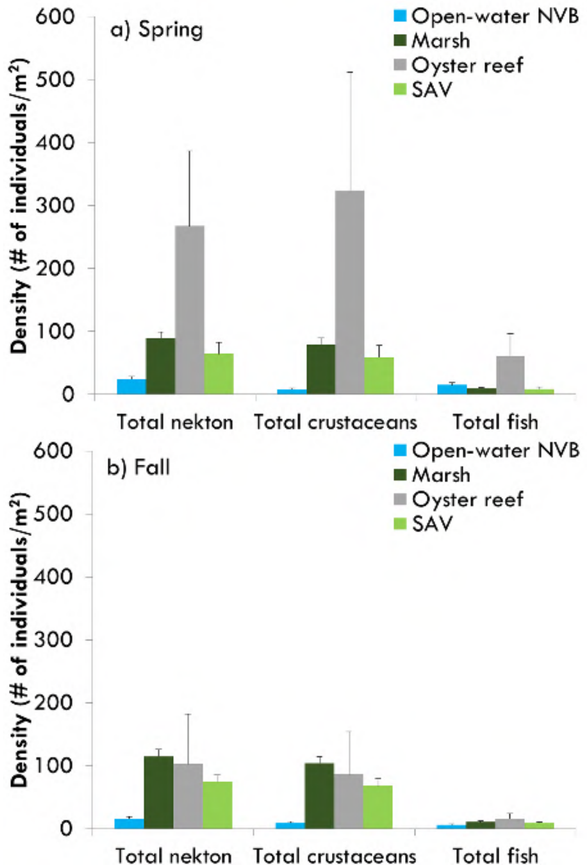
As presented above, marshes, oyster reefs, SAV beds, and open-water NVBs all serve as important habitats for nekton in the northern Gulf of Mexico. This section compares nekton use across the four estuarine habitats, including both nekton use (Section 6.1) and nekton composition (Section 6.2). Key findings of the meta-analysis are highlighted, with additional information from the scientific literature. As discussed in Section 2.2.2.2, the meta-analysis was limited to studies conducted in the saline zone during the spring and fall.

6.1 Nekton Use

Key finding: Within the saline zone during the spring and fall, total nekton and crustacean densities were higher in structured estuarine habitats (i.e., marsh, oyster reef, SAV) compared to open-water NVB habitat.

Total nekton density and total crustacean density were higher in structured estuarine habitats (e.g., marsh, oyster reef, SAV) than in open-water NVB habitat during both the spring and fall in the saline zone (Figure 37). Total fish density was somewhat higher in structured habitats compared to open-water NVB habitat during the fall, but during the spring, the highest densities were observed in oyster reef habitat, with densities in the other structured habitats (i.e., marsh, SAV) slightly lower than open-water NVB habitat (Figure 37). While total nekton densities were similar between the spring and fall in marsh, SAV, and open-water NVB habitats, total nekton densities in oyster reef habitat were nearly three times higher during the spring than the fall; only a few taxa appeared to drive these differences, with high variability among studies.

Figure 37. Estimated mean density (# of individuals per m^2 ± 1 SE) of total nekton (sum of crustacean and fish species), total crustaceans, and total fish in open-water NVB, marsh, oyster reef, and SAV habitats in the saline zone during the a) spring and b) fall.



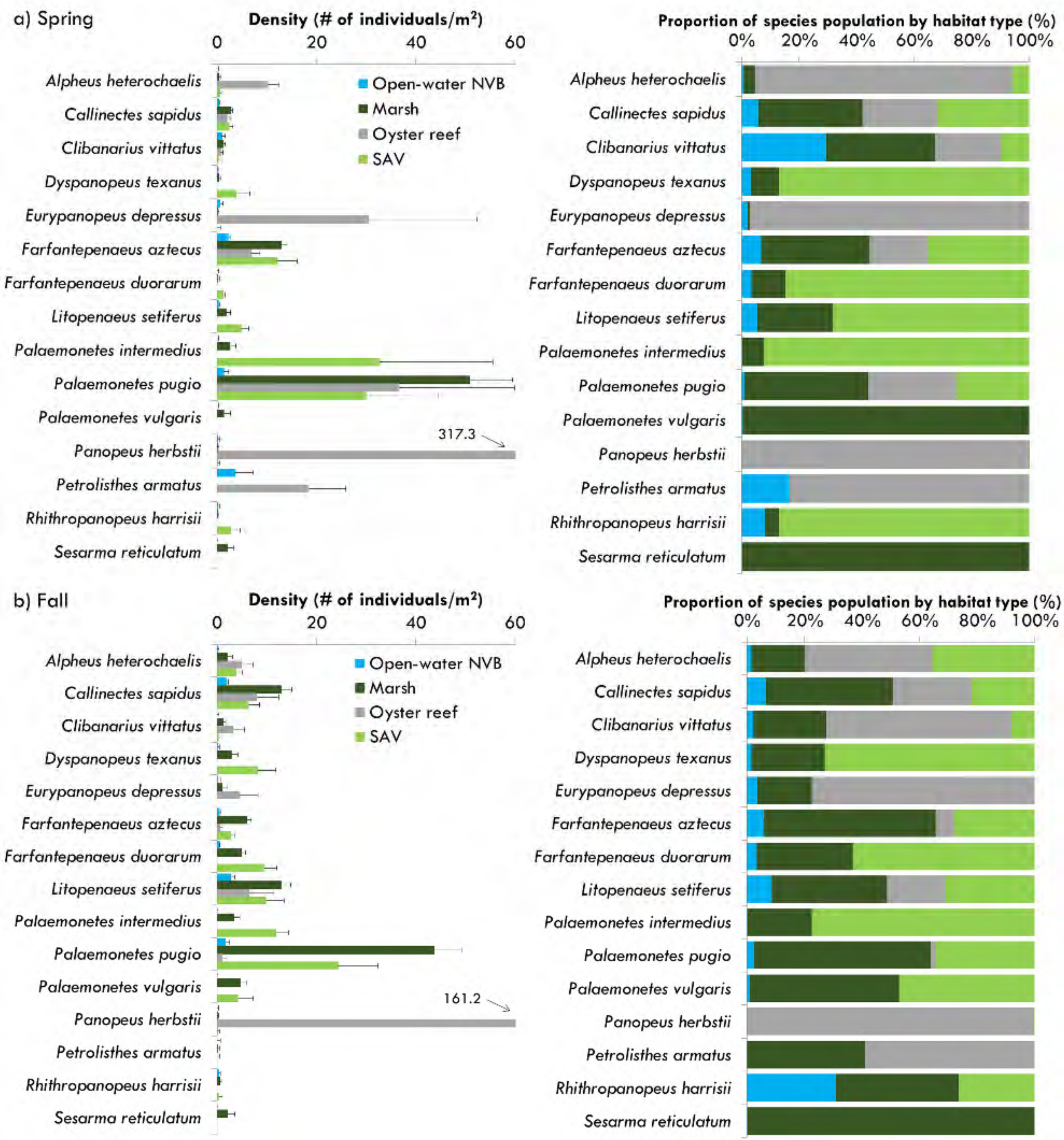
Source: Figures adapted from Hollweg et al. (2019b).

This meta-analysis is consistent with many site-specific studies in the Gulf of Mexico (many of which were included in the meta-analysis) that have documented higher nekton densities in one or more structured habitats compared to NVB habitat (e.g., Rozas and Minello, 1998, 2006; Castellanos and Rozas, 2001; Shervette and Gelwick, 2008; Stunz et al., 2010; Shervette et al., 2011). These findings are also similar to a regional analysis by Minello (1999).

Key finding: Many crustacean and fish species show a preference for structured habitats than unstructured habitats, with a few exceptions.

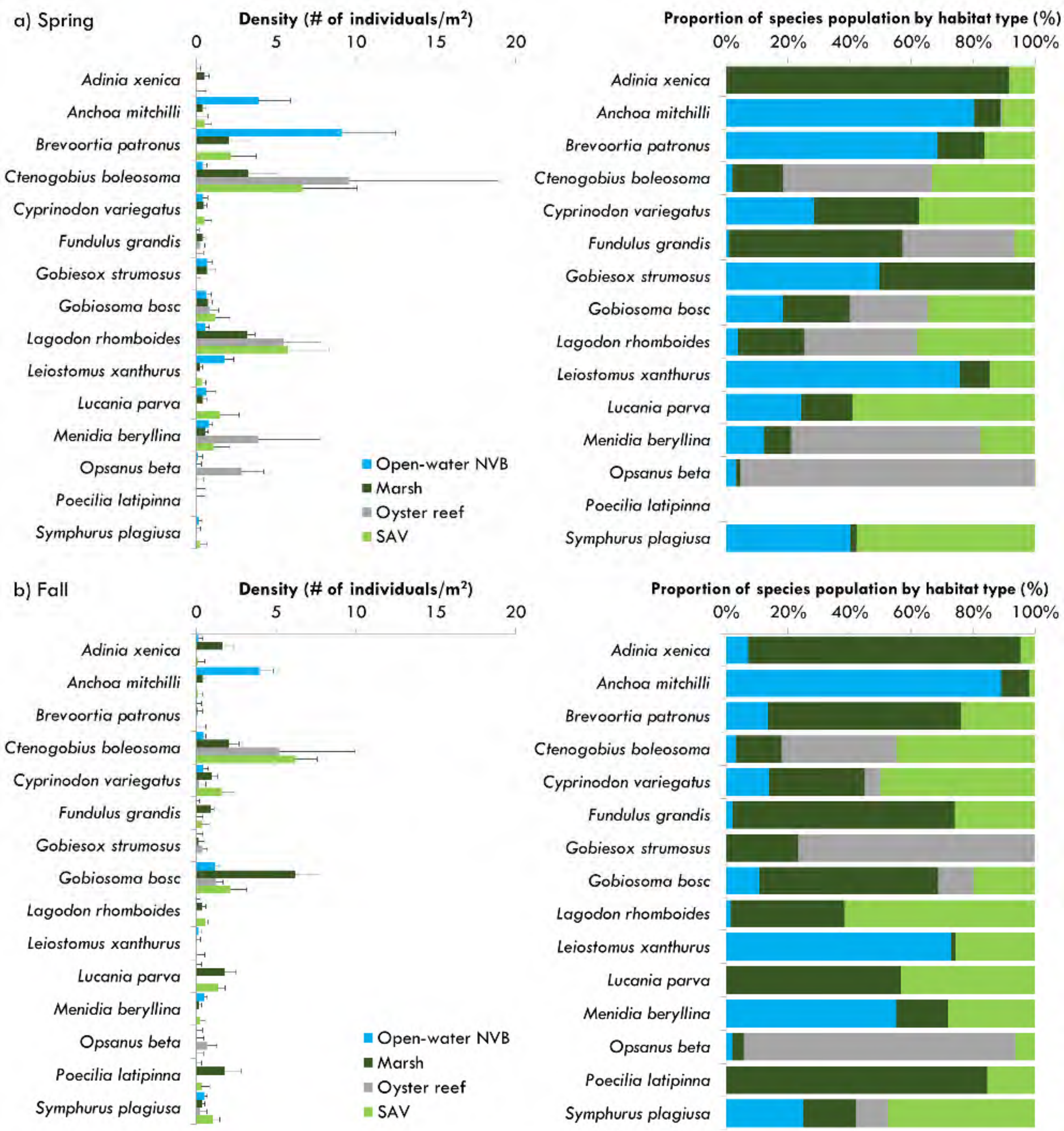
Densities of several crustacean and fish species were higher in structured habitats than in open-water NVB habitats, including blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), daggerblade grass shrimp (*Palaemonetes pugio*), darter goby (*Ctenogobius boleosoma*), and pinfish (*Lagodon rhomboides*) (Figure 38 and Figure 39). In contrast, bay anchovy (*Anchoa mitchilli*) and Gulf menhaden (*Brevoortia patronus*, spring) showed an opposite pattern, with higher densities in open-water NVB than structured habitats (Figure 39). See Table S4 for the complete list of taxa densities by habitat type.

Figure 38. Estimated mean density (# of individuals per m^2 ± 1 SE) and proportion of species population by habitat type (%) of individual crustacean species in open-water NVB, marsh, oyster reef, and SAV habitats in the saline zone during the a) spring and b) fall. Of the 50 taxa analyzed, this figure displays the 15 most-abundant crustacean species observed within this habitat-season combination. The proportion of species population by habitat type (%) was calculated by dividing a species mean density within one habitat type by the sum of the species densities across all four habitat types. Estimated mean density values for all 50 taxa are presented in Table S4.



Source: Figures adapted from Hollweg et al. (2019b).

Figure 39. Estimated mean density (# of individuals per m^2 ± 1 SE) and proportion of species population by habitat type (%) of individual fish species in open-water NVB, marsh, oyster reef, and SAV habitats in the saline zone during the a) spring and b) fall. Of the 50 taxa analyzed, this figure displays the 15 most-abundant fish species observed within this habitat-season combination. The proportion of species population by habitat type (%) was calculated by dividing a species mean density within one habitat type by the sum of the species densities across all four habitat types. Estimated mean density values for all 50 taxa are presented in Table S4.



Source: Figures adapted from Hollweg et al. (2019b).

6.2 Nekton Composition

Key finding: Within the saline zone during the spring and fall, the composition of nekton communities varied among habitat types. Marsh and SAV nekton composition were similar, but different from those associated with oyster reef and open-water NVB habitats, which supported unique assemblages.

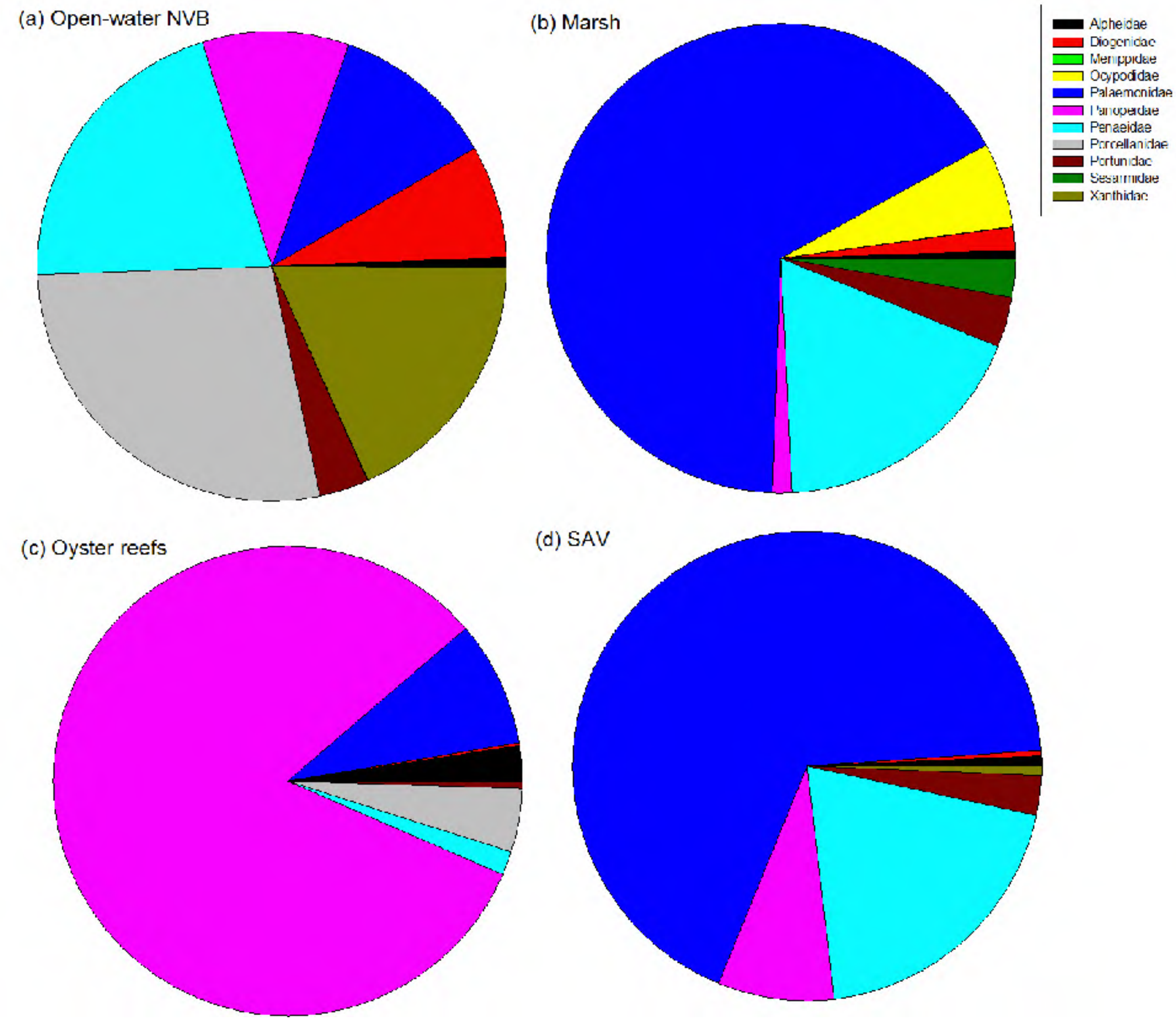
Open-water NVB habitat. Within the saline zone, open-water NVB habitat had a unique community composition compared to the other three habitat types (Figure 40a, Figure 41a, Figure 42a, Figure 43a). Species in the families Penaeidae (penaeid shrimp), Clupeidae [primarily Gulf menhaden (*Brevoortia patronus*, spring)], and Engraulidae (anchovies) were associated with open-water NVB habitat.

Marsh and SAV habitats. Within the saline zone, nekton community composition was relatively similar in marsh and SAV habitats, and consisted of species from the families Palaemonidae (grass shrimp), Penaeidae (penaeid shrimp), Fundulidae (killifish), Gobiidae (gobies), and Sparidae [primarily pinfish (*Lagodon rhomboides*, spring)] (Figure 40b, Figure 40d, Figure 41b, Figure 41d, Figure 42b, Figure 42d, Figure 43b, Figure 43d). Other site-specific studies in the Gulf of Mexico (some of which were included in the meta-analysis) also support this finding (e.g., Rozas and Minello, 1998, 2006; Castellanos and Rozas, 2001; Glancy et al., 2003). For example, Castellanos and Rozas (2001) found that among vegetation types in a tidal freshwater system, most species showed no apparent preference between SAV and marsh habitats. Similarly, Rozas and Minello (2006) found that in an oligohaline system, marsh and SAV habitats supported similar densities for most species, with a few exceptions. Variations in nekton densities across these two vegetated habitat types were found to be related to vegetative complexity (Rozas and Minello, 1998), water depth (Rozas and Minello, 1998, 2006), and distance to edge (Rozas and Minello, 2006). However, there are inconsistencies to this trend across individual studies, species, and seasons (e.g., Rozas et al., 2012).

Oyster reef habitat. Oyster reef habitat had a unique community composition compared to the other three habitat types (Figure 40c, Figure 41c, Figure 42c, Figure 43c). Oyster reef habitat consisted of species in the families Panopeidae (mud crabs), Batrachoididae [primarily toad fish (*Opsanus tau*)], Gobiidae (gobies), and Sparidae [primarily pinfish (*Lagodon rhomboides*, spring)]. Several other site-specific studies across the Gulf of Mexico (many of which were included in the meta-analysis) have reported that the nekton community composition of oyster reefs differs from that of marsh (Glancy et al., 2003; Shervette and Gelwick, 2008; Gain, 2009; Nevins et al., 2014) and SAV (Glancy et al., 2003; Gain, 2009) habitats. For example, oyster reefs supported a higher density and biomass of benthic crustaceans than vegetated marsh edge, such as green porcelain crab (*Petrolisthes armatus*), flatback mud crab (*Eurypanopeus depressus*), Atlantic mud crab (*Panopeus herbstii*), mud crab (Xanthidae spp.), and snapping shrimp (Alpheidae spp.) (Stunz et al., 2010). Similarly, decapod assemblages associated with oyster reefs were distinct from those associated with seagrass and marsh edge habitats, and high densities of flatback mud crab (*Eurypanopeus depressus*), green porcelain crab (*Petrolisthes armatus*), and Atlantic mud crab (*Panopeus herbstii*) accounted for the major differences in oyster reefs compared to the other two habitat types (Glancy et al., 2003). This difference in community composition has been attributed to the unique structure of oyster reefs, which possess numerous refugia accessible to small crabs, such as mud crab (Shervette et al., 2011). These results support the idea that oyster reefs provide an ecologically unique and important habitat for fish and crustacean species (Glancy et al., 2003; Robillard et al., 2010).

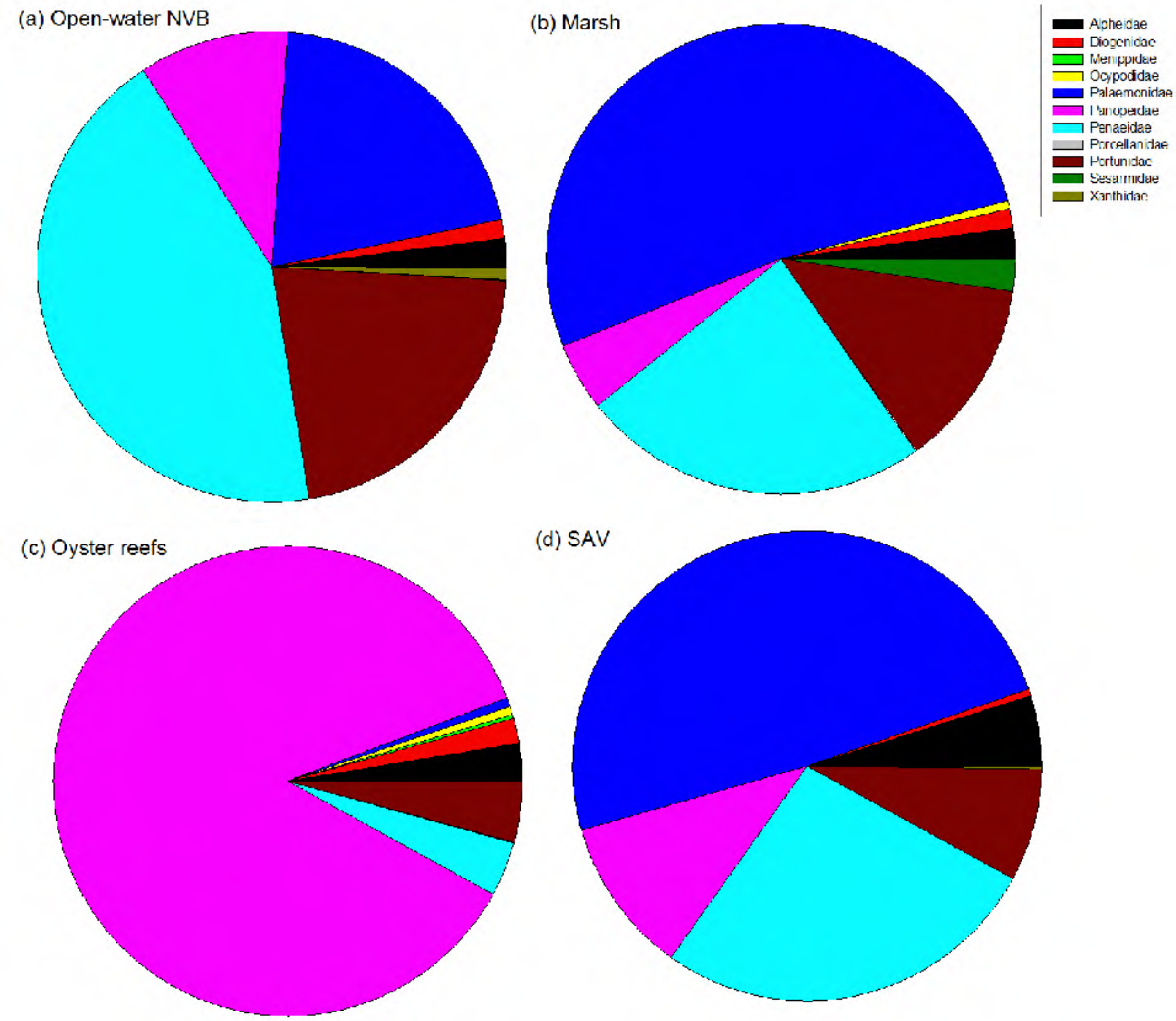
See Table S4 for the complete list of taxa densities by habitat type.

Figure 40. Relative abundance of crustacean families in the spring by habitat type in the saline zone. Wedge size corresponds to the proportional densities of each family relative to the total family densities for each habitat type reported in the spring. Habitat types include (a) open-water NVB, (b) marsh, (c) oyster reefs, and (d) SAV during the spring.



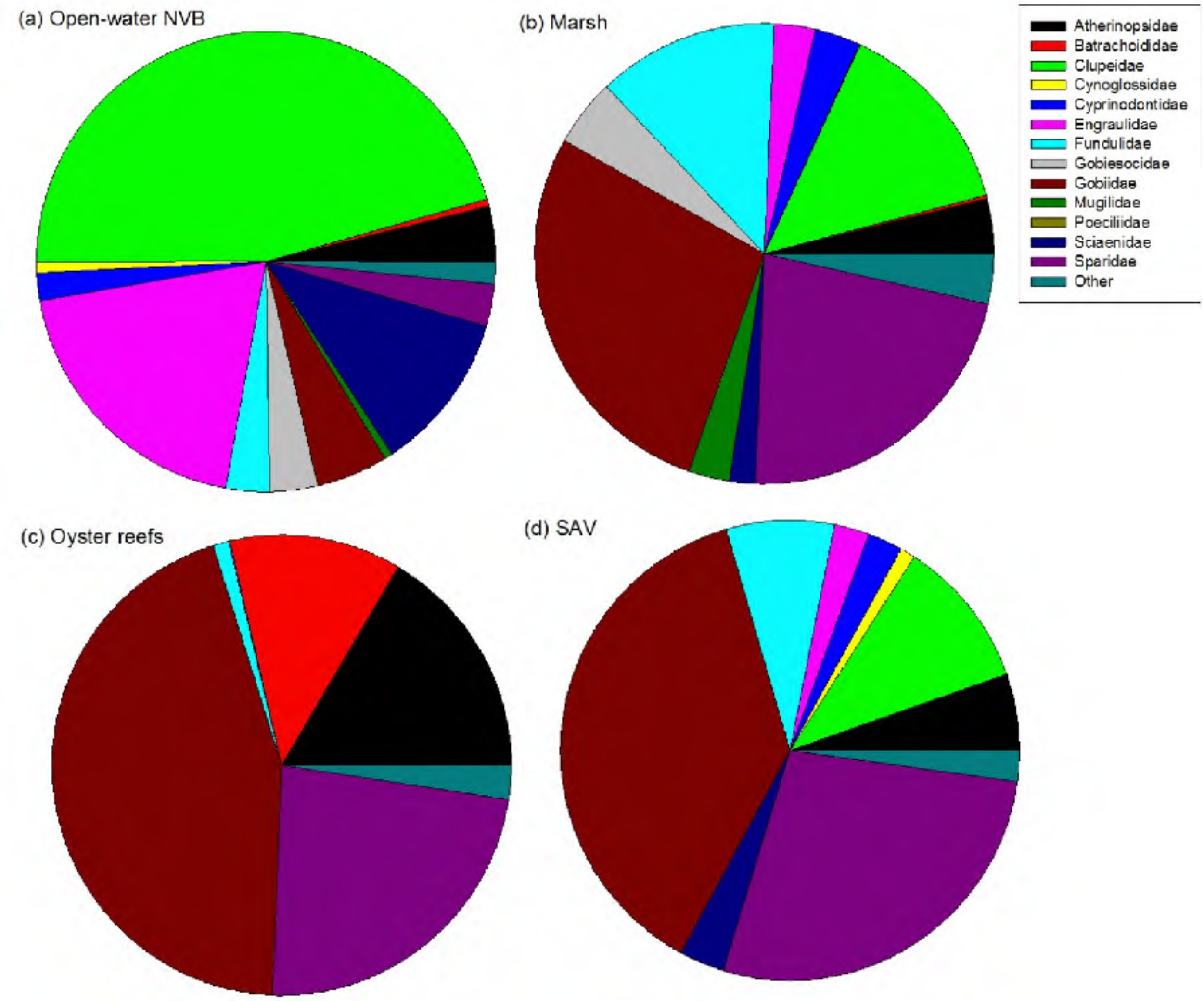
Source: Figures from Hollweg et al. (2019b).

Figure 41. Relative abundance of crustacean families in the fall by habitat type in the saline zone. Wedge size corresponds to the proportional densities of each family relative to the total family densities for each habitat type reported in the fall. Habitat types include (a) open-water NVB, (b) marsh, (c) oyster reefs, and (d) SAV during the fall.



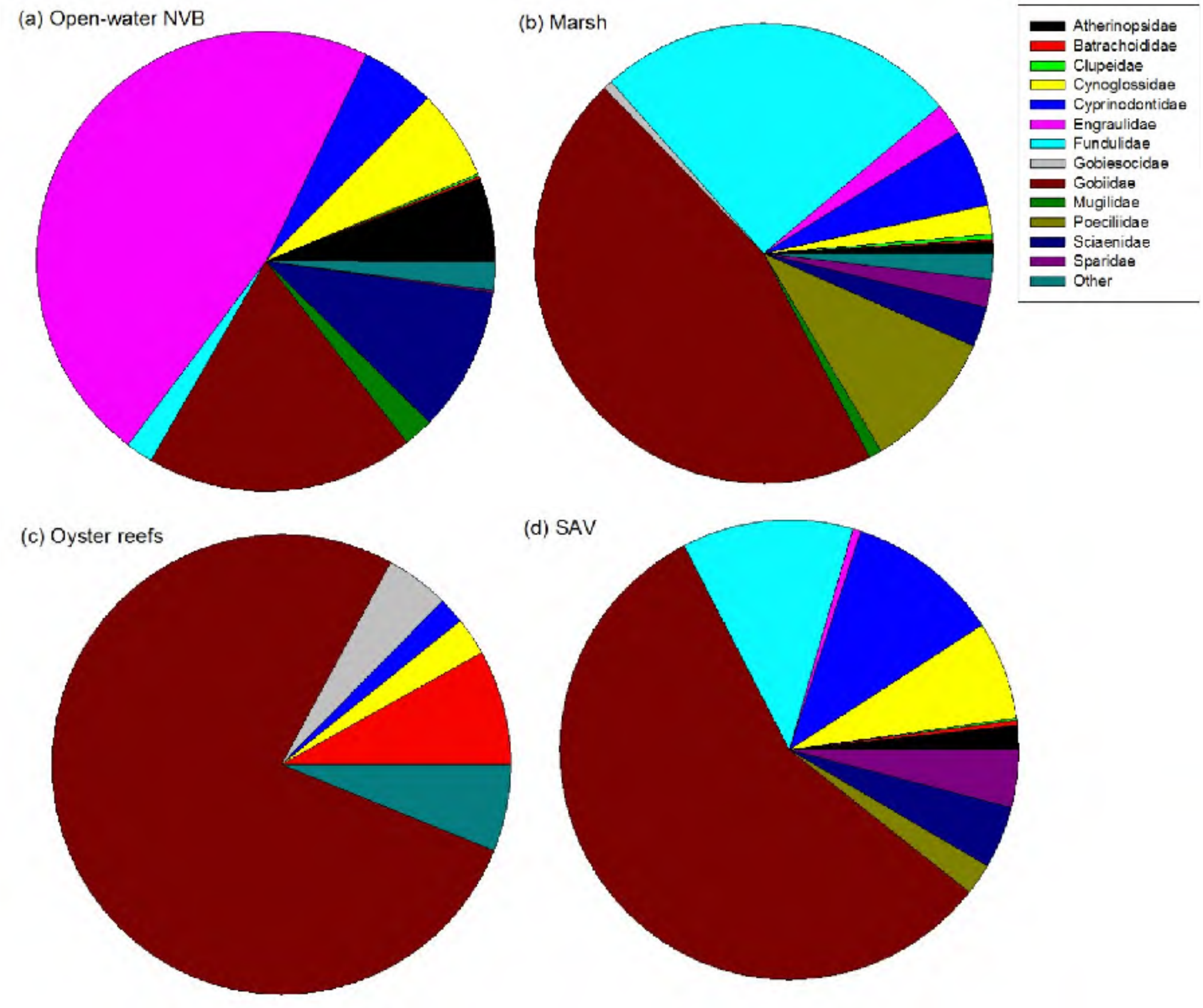
Source: Figures from Hollweg et al. (2019b).

Figure 42. Relative abundance of fish families in the spring by habitat type in the saline zone. Wedge size correspond to the proportional densities of each family relative to the total family densities for each habitat type reported in the spring. Habitat types include (a) open-water NVB, (b) marsh, (c) oyster reefs, and (d) SAV during the spring.



Source: Figures from Hollweg et al. (2019b).

Figure 43. Relative abundance of fish families in the fall by habitat type in the saline zone. Wedge size corresponds to the proportional densities of each family relative to the total family densities for each habitat type reported in the fall. Habitat types include (a) open-water NVB, (b) marsh, (c) oyster reefs, and (d) SAV during the fall.



Source: Figures from Hollweg et al. (2019b).

7. Discussion

This guidebook is intended to provide information on habitat-specific nekton use and recovery to help natural resource managers and restoration practitioners plan, design, implement, and evaluate habitat restoration and protection projects. For example, information has been presented that can be used to aid in:

- Communicating expected benefits of restoration and protection projects – such as benefits to commercially, recreationally, and/or ecologically important species that use these habitat types
- Setting conservation and restoration goals – these goals could include expected densities of specific species or target species composition
- Designing projects to maximize benefits for important resources – such as the location of projects or key project elements (e.g., high ratio of marsh edge to open water)
- Identifying important components of the project to monitor – including not only the nekton community but abiotic and biotic parameters that are known to influence nekton abundance and distribution
- Determining if projects are on-track for success or if there is the need for corrective actions or adaptive management – including what densities and species to expect, when to expect them, and other considerations that may influence recovery or explain the observed variability.

Below we present a summary of key findings and considerations (Section 7.1); the utility of meta-analysis and key limitations (Section 7.2); additional considerations for project planning, monitoring, and evaluation (Section 7.3); and data gaps and future needs (Section 7.4).

7.1 Summary of Key Findings and Considerations

Despite the clear ecological and commercial importance of estuarine habitats to fish and crustacean species, few studies have summarized patterns of nekton use (e.g., Minello, 1999; Minello et al., 2003) or nekton recovery following restoration (e.g., Moreno-Mateos et al., 2012) at regional or global scales. By compiling data reported in the scientific and grey literature on nekton abundance and density collected in restored and reference estuarine habitats throughout the northern Gulf of Mexico, this guidebook identified key patterns among and within habitat types, across salinity zones and seasons, and between restored and reference sites. Below, a summary of key findings are presented.

Overall

- Habitat type, salinity zone, and season were important drivers of variations in nekton density; in particular, structured, saline estuarine habitats (marsh, SAV, oyster reefs) tend to support relatively high densities of ecologically and commercially important crustacean and fish species.
- Habitat type, salinity zone, and season were also important drivers in individual species distribution and assemblages; in particular, habitat and salinity zone-specific seasonal changes

in species assemblages were evident, reflecting differences in species habitat use and life history requirements.

- Based on a literature review, nekton recovery following oyster reef and SAV restoration appears to be relatively quick. However, based on the results of a meta-analysis, nekton recovery following marsh restoration appears to be more delayed, with nekton densities at restored marsh sites generally lower than at reference sites, even more than a decade post-restoration in some cases. This is particularly true in the earlier years, during which time baseline ecological functions (e.g., sediment characteristics, organic matter, nutrient composition) must develop to support subsequent phases of ecological recovery (e.g., productivity of benthic infauna, fish, and crustaceans).
- The results of the meta-analyses are consistent with site-specific studies from the Gulf of Mexico (many of which were included in the analyses) and regional and global analyses, and provide further evidence for the observed patterns in nekton use of restored and reference estuarine habitats at a regional scale.

Nekton Use of Marsh Habitat and Adjacent Open-Water Habitat

- In the saline zone, the marsh edge supports higher total nekton densities compared to marsh interior or open-water NVB habitats. This trend was primarily driven by densities of many crustacean species, whereas density patterns of fish species were more variable across taxa. Many transient fish and crustacean species (including those that are commercially and recreationally important) and some resident species exhibited higher densities in the saline marsh edge compared to the other habitat zones, while other resident species were more abundant in the marsh interior.
- Total nekton density was highest in saline marsh compared to brackish and intermediate zones, primarily driven by total crustacean density. Saline and brackish marsh support high densities of many commercially and recreationally important species. However, the intermediate zone should not be dismissed for its importance to coastal fisheries due to life history requirements of some species, its large area, and the potential for changing environmental conditions.
- In the saline zone, total nekton densities were highest during the spring, summer, and fall; and decreased over the winter. However, seasonal trends varied by species and reflected species-specific life history patterns.
- Temperature and salinity were shown to have an effect on nekton density (including total communities and individual species), with many of the effects being interactive. However, the exact nature and extent of the effects varied across taxa, marsh landscape, and seasons.
- Using a meta-analysis approach, total nekton densities measured on the marsh platform at restored marsh sites were generally lower than densities measured on the marsh platform at reference marsh sites during the first decade following restoration, but then approached reference values in the later years. Reasons for the slow recovery of nekton following restoration may be attributed to several abiotic and biotic factors, including differences in the physical structure and/or the slow development of biological components of the restored habitat.

Nekton Use of Oyster Reef Habitat

- Within the saline zone, total nekton densities were relatively higher during the spring than the fall; however, seasonal trends varied by species.
- Nekton using oyster reef habitat were dominated by year-round resident species. Oyster reefs also support commercially and recreationally important species.

- Based on a literature review, faunal colonization is relatively rapid following oyster reef restoration, with nekton densities and assemblages matching reference reefs within a year or two following restoration.

Nekton Use of SAV Habitat

- Within the saline zone (dominated by seagrass habitat), total nekton densities were relatively similar across the spring and fall; however, seasonal trends were evident at the species level.
- Saline SAV habitat (primarily seagrass) supports many commercially and recreationally important species.
- Based on a literature review, nekton colonization is relatively rapid following seagrass restoration, with densities similar to natural beds within five years.
- Limited data exist in brackish or intermediate SAV habitats related to faunal use or colonization post-restoration.

Comparison of Nekton Use across Habitats

- Within the saline zone, total nekton densities were higher in structured estuarine habitats (i.e., marsh, oyster reefs, and SAV) compared to open-water NVB habitats. At a species level, many crustacean and fish species showed a preference for structured habitat than unstructured habitat, with a few exceptions [e.g., bay anchovy (*Anchoa mitchilli*), Gulf menhaden (*Brevoortia patronus*)].
- The composition of nekton communities varied among habitat types in the saline zone. Marsh and SAV nekton composition was similar, but different from those associated with oyster reef and open-water NVB habitats, which supported unique assemblages.

7.2 Utility of Meta-Analysis and Key Limitations

This study provides support for the utility of conducting meta-analyses of separate datasets to understand nekton use across the region. These meta-analyses highlighted several important trends in nekton densities associated with both relatively static (e.g., habitat type, marsh landscape) and more dynamic (e.g., season, salinity, recovery following restoration) features across estuarine habitats in the northern Gulf of Mexico. These results are also generally consistent with many site-specific studies from the Gulf of Mexico as well as regional and global analyses (e.g., Minello, 1999; Minello et al., 2003), and provide further evidence in support of these patterns at a regional scale. Furthermore, the meta-analytical approach presented allows for the ability to aggregate densities from different studies, using different gear types, to understand key research questions. This protocol is relatively easy to apply and implement for diverse research and management purposes, and can be used to advance our understanding of the value and role of coastal habitats to nekton communities.

Notably, however, there were inconsistencies in patterns across species, seasons, habitat types, and studies, and in some cases high variability when studies were aggregated. Much of this is due to the nature of working with nekton data and combining data across studies. More specifically, likely reasons for the observed variability are several-fold, and include:

- Nekton densities are inherently highly variable due to variations in site conditions (e.g., hydroperiod, elevation), habitat conditions (e.g., vegetation, soil, water quality), prey availability, other environmental conditions (e.g., temperature, salinity), disturbances (e.g., storms), and annual recruitment.

- While the meta-analyses aggregated data by season, salinity zone, and habitat type, additional site-specific, sampling protocol, and timing factors likely contribute to variations in nekton densities within these habitat-season combinations.
- Nekton are highly mobile, moving between coastal habitats on smaller timescales, such as hours to days; and migrating across larger geographic ranges on longer timescales, such as months to years. Due to logistical and financial constraints, it is challenging to adequately sample to capture these trends.
- Low sample sizes, in combination with a high variability of nekton data, often result in high variance and difficulty detecting differences across treatments.
- Additional sources of error related to the general analytical approach used, such as aggregating data into general categories (e.g., season, salinity zone, habitat type) and standardizing data using gear correction factors. While habitat-specific gear correction factors were used, gear efficiency may vary by user, species, and site conditions (e.g., water clarity, vegetative cover).

Many of these caveats are inevitable byproducts of meta-analyses that combine data from different, independent sources, such as disparate sites, times, sampling protocols, and restoration techniques.

The results presented were also restricted to the habitat-season combinations and taxa included in the meta-analysis. For example, this guidebook only presented corrected density data for the top 50 taxa; and conducted more limited analyses in oyster reef, SAV, and open-water NVB habitats compared to marsh habitat. In addition, many of the data included in the meta-analysis were from Louisiana and Texas. Furthermore, this guidebook primarily presented density and relative abundance data; however, other metrics (e.g., diversity, size) are also important indicators of the nekton community. See Section 7.4 for a discussion on data gaps and future needs.

7.3 Additional Considerations for Project Planning, Monitoring, and Evaluation

As discussed above, this guidebook is intended to provide information to resource managers to aid in the planning, design, implementation, and evaluation of restoration and protection projects. Below are additional considerations for target setting (Section 7.3.1), project monitoring (Section 7.3.2), and project evaluation (Section 7.3.3).

7.3.1 Target Setting

Establishing milestones or targets for restoration and protection projects are important to help project managers determine if their projects are on-track or if interim corrective actions are needed. However, setting targets for nekton use can often be difficult due to the inherent variability in nekton data, which may necessitate very large sample sizes to achieve a given precision. Below, a few considerations are provided when developing targets for the nekton community.

Consider setting a relative target rather than an absolute target. Setting an absolute target (e.g., 50 individuals per m^2) may not be useful in some cases, particularly when a desired endpoint is not well-understood or there is no clear value that would constitute restoration success. Thus, one could consider setting a relative target that incorporates comparisons of the key metric in respect to a control site (e.g., 10% increase over a control) or a reference site (e.g., similar to a reference site), or from existing conditions (e.g., 10% increase per year).

Consider metrics other than total nekton density. Due to the high variability of nekton data, total nekton density (# of individuals per m^2) can be difficult to measure with a given precision and accuracy, and detecting a change over baseline values may be challenging. Total values may also miss key species or life stages. Thus, consider setting targets based on species diversity (# of species) or the presence of target species that may be either indicator species or key species valued for their ecological or economic role.

7.3.2 Project Monitoring

Robust quantitative study designs are critical for effectively monitoring the success of restoration and protection efforts, and to inform adaptive management. Recently, several studies have outlined specific monitoring considerations for restoration projects, which can be used to better inform nekton habitat needs and adaptively manage ongoing and planned restoration efforts (e.g., Baggett et al., 2014; NAS, 2016; DWH NRDA Trustees, 2017). Below, a few considerations and recommendations are provided when planning and implementing monitoring efforts to assess nekton use of restored or protected habitats.

Identify goals and objectives. Optimal sampling designs vary depending on the questions the study is intended to answer, the types of data that will be collected, and the planned statistical analyses. In designing a sampling plan, the restoration team should consider the goals and objectives of the project, the proposed monitoring effort, and the analyses the team will conduct when evaluating the monitoring data.

Consult other experts. Consulting a statistician and a natural resource expert early on in the process can help identify analyses and focus data collection efforts.

Identify baseline data. Baseline data from the site targeted for restoration or protection provide valuable information for assessing changes to the system following the intervention. If baseline data are available, determine how they were collected, if the data are current and consistent, and if the methods suit the monitoring goals. If the data appear to be valuable and the methods suit the monitoring goals, the project team may consider using or adapting the baseline data collection methods when collecting new data to allow for comparison with the existing data.

Identify an appropriate reference and/or control site. Adding a reference site (i.e., desired state) and/or control site (i.e., unrestored state) to a study design is often desirable. As many environmental factors affect community structure and function, the selection of an appropriate reference or control site relies on identifying similar site conditions, such as hydrology and elevation. However, as many variables influence the suitability of a reference or control site, incorporating them into a study design can often be costly and difficult. In the State of Louisiana, the Coastwide Reference Monitoring System consists of a network of many reference sites that allows for comparisons against a large sample of various habitat types for environmental factors (Folse et al., 2018). Similarly, many states have long-term fisheries sampling efforts that might provide some long-term records of nekton communities captured in certain habitats or regions that could be used for comparison.

If both a control site and baseline data are used in the monitoring design, the statistical methodology is known as the before-after, control-impact (BACI) approach (Stewart-Oaten and Bence, 2001). This common method involves measuring endpoints at a project and a control site before the intervention, and throughout the intervention process. Using a BACI design helps researchers determine whether changes are likely to be due to the intervention, or to other factors.

Consider stratification. The distribution and condition of fauna can be greatly affected by the habitat type and other site characteristics. If the project site is heterogeneous, the project team may want to consider stratifying the sampling based on habitat type and other observed differences (e.g., vegetation, elevation, distance from marsh edge). The inclusion of "strata," or groups with the same set of characteristics, can improve the precision of estimates for each strata, and allow for comparison within the sub-habitats to the controls. However, if this approach is taken, more sampling is likely required spatially (or temporally), which may be more than the project team initially planned for.

Pair resource assessments with ancillary data collection. The distribution and condition of fauna are strongly affected by local environmental conditions of the site. Thus, environmental data should be collected concurrently with the resource sampling to aid in statistical analyses. Including the variables that have a known effect on resource distribution and condition can improve power and precision in the same way that stratification can. In addition to nekton sampling, the project team should consider collecting water quality data (e.g., temperature, salinity, dissolved oxygen, turbidity), sediment data (e.g., bulk density, organic matter content, grain size distribution), and additional environmental information (e.g., habitat type, distance from marsh edge, water depth, time of day, tidal cycle).

Select the appropriate gear type(s) for the target species, and use the same gear type(s) and level of effort throughout the study. Gear types are known to vary in their ability to capture target organisms, and their capture ability may differ across different habitat types (Rozas and Minello, 1997). Thus, it is important to select the appropriate gear(s) based on the habitat type and/or species targeted, and use the same gear type(s) and level of effort for the duration of the study. Also, if other data are available for comparison (e.g., collected during baseline, or at a control or reference site), the project team may consider using the same gear type and method when collecting new data to allow for comparison with the existing data.

7.3.3 Project Evaluation

Following the collection of monitoring data, a critical next step is the evaluation of the data to determine if the project is on-track and/or if there is the need for adaptive management. When evaluating project success in regard to nekton use, it is suggested to:

1. Assess not only the total abundance but also the abundance of a particular species that may be slower to respond, more sensitive to changes, representative of a group of species (e.g., indicator species), or of specific interest (e.g., commercially important species)
2. Evaluate other metrics of functional equivalence, such as nekton community composition, fish health or condition factor, growth rates, population age/size structure, and food web structure
3. Separate analyses by site characteristics (e.g., habitat type, landscape position) or sampling variables (e.g., gear types, seasons)
4. Evaluate sampling over many years to better understand recovery trajectories
5. Compare results to an appropriate reference or control site with similar environmental conditions
6. Evaluate whether ancillary data explain variability in nekton use (e.g., water quality, sediment quality, distance to marsh edge).

7.4 Data Gaps and Future Needs

As evidenced by this guidebook, there is a vast amount of research that has gone into understanding nekton use of estuarine habitats in the Gulf of Mexico. However, this study also identified some key data gaps and future needs to further investigate how patterns of nekton use vary spatially and temporary, and the functional equivalence of restored sites to natural sites. Key data gaps and future needs include:

- **Understanding of baseline conditions and sources of short- and long-term variation.** Knowing the historical variation and densities of nekton communities provide valuable insight into evaluating outcomes. Long-term monitoring programs provide insight into variation in environmental conditions and nekton communities over seasonal, annual, and inter-annual cycles.
- **Additional spatial and temporal analyses.** This guidebook presents nekton density by specific habitat-season combinations, with more information presented for marsh habitat compared to oyster reef and SAV habitats, driven by data availability. Additional data collection and/or synthesis of existing data on nekton use for these other habitats spatially and temporally would be valuable.
- **Going beyond density.** This guidebook focuses on presenting density values for total nekton, total fish, and total crustaceans; as well as densities for specific species. However, further evaluation of how the nekton community varies across and within habitat types and between restored and reference sites using other metrics, such as species composition, size distribution, growth, etc., would be valuable.
- **Biotic or abiotic factors that affect nekton recovery of restored sites.** Due to data limitations, this study was unable to investigate how aspects of restoration design (e.g., plantings, dredge material source) or site conditions (e.g., elevation, soil, marsh edge) affect nekton use and recovery of a restored site. While site-specific studies often document explanations for observed differences, a quantitative or qualitative synthesis of this information would be beneficial.
- **Long-term monitoring of restoration projects.** A limited number of studies in the scientific literature have monitored nekton use of restored habitats on longer time scales, especially for oyster reef and seagrass restoration projects. This information would be valuable to understand longer-term trends of nekton use of these important habitats and recovery following restoration.
- **Productivity of estuarine habitats.** While numerous studies have documented nekton use (e.g., density, species composition) of estuarine habitats, only a limited number have quantified the productivity of these habitats. This information would be valuable to communicate the importance of restoring these estuarine habitats.
- **Onshore-offshore connectivity.** Many transient species are known to use estuarine habitats as juveniles before moving offshore as adults. More information is needed on onshore-offshore connectivity, and the relative contribution of the estuarine environment to offshore production.
- **Standardization of nekton densities by gear types.** While this guidebook presents an approach to standardize nekton densities for a variety of gear types, further work is suggested to refine and validate these correction factors.

8. Other Sources of Information

Additional sources are presented below, organized by topic.

Importance of Estuarine Habitats

Beck, M.W., K.L. Heck Jr., K.W. Able, D.L. Childers, D.B. Eggleston, B.M. Gillanders, B. Halpern, C.G. Hays, K. Hoshino, T.J. Minello, R.J. Orth, P.F. Sheridan, and M.P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. *Bioscience* 51(8):633–641.

Chesney, E.J., D.M. Baltz, and R.G. Thomas. 2000. Louisiana estuarine and coastal fisheries and habitats: Perspectives from a fish's eye view. *Ecological Applications* 10(2):350–366.

Deegan, L.A., J.E. Hughes, and R.A. Rountree. 2000. Salt marsh ecosystem support of marine transient species. In *Concepts and Controversies in Tidal Marsh Ecology*. Kluwer Academic Publishers, Boston, MA. pp. 333–365.

O'Connell, M.T., C.D. Franze, E.A. Spalding, and M.A. Poirrier. 2005. Biological resources of the Louisiana coast: Part 2. Coastal animals and habitat associations. *Journal of Coastal Research SI* 44:146–161.

Other Regional and National Compilations of Nekton Use

McIvor, C.C. and L.P. Rozas. 1996. Direct nekton use of intertidal saltmarsh habitat and linkage with adjacent habitats: A review from the southeastern United States. In *Estuarine Shores: Evolution, Environments and Human Alterations*, K.F. Nordstrom and C.T. Roman (eds.). John Wiley & Sons, New York. pp. 311–334.

Minello, T.J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat. *American Fisheries Society Symposium* 22:43–75.

Minello, T.J., K.W. Able, M.P. Weinstein, and C.G. Hays. 2003. Salt marshes as nurseries for nekton: Testing hypotheses on density, growth and survival through meta-analysis. *Marine Ecology Progress Series* 246:39–59.

Nelson, D.M. (ed.). 1992. *Distribution and Abundance of Fishes and Invertebrates in Gulf of Mexico Estuaries, Volume I: Data Summaries*. ELMR Rep. No. 10. NOAA/NOS Strategic Environmental Assessments Division, Rockville, MD. September. Available: https://repository.library.noaa.gov/view/noaa/2882/noaa_2882_DS1.pdf.

NOAA. 2017. Estuarine Living Marine Resources Database. National Oceanic and Atmospheric Administration. Available: https://products.coastalscience.noaa.gov/elmr/.

Pattillo, M.E., T.E. Czapla, D.M. Nelson, and M.E. Monaco. 1997. *Distribution and Abundance of Fishes and Invertebrates in Gulf of Mexico Estuaries, Volume II: Species Life History Summaries*. ELMR Rep. No. 11. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD. August.

Gear Correction Reviews

Rozas, L.P. and T.J. Minello. 1997. Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: A review of sampling design with focus on gear selection. *Estuaries* 20(1):199–213.

Monitoring and Evaluation Guidelines

Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock. 2014. *Oyster Habitat Restoration Monitoring and Assessment Handbook*. The Nature Conservancy, Arlington, VA. Available: http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf.

DWH NRDA Trustees. 2017. *Monitoring and Adaptive Management Procedures and Guidelines Manual*. Version 1.0. Appendix to the Trustee Council Standard Operating Procedures for Implementation of the Natural Resource Restoration for the DWH Oil Spill. *Deepwater Horizon* Natural Resource Damage Assessment. December. Available: https://www.gulfspillrestoration.noaa.gov/sites/default/files/2018_01_TC_MAM_Procedures_Guidelines_Manual_12-2017_508_c.pdf.

NAS. 2016. *Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico*. The National Academies of Sciences. The National Academies Press, Washington, DC. Available: http://dels.nas.edu/Report/Effective-Monitoring-Evaluate-Ecological-Restoration/23476.

U.S. EPA. 1994. *Guidance for the Data Quality Objectives Process*. EPA/600/R-96/0565. U.S. Environmental Protection Agency. September. Available: https://archive.epa.gov/epawaste/hazard/web/pdf/epaqag4.pdf.

zu Ermgassen, P., B. Hancock, B. DeAngelis, J. Greene, E. Schuster, M. Spalding, and R. Brumbaugh. 2016. *Setting Objectives for Oyster Habitat Restoration Using Ecosystem Services: A Manager's Guide*. The Nature Conservancy, Arlington VA. Available: http://www.oyster-restoration.org/setting-objectives-for-oyster-habitat-restoration-using-ecosystem-services-a-managers-guide/.

References

Able K.W. and R.W. Palmer. 1988. Salinity effects on fertilization success and larval mortality of Fundulus heteroclitus. *Copeia* 2:345–350.

Able, K.W., D.M. Nemerson, R. Bush, and P. Light. 2001. Spatial variation in Delaware Bay (USA) marsh creek fish assemblages. *Estuaries and Coasts* 24(3):441–452.

Armitage, A.R., C.-K. Ho, E.N. Madrid, M.T. Bell, and A. Quigg. 2014. The influence of habitat construction technique on the ecological characteristics of a restored brackish marsh. *Ecological Engineering* 62:33–42.

Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock. 2014. *Oyster Habitat Restoration Monitoring and Assessment Handbook*. The Nature Conservancy, Arlington, VA. Available: http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf.

Baker, R., B. Fry, L.P. Rozas, and T.J. Minello. 2013. Hydrodynamic regulation of salt marsh contributions to aquatic food webs. *Marine Ecology Progress Series* 490:37–52.

Baltz, D.M., C. Rakocinski, and J.W. Fleeger. 1993. Microhabitat use by marsh-edge fishes in a Louisiana estuary. *Environmental Biology of Fishes* 36:109–126.

Beck, M.W., R.D. Brumbaugh, L. Airoldi, A. Carranza, L.D. Coen, C. Crawford, O. Defeo, G.J. Edgar, B. Hancock, M.C. Kay, and H.S. Lenihan. 2011. Oyster reefs at risk and recommendations for conservation, restoration, and management. *Bioscience* 61(2):107–116.

Bell, S.S., L.A.J. Clements, and J. Kurdziel. 1993. Production in natural and restored seagrasses: A case study of a macrobenthic polychaete. *Ecological Applications* 3(4):610–621.

Bell, S.S., M.L. Middlebrooks, and M.O. Hall. 2014. The value of long-term assessment of restoration: Support from a seagrass investigation. *Restoration Ecology* 22(3):304–310.

Bell, S.S., A. Tewfik, M.O. Hall, and M.S. Fonseca. 2008. Evaluation of seagrass planting and monitoring techniques: Implications for assessing restoration success and habitat equivalency. *Restoration Ecology* 16(3):407–416.

Boesch, D.F. and R.E. Turner. 1984. Dependence of fishery species on salt marshes: The role of food and refuge. *Estuaries* 7(4A):460–468.

Boesch, D.F., M.N. Josselyn, A.J. Mehta, J.T. Morris, W.K. Nuttle, C.A. Simenstad, and D.J.P. Swift. 1994. Scientific assessment of coastal wetland loss, restoration and management in Louisiana. *Journal of Coastal Research* (Special Issue No. 20):1–103.

Broome, S.W., C.B. Craft, and W.A. Toomey Jr. 2000. Soil organic matter (SOM) effects on infaunal community structure in restored and created tidal marshes. In *Concepts and Controversies in Tidal Marsh Ecology,* M.P. Weinstein and D.A. Kreeger (eds.). Kluwer Academic Publishers, Boston MA. pp. 737–747.

Broome, S.W., E.D. Seneca, and W.W. Woodhouse. 1986. Long-term growth and development of transplants of the salt-marsh grass *Spartina alterniflora*. *Estuaries* 9(1):63–74.

Cake Jr., E.W. 1983. *Habitat Suitability Index Models: Gulf of Mexico American Oyster*. FWS/OBS-82/10.57. U.S. Department of the Interior, U.S. Fish and Wildlife Service.

Callaway, J.C. 2005. The challenge of restoring functioning salt marsh ecosystems. *Journal of Coastal Research* SI40:24–36.

Callaway, J.C., G. Sullivan, J.S. Desmond, G.D. Williams, and J.B. Zedler. 2001. Assessment and monitoring. In *Handbook for Restoring Tidal Wetlands*, J.B. Zedler (ed.). 1st edition. CRC Press, Boca Raton, FL. pp. 271–335.

Carter, J., J.H. Merino, and S.L. Merino. 2009. Mesohaline submerged aquatic vegetation survey along the US Gulf of Mexico coast, 2000: A stratified random approach. *Gulf of Mexico Science* 27(1):1.

Castellanos, D.L. and L.P. Rozas. 2001. Nekton use of submerged aquatic vegetation, marsh, and shallow unvegetated bottom in the Atchafalaya River Delta, a Louisiana tidal freshwater ecosystem. *Estuaries* 24:184–197.

Chambers, J.R. 1992. Coastal degradation and fish population losses. In *Stemming the Tide of Coastal Fish Habitat Loss*, R.H. Stroud (ed.). National Coalition for Marine Conservation, Savannah, GA. pp. 45–51.

Chesney, E.J., D.M. Baltz, and R.G. Thomas. 2000. Louisiana estuarine and coastal fisheries and habitats: Perspectives from a fish's eye view. *Ecological Applications* 10(2):350–366.

Coen, L.D. and R.E. Grizzle. 2007. The importance of habitat created by molluscan shellfish to managed species along the Atlantic Coast of the United States. Habitat Management Series No. 8, 115.

Coen, L.D., M.W. Luckenbach, and D.L. Breitburg. 1999. The role of oyster reefs as essential fish habitat: A review of current knowledge and some new perspectives. In *American Fisheries Society Symposium* 22:438–454.

Coen, L.D., R.D. Brumbaugh, D. Bushek, R. Grizzle, M.W. Luckenbach, M.H. Posey, S.P. Powers, and S.G. Tolley. 2007. Ecosystem services related to oyster restoration. *Marine Ecology Progress Series* 341:303–307.

Couvillion, B.R., J.A. Barras, G.D. Steyer, W. Sleavin, M. Fischer, H. Beck, N. Trahan, B. Griffin, and D. Heckman. 2011. Land area change in coastal Louisiana from 1932 to 2010. Scientific investigations map 3164, scale 1:265,000, 12 p. pamphlet. U.S. Geological Survey.

CPRA. 2017. *Louisiana's Comprehensive Master Plan for a Sustainable Coast.* Coastal Protection and Restoration Authority, Baton Rouge, LA. June. Available: http://coastal.la.gov/our-plan/2017-coastal-master-plan/.

Craft, C. 2000. Co-development of wetland soils and benthic invertebrate communities following salt marsh creation. *Wetlands Ecology and Management* 8:197–207.

Craft, C., S. Broome, and C. Campbell. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. *Restoration Ecology* 10(2):248–258.

Craft, C.B., S.W. Broome, and E.D. Seneca. 1988a. Nitrogen, phosphorus and organic carbon pools in natural and transplanted marsh soils. *Estuaries* 11(4):272–280.

Craft, C.B., S.W. Broome, E.D. Seneca, and W.J. Showers. 1988b. Estimating sources of soil organic matter in natural and transplanted estuarine marshes using stable isotopes of carbon and nitrogen. *Estuarine, Coastal and Shelf Science* 26:633–641.

Craft, C., J. Reader, J.N. Sacco, and S.W. Broome. 1999. Twenty-five years of ecosystem development of constructed Spartina alterniflora (Loisel) marshes. *Ecological Applications* 9(4):1405–1419.

Craft, C., P. Megonigal, S. Broome, J. Stevenson, R. Freese, J. Cornell, L. Zheng, and J. Sacco. 2003. The pace of ecosystem development of constructed Spartina alterniflora marshes. *Ecological Applications* 13(5):1417–1432.

Dahl, T.E. and S.M. Stedman. 2013. *Status and Trends of Wetlands in the Coastal Watersheds of the Conterminous United States, 2004 to 2009*. Report to Congress. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. Available: https://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-In-the-Coastal-Watersheds-of-the-Conterminous-US-2004-to-2009.pdf.

Day Jr., J.W., L.D. Britsch, S.R. Hawes, G.P. Shaffer, D.J. Reed, and D. Cahoon. 2000. Pattern and process of land loss in the Mississippi Delta: A spatial and temporal analysis of wetland habitat change. *Estuaries* 23(4):425–438.

Day Jr., J.W., D.F. Boesch, E.J. Clairain, G.P. Kemp, S.B. Laska, W.J. Mitsch, K. Orth, H. Mashriqui, D.J. Reed, L. Shabman, C.A. Simenstad, B.J. Streever, R.R. Twilley, C.C. Watson, J.T. Wells, and D.F. Whigham. 2007. Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita. *Science* 315:1679–1684.

De Angelo, J.A., P.W. Stevens, D.A. Blewett, and T.S. Switzer. 2014. Fish assemblages of shoal- and shoreline-associated seagrass beds in eastern Gulf of Mexico estuaries. *Transactions of the American Fisheries Society* 143(4):1037–1048.

Deegan, L.A. 1993. Nutrient and energy transport between estuaries and coastal marine ecosystems by fish migration. *Canadian Journal of Fisheries and Aquatic Sciences* 50(1):74–79.

Deegan, L.A., J.E. Hughes, and R.A. Rountree. 2000. Salt marsh ecosystem support of marine transient species. In *Concepts and Controversies in Tidal Marsh Ecology*. Kluwer Academic Publishers, Boston MA. pp. 333–365.

De Santiago, K., T.A. Palmer, M. Dumesnil, and J.B. Pollack. 2019. Rapid development of a restored oyster reef facilitates habitat provision for estuarine fauna. *Restoration Ecology* 27(4):1007–1012.

Dunson, W.A. and J. Travis. 1991. The role of abiotic factors in community organization. *The American Naturalist* 138(5):1067–1091.

DWH NRDA Trustees. 2016. *Deepwater Horizon* Oil Spill: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. *Deepwater Horizon* Natural Resource Damage Assessment Trustees. February. Available: http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan/.

DWH NRDA Trustees. 2017. Monitoring and Adaptive Management Procedures and Guidelines Manual. Version 1.0. Appendix to the Trustee Council Standard Operating Procedures for Implementation of the Natural Resource Restoration for the DWH Oil Spill. *Deepwater Horizon* Natural Resource Damage Assessment. December. Available: https://www.gulfspillrestoration.noaa.gov/sites/default/files/2018_01_TC_MAM_Procedures_Guidelines_Manual_12-2017_508_c.pdf.

Ebbets, A.L., D.R. Lane, P. Dixon, T.A. Hollweg, M.T. Huisenga, and J. Gurevitch. 2019. Using meta-analysis to develop evidence-based recovery trajectories of vegetation and soils in restored wetlands in the northern Gulf of Mexico. *Estuaries and Coasts*. Available: https://doi.org/10.1007/s12237-019-00536-y.

Edwards, K.R. and C.E. Proffitt. 2003. Comparison of wetland structural characteristics between created and natural salt marshes in southwest Louisiana, USA. *Wetlands* 23(2):344–356.

Enwright, N.M., S.B. Hartley, M.G. Brasher, J.M. Visser, M.K. Mitchell, B.M. Ballard, M.W. Parr, B.R. Couvillion, and B.C. Wilson. 2014. *Delineation of Marsh Types of the Texas Coast from Corpus Christi Bay to the Sabine River in 2010*. U.S. Geological Survey Scientific Investigations Report 2014–5110.

Enwright, N.M., S.B. Hartley, B.R. Couvillion, M.G. Brasher, J.M. Visser, M.K. Mitchell, B.M. Ballard, M.W. Parr, and B.C. Wilson. 2015. *Delineation of Marsh Types from Corpus Christi Bay, Texas, to Perdido Bay, Alabama, in 2010*. U.S. Geological Survey Scientific Investigations Map 3336, 1 sheet, scale 1:750,000. Available: http://dx.doi.org/10.3133/sim3336.

Felley, J.D. 1987. Nekton assemblages of three tributaries to the Calcasieu estuary, Louisiana. *Estuaries* 10(4):321–329.

Fodrie, F.J. and K.L. Heck. 2011. Response of coastal fishes to the Gulf of Mexico oil disaster. *PLoS ONE* 6(7):e21609.

Folse, T.M., L.A. Sharp, J.L. West, M.K. Hymel, J.P. Troutman, T.E. McGinnis, D. Weifenbach, W.M. Boshart, L.B. Rodrigue, D.C. Richardi, W.B. Wood, and C.M. Miller. 2018. A Standard Operating Procedures Manual for the Coastwide Reference Monitoring System-Wetlands: Methods for Site Establishment, Data Collection, and Quality Assurance/Quality Control. Louisiana Coastal Protection and Restoration Authority, Office of Coastal Protection and Restoration. Baton Rouge, LA. Available: https://lacoast.gov/reports/project/CRMS_SOP_2018_2-2018.pdf.

Fonseca, M.S., W.J. Kenworthy, and F.X. Courtney. 1996a. Development of planted seagrass beds in Tampa Bay, Florida, USA. I. Plant components. *Marine Ecology Progress Series* 132:127–139.

Fonseca, M.S., D.L. Meyer, and M.O. Hall. 1996b. Development of planted seagrass beds in Tampa Bay, Florida, USA. II. Faunal components. *Marine Ecology Progress Series* 132:141–156.

FWC and FLDEP. 2018. *Florida Gulf Environmental Benefit Fund Restoration Strategy*. Prepared with assistance from Abt Associates. Florida Fish and Wildlife Conservation Commission and Florida Department of Environmental Protection. January.

Gain, I. 2009. Oyster Reefs as Nekton Habitat in Estuarine Ecosystems. MS Thesis, Texas A&M University.

Geraldi, N.R., S.P. Powers, K.L. Heck, and J. Cebrian. 2009. Can habitat restoration be redundant? Response of mobile fishes and crustaceans to oyster reef restoration in marsh tidal creeks. *Marine Ecology Progress Series* 389:171–180.

Glancy, T.P., T.K. Frazer, C.E. Cichra, and W.J. Lingberg. 2003. Comparative patterns of occupancy by decapod crustaceans in seagrass, oyster, and marsh-edge habitats in a northeast Gulf of Mexico estuary. *Estuaries* 26(5):1291–1301.

Grabowski, J.H. and C.H. Peterson. 2007. Restoring oyster reefs to recover ecosystem services. *Ecosystem Engineers: Plants to Protists* 4:281–298.

Grabowski, J.H., A.R. Hughes, D.L. Kimbro, and M.A. Dolan. 2005. How habitat setting influences restored oyster reef communities. *Ecology* 86(7):1926–1935.

Grabowski, J.H., R.D. Brumbaugh, R.F. Conrad, A.G. Keeler, J.J. Opaluch, C.H. Peterson, M.F. Piehler, S.P. Powers, and A.R. Smyth. 2012. Economic valuation of ecosystem services provided by oyster reefs. *BioScience* 62(10):900–909.

Graham, P.M., T.A. Palmer, and J. Beseres Pollack. 2017. Oyster reef restoration: Substrate suitability may depend on specific restoration goals. *Restoration Ecology* 25(3):459–470.

Gregalis, K.C., S.P. Powers, and K.L. Heck. 2008. Restoration of oyster reefs along a bio-physical gradient in Mobile Bay, Alabama. *Journal of Shellfish Research* 27(5):1163–1170.

Gulf Coast Ecosystem Restoration Council. 2016. *Comprehensive Plan Update 2016: Restoring the Gulf Coast's Ecosystem and Economy*. Available: https://www.restorethegulf.gov/sites/default/files/CO-PL_20161208_CompPlanUpdate_English.pdf.

Gulf Coast Ecosystem Restoration Task Force. 2011. *Gulf of Mexico Regional Ecosystem Restoration Strategy*. December. Available: http://www.gulfofmexicoalliance.org/pdfs/GulfCoastReport_Full_12-04_508-1_final.pdf.

Gunter, G. 1961. Some relations of estuarine organisms to salinity. *Limnology and Oceanography* 6(2):182–190.

Handley, L., D. Altsman, and R. DeMay (eds.). 2007. *Seagrass Status and Trends in the Northern Gulf of Mexico: 1940–2002*. U.S. Geological Survey Scientific Investigations Report 2006-5287 and U.S. Environmental Protection Agency 855-R-04-003. Available: https://pubs.usgs.gov/sir/2006/5287/.

Higgins, J.P.T. and S. Green (eds.). 2011. *Cochrane Handbook for Systematic Reviews of Interventions*. Version 5.1.0. The Cochrane Collaboration. Available: http://www.cochrane-handbook.org.

Hillmann, E.R., K.E. DeMarco, and M.K. La Peyre. 2016. Establishing a baseline of estuarine submerged aquatic vegetation resources across salinity zones within coastal areas of the northern Gulf of Mexico. *Journal of the Southeastern Association of Fish and Wildlife Agencies* 3:25–32.

Hitch, A.T., K.M. Purcell, S.B. Martin, P.L. Klerks, and P.L. Leberg. 2011. Interactions of salinity, marsh fragmentation and submerged aquatic vegetation on resident nekton assemblages of coastal marsh ponds. *Estuaries and Coasts* 34:653–662.

Hollweg, T.A., M.C. Christman, J. Lipton, B.P. Wallace, M.T. Huisenga, D. Lane, and K.G. Benson. 2019a. Meta-analysis of nekton recovery following marsh restoration in the northern Gulf of Mexico. *Estuaries and Coasts*. Available: https://doi.org/10.1007/s12237-019-00630-1.

Hollweg, T.A., M.C. Christman, J. Cebrian, B.P. Wallace, S.L. Friedman, H.R. Ballestero, M.T. Huisenga, and K.G. Benson. 2019b. Meta-analysis of nekton utilization of coastal habitats in the northern Gulf of Mexico. *Estuaries and Coasts*. Available: https://doi.org/10.1007/s12237-019-00633-y.

Humphries, A.T., M.K. La Peyre, M.E. Kimball, and L.P. Rozas. 2011. Testing the effect of habitat structure and complexity on nekton assemblages using experimental oyster reefs. *Journal of Experimental Marine Biology and Ecology* 409(1-2):172–179.

Kang, S.-R. and S.L. King. 2013. Effects of hydrologic connectivity and environmental variables on nekton assemblage in a coastal marsh system. *Wetlands* 33:321–334.

Kanouse, S., M.K. La Peyre, and J.A. Nyman. 2006. Nekton use of Ruppia maritima and non-vegetated bottom habitat types within brackish marsh ponds. *Marine Ecology Progress Series* 327:61–69.

King, S.P. and P. Sheridan. 2006. Nekton of new seagrass habitats colonizing a subsided salt marsh in Galveston Bay, Texas. *Estuaries* 29(2):286–296.

Kneib, R.T. 1997. The role of tidal marshes in the ecology of estuarine nekton. In *Oceanography and Marine Biology: An Annual Review,* A.D. Ansell, R.N. Gibson, and M. Barnes (eds.). UCL Press, Bristol, PA. pp. 163–220.

Kneib, R.T. and S.L. Wagner. 1994. Nekton use of vegetated marsh habitats at different stages of tidal inundation. *Marine Ecology Progress Series* 106:227–238.

La Peyre, M., K. DeMarco, and E. Hillmann. 2017. Submerged Aquatic Vegetation and Environmental Data for Coastal Areas from Texas through Alabama, 2013–2015. U.S. Geological Survey data release. Available: https://doi.org/10.5066/F7GH9G44.

La Peyre, M.K. and J. Gordon. 2012. Nekton density patterns and hurricane recovery in submerged aquatic vegetation, and along non-vegetated natural and created edge habitats. *Estuarine, Coastal and Shelf Science* 98:108–118.

La Peyre, M.K., B. Gossman, and J.A. Nyman. 2007. Assessing functional equivalency of nekton habitat in enhanced habitats: Comparison of terraced and unterraced marsh ponds. *Estuaries and Coasts* 30(3):526–536.

La Peyre, M.K., L. Schwarting, and S. Miller. 2013a. *Baseline Data for Evaluating the Development Trajectory and Provision of Ecosystem Services by Created Fringing Oyster Reefs in Vermilion Bay, Louisiana*. U.S. Department of the Interior, U.S. Geological Survey. Open-File Report 2013–1053. Available: https://pubs.er.usgs.gov/publication/ofr20131053.

La Peyre, M.K., L. Schwarting, and S. Miller. 2013b. *Preliminary Assessment of Bioengineered Fringing Shoreline Reefs in Grand Isle and Breton Sound, Louisiana*. U.S. Department of the Interior, U.S. Geological Survey. Open-File Report 2013–1040. Available: https://pubs.er.usgs.gov/publication/ofr20131040.

La Peyre, M.K., A.T. Humphries, S.M. Casas, and J.F. La Peyre. 2014. Temporal variation in development of ecosystem services from oyster reef restoration. *Ecological Engineering* 63:34–44.

Lartigue, J., A. Neill, B.L. Hayden, J. Pulfer, and J. Cebrian. 2003. The impact of salinity fluctuations on net oxygen production and inorganic nitrogen uptake by *Ulva lactuca* (Chlorophyceae). *Aquatic Botany* 75:339–350.

LaSalle, M.W., M.C. Landin, and J.G. Sims. 1991. Evaluation of the flora and fauna of a Spartina alterniflora marsh established on dredged material in Winyah Bay, South Carolina. *Wetlands* 11(2):191–208.

Lellis-Dibble, K.A., K.E. McGlynn, and T.E. Bigford. 2008. Estuarine Fish and Shellfish Species in U.S. Commercial and Recreational Fisheries: Economic Value as an Incentive to Protect and Restore Estuarine Habitat. NOAA Technical Memorandum NMFS-F/SPO-90. U.S. Department of Commerce.

Levin, L.A., D. Talley, and G. Thayer. 1996. Succession of macrobenthos in a created salt marsh. *Marine Ecology Progress Series* 141:67–82.

Lima, S.L. and L.M. Dill. 1990. Behavioral decisions made under the risk of predation: A review and prospectus. *Canadian Journal of Zoology* 68(4):619–640.

Lindau, C.W. and L.R. Hossner. 1981. Substrate characterizations of an experimental marsh and three natural marshes. *Journal of the American Soil Science Society* 45:1171–1176.

Llewellyn, C. and M. La Peyre. 2011. Evaluating ecological equivalence of created marshes: Comparing structural indicators with stable isotope indicators of blue crab trophic support. *Estuaries and Coasts* 34:172–184.

Louisiana Trustee Implementation Group. 2018. Strategic Restoration Plan and Environmental Assessment #3: Restoration of Wetlands, Coastal, and Nearshore Habitats in the Barataria Basin, Louisiana. Available: https://la-dwh.com/wp-content/uploads/2018/03/Final_SRP.EA_508-Compliant.pdf.

Luckenbach, M.W., L.D. Coen, P.G. Ross Jr., and J.A. Stephen. 2005. Oyster reef habitat restoration: Relationships between oyster abundance and community development based on two studies in Virginia and South Carolina. *Journal of Coastal Research* 40:64–78.

Mace III, M.M. and L.P. Rozas. 2017. Population dynamics and secondary production of juvenile white shrimp (*Litopenaeus setiferus*) along an estuarine salinity gradient. *Fishery Bulletin* 115(1).

Manley, J., A. Power, R. Walker, D. Hurley, C. Belcher, and J. Richardson. 2010. Ecological succession on restored intertidal oyster habitat in the tidal creeks of coastal Georgia. *Journal of Shellfish Research* 29(4):917–927.

McDonald, R.B., R.M. Moody, K.L. Heck, and J. Cebrian. 2016. Fish, macroinvertebrate and epifaunal communities in shallow coastal lagoons with varying seagrass cover of the northern Gulf of Mexico. *Estuaries and Coasts* 39:718–730.

McIvor, C.C. and W.E. Odum. 1988. Food, predation risk, and microhabitat selection in a marsh fish assemblage. *Ecology* 69(5):1341–1351.

Merino, J.H., J.A. Nyman, and T. Michot. 2005. Effects of season and marsh management on submerged aquatic vegetation in coastal Louisiana brackish marsh ponds. *Ecological Restoration* 23(4):235–243.

Meyer, D.L. and E.C. Townsend. 2000. Faunal utilization of created intertidal eastern oyster (*Crassostrea virginica*) reefs in the southeastern United States. *Estuaries* 23(1):34–45.

Minello, T.J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat. *American Fisheries Society Symposium* 22:43–75.

Minello, T.J. 2000. Temporal development of salt marsh value for nekton and epifauna: Utilization of dredged material marshes in Galveston Bay, Texas, USA. *Wetlands Ecology and Management* 8:327–341.

Minello, T.J. and L.P. Rozas. 2002. Nekton in Gulf Coast wetlands: Fine-scale distributions, landscape patterns, and restoration implications. *Ecological Applications* 12(2):441–455.

Minello, T.J. and J.W. Webb. 1997. Use of natural and created *Spartina alterniflora* salt marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. *Marine Ecology Progress Series* 151:165–179.

Minello, T.J. and R.J. Zimmerman. 1991. The role of estuarine habitats in regulating growth and survival of juvenile penaeid shrimp. In F*rontiers in Shrimp Research* P. DeLoach, W.J. Dougherty, and M.A. Davidson (eds.). Elsevier Scientific Publications, Amsterdam. pp. 1–16.

Minello, T.J. and R.J. Zimmerman. 1992. Utilization of natural and transplanted Texas salt marshes by fish and decapod crustaceans. *Marine Ecology Progress Series* 90:273–285.

Minello, T.J., L.P. Rozas, and R. Baker. 2012. Geographic variability in salt marsh flooding patterns may affect nursery value for fishery species. *Estuaries and Coasts* 35:501–514.

Minello, T.J., R.J. Zimmerman, and R. Medina. 1994. The importance of edge for natant macrofauna in a created salt marsh. *Wetlands* 14(3):184–198.

Minello, T.J., K.W. Able, M.P. Weinstein, and C.G. Hays. 2003. Salt marshes as nurseries for nekton: Testing hypotheses on density, growth and survival through meta-analysis. *Marine Ecology Progress Series* 246:39–59.

Minello, T.J., G.A. Matthews, P.A. Caldwell, and L.P. Rozas. 2008. Population and production estimates for decapod crustaceans in wetlands of Galveston Bay, Texas. *Transactions of the American Fisheries Society* 137:129–146.

Moreno-Mateos, D., M.E. Power, F.A. Comin, and R. Yockteng. 2012. Structural and functional loss in restored wetland ecosystems. *PLoS Biology* 10(1):e1001247. doi: 10.1371/journal.pbio.1001247.

Moy, L.D. and L.A. Levin. 1991. Are Spartina marshes a replaceable resource? A functional approach to evaluation of marsh creation efforts. *Estuaries* 14(1):1–16.

Muncy, R.J. 1984. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Gulf of Mexico). Pinfish.

NAS. 2016. *Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico*. The National Academies of Sciences. The National Academies Press, Washington, DC. Available: http://dels.nas.edu/Report/Effective-Monitoring-Evaluate-Ecological-Restoration/23476.

Nevins, J.A., J.B. Pollack, and G.W. Stunz. 2014. Characterizing nekton use of the largest unfished oyster reef in the United States compared with adjacent estuarine habitats. *Journal of Shellfish Research* 33(1):227–238.

NMFS. 2018. *Fisheries of the United States, 2017*. Current Fishery Statistics No. 2017. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. September. Available: https://www.fisheries.noaa.gov/resource/document/fisheries-united-states-2017-report.

O'Connell, M.T., C.D. Franze, E.A. Spalding, and M.A. Poirrier. 2005. Biological resources of the Louisiana coast: Part 2. Coastal animals and habitat associations. *Journal of Coastal Research SI* 44:146–161.

O'Connor, M.I., M.F. Piehler, D.M. Leech, A. Anton, and J.F. Bruno. 2009. Warming and resource availability shift food web structure and metabolism. *PLoS Biol* 7(8):e1000178. Available: https://doi.org/10.1371/journal.pbio.1000178.

Osland, M.J., R.H. Day, C.T. Hall, M.D. Brumfield, J.L. Dugas, and W.R. Jones. 2017. Mangrove expansion and contraction at a poleward range limit: Climate extremes and land-ocean temperature gradients. *Ecology* 98(1):125–37.

Pattillo, M.E., T.E. Czapla, D.M. Nelson, and M.E. Monaco. 1997. *Distribution and Abundance of Fishes and Invertebrates in Gulf of Mexico Estuaries, Volume II: Species Life History Summaries*. ELMR Rep. No. 11. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD. August. Available: ftp://ftp.library.noaa.gov/noaa_documents.lib/NOS/ORCA/ELMR_report/ELMR_11.pdf.

Peterson, C.H., J.H. Grabowski, and S.P. Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: Quantitative valuation. *Marine Ecology Progress Series* 264:249–264.

Peterson, G.W. and R.E. Turner. 1994. The value of salt marsh edge vs interior as a habitat for fish and decapod crustaceans in a Louisiana tidal marsh. *Estuaries* 17(1B):235–262.

Plunket, J. and M.K. La Peyre. 2005. Oyster beds as fish and macroinvertebrate habitat in Barataria Bay, Louisiana. *Bulletin of Marine Science* 77(1):155–164.

Poulakis, G.R., D.A. Blewett, and M.E. Mitchell. 2003. The effects of season and proximity to fringing mangroves on seagrass-associated fish communities in Charlotte Harbor, Florida. *Gulf of Mexico Science* 21(2):171–184.

Rezek, R.J., B. Lebreton, E.B. Roark, T.A. Palmer, and J.B. Pollack. 2017. How does a restored oyster reef develop? An assessment based on stable isotopes and community metrics. *Marine Biology* 164(3):54.

Robillard, M.M.R., G.W. Stunz, and J. Simons. 2010. Relative value of deep subtidal oyster reefs to other estuarine habitat types using a novel sampling method. *Journal of Shellfish Research* 29(2):291–302.

Rogers, S.G., T.E. Targett, and S.B. Van Sant. 1984. Fish-nursery use in Georgia salt-marsh estuaries: The influence of springtime freshwater conditions. T*ransactions of the American Fisheries Society* 113(5):595–606.

Roth, B.M., K.A. Rose, L.P. Rozas, and T.J. Minello. 2008. Relative influence of habitat fragmentation and inundation on brown shrimp *Farfantepenaeus aztecus* production in northern Gulf of Mexico salt marshes. *Marine Ecology Progress Series* 359:185–202.

Rountree R.A. and K.W. Able. 2007. Spatial and temporal habitat use patterns for salt marsh nekton: Implications for ecological functions. *Aquatic Ecology* 41:25-45

Rozas, L.P. 1995. Hydroperiod and its influence on nekton use of the salt marsh: A pulsing ecosystem. *Estuaries* 18(4):579–590.

Rozas, L.P. and T.J. Minello. 1997. Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: A review of sampling design with focus on gear selection. *Estuaries* 20(1):199–213.

Rozas, L.P. and T.J. Minello. 1998. Nekton use of salt marsh, seagrass, and nonvegetated habitats in a south Texas (USA) estuary. *Bulletin of Marine Science* 63(3):481–501.

Rozas, L.P. and T.J. Minello. 2001. Marsh terracing as a wetland restoration tool for creating fishery habitat. *Wetlands* 21(3):327–341.

Rozas, L.P. and T.J. Minello. 2006. Nekton use of *Vallisneria americana Michx*. (wild celery) beds and adjacent habitats in coastal Louisiana. *Estuaries and Coasts* 29(2):297–310.

Rozas, L.P. and T.J. Minello. 2007. Restoring coastal habitat using marsh terracing: The effect of cell size on nekton use. *Wetlands* 27(3):595–609.

Rozas, L.P. and T.J. Minello. 2009. Using nekton growth as a metric for assessing habitat restoration by marsh terracing. *Marine Ecology Progress Series* 394:179–193.

Rozas, L.P. and T.J. Minello. 2010. Nekton density patterns in tidal ponds and adjacent wetlands related to pond size and salinity. *Estuaries and Coasts* 33:652–667.

Rozas, L.P. and T.J. Minello. 2015. Small-scale nekton density and growth patterns across a saltmarsh landscape in Barataria Bay, Louisiana. *Estuaries and Coasts* 38(6):2000–2018. doi: 10.1007/s12237-015-9945-3.

Rozas, L.P. and D.J. Reed. 1993. Nekton use of marsh-surface habitats in Louisiana (USA) deltaic salt marshes undergoing submergence. *Marine Ecology Progress Series* 96:147–157.

Rozas, L.P. and R.J. Zimmerman. 2000. Small-scale patterns of nekton use among marsh and adjacent shallow nonvegetated areas of the Galveston Bay Estuary, Texas (USA). *Marine Ecology Progress Series* 193:217–239.

Rozas, L.P., P. Caldwell, and T.J. Minello. 2005. The fishery value of salt marsh restoration projects. *Journal of Coastal Research* Special Issue 40:37–50.

Rozas, L.P., T.J. Minello, and D.D. Dantin. 2012. Use of shallow lagoon habitats by nekton of the northeastern Gulf of Mexico. *Estuaries and Coasts* 35:572–586.

Rozas, L.P., T.J. Minello, R.J. Zimmerman, and P. Caldwell. 2007. Nekton populations, long-term wetland loss, and the effect of recent habitat restoration in Galveston Bay, Texas. *Marine Ecology Progress Series* 344:119–130.

Sacco, J.N., E.D. Seneca, and T.R. Wentworth. 1994. Infaunal community development of artificially established salt marshes in North Carolina. *Estuaries* 17(2):489–500.

Sasser, C.E., J.M. Visser, E. Mouton, J. Linscombe, and S.B. Hartley. 2014. Vegetation Types in Coastal Louisiana in 2013. U.S. Scientific Investigations Map 3290.

Schmidt-Nielsen, K. 1997. *Animal Physiology: Adaptation and Environment*. Fifth ed. Cambridge University Press, Cambridge, UK.

Scott, E. 1998. Utilization of Submerged Aquatic Vegetation Habitats by Fishes and Decapods in the Galveston Bay Ecosystem, Texas. MS Thesis, Texas A&M University.

Scyphers, S.B., S.P. Powers, K.L. Heck Jr., and D. Byron. 2011. Oyster reefs as natural breakwaters mitigate shoreline loss and facilitate fisheries. *PLoS ONE* 6(8):e22396.

Sheridan, P. 2004. Comparison of restored and natural seagrass beds near Corpus Christi, Texas. *Estuaries* 27(5):781–792.

Sheridan, P., G. McMahan, K. Hammerstrom, and W. Pulich Jr. 1998. Factors affecting restoration of *Halodule wrightii* to Galveston Bay, Texas. *Restoration Ecology* 6(2):144–158.

Shervette, V.R. and F. Gelwick. 2008. Seasonal and spatial variations in fish and macroinvertebrate communities of oyster and adjacent habitats in a Mississippi estuary. *Estuaries and Coasts* 31:584–596.

Shervette, V.R., F. Gelwick, and N. Hadley. 2011. Decapod utilization of adjacent oyster, vegetated marsh, and non-vegetated bottom habitats in a Gulf of Mexico estuary. *Journal of Crustacean Biology* 31(4):660–667.

Stewart-Oaten, A. and J.R. Bence. 2001. Temporal and spatial variation in environmental impact assessment. *Ecological Monographs 71*(2):305–339.

Strange, E., H. Galbraith, S. Bickel, D. Mills, D. Beltman, and J. Lipton. 2002. Determining ecological equivalence in service-to-service scaling of salt marsh restoration. *Environmental Management* 29(2):290–300.

Streever, W.J. 2000. Spartina alterniflora marshes on dredged material: A critical review of the ongoing debate over success. *Wetlands Ecology and Management* 8:295–316.

Stunz, G.W., T.J. Minello, and L.P. Rozas. 2010. Relative value of oyster reef as habitat for estuarine nekton in Galveston Bay, Texas. *Marine Ecology Progress Series* 406:147–159.

Thom, C.S.B., M.K.G. La Peyre, and J.A. Nyman. 2004. Evaluation of nekton use and habitat characteristics of restored Louisiana marsh. *Ecological Engineering* 23:63–75.

Upchurch, S. and E. Wenner. 2008. Fish and decapod crustacean assemblages from the Ashepoo-Combahee-Edisto Basin, South Carolina (1993–1999). *Journal of Coastal Research* Special Issue 55:200–213.

USFWS. 2019. National Wetlands Inventory website. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. Available: http://www.fws.gov/wetlands/.

Valiela, I. 2015. *Marine Ecological Processes*. Third edition. Springer, New York.

VanderKooy, S. (ed.). 2012. *The Oyster Fishery of the Gulf of Mexico, United States: A Regional Management Plan – 2012 Revision*. Publication No. 202, Gulf States Marine Fisheries Commission, Ocean Springs, MS.

VanderKooy, S.J. and J.W. Smith (eds.). 2015. The Gulf Menhaden Fishery of the Gulf of Mexico: A Regional Management Plan. Gulf States Marine Fisheries Commission. March. Available: http://www.gsmfc.org/publications/GSMFC%20Number%20240.pdf.

Vetter, D., G. Rucker, and I. Storch. 2013. Meta-analysis: A need for well defined usage in ecology and conservation biology. *Ecosphere* 4(6):1–24. Available: https://doi.org/10.1890/ES13-00062.1.

Visser, J.M., C.E. Sasser, R.H. Chabreck, and R.G. Linscombe. 1998. Marsh vegetation types of the Mississippi River Deltaic Plain. *Estuaries* 21(4B):818–828.

Visser, J.M., C.E. Sasser, R.H. Chabreck, and R.G. Linscombe. 2000. Marsh vegetation types of the Chenier Plain, Louisiana, USA. *Estuaries* 23(3):318–327.

Visser, J.M., C.E. Sasser, R.H. Chabreck, and R.G. Linscombe. 2002. The impact of a severe drought on the vegetation of a subtropical estuary. *Estuaries* 25(6A):1184–1195.

Waycott, M., C.M. Duarte, T.J. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik, A. Calladine, J.W. Fourqurean, K.L. Heck, A.R. Hughes, and G.A. Kendrick. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences* 106(30):12377–12381.

Wells, H.W. 1961. The fauna of oyster beds, with special reference to the salinity factor. *Ecological Monographs* 31(3):239–266.

Werner, E.E., J.F. Gilliam, D.J. Hall, and G.G. Mittelbach. 1983. An experimental test of the effects of predation risk on habitat use in fish. *Ecology* 64(6):1540–1548.

Whaley, S.D. and T.J. Minello. 2002. The distribution of benthic infauna of a Texas salt marsh in relation to the marsh edge. *Wetlands* 22(4):753–766.

Zedler, J.B. 2000. Progress in wetland restoration ecology. *TREE* 15(10):402–407.

Zeug, S.C., V.R. Shervette, D.J. Hoeinghaus, and S.E.I. Davis. 2007. Nekton assemblage structure in natural and created marsh-edge habitats of the Guadalupe Estuary, Texas, USA. *Estuarine, Coastal and Shelf Science* 71:457–466.

Zimmerman, R.J., T.J. Minello, and L.P. Rozas. 2000. Salt marsh linkages to productivity of Penaeid shrimps and blue crabs in the northern Gulf of Mexico. In *Concepts and Controversies in Tidal Marsh Ecology*, M.P. Weinstein and D.A. Kreeger (eds.). Kluwer Academic Publishers, Boston, MA. pp. 293–314.

zu Ermgassen, P.S., J.H. Grabowski, J.R. Gair, and S.P. Powers. 2015. Quantifying fish and mobile invertebrate production from a threatened nursery habitat. *Journal of Applied Ecology* 53(2):596–606.

zu Ermgassen, P.S., M.D. Spalding, B. Blake, L.D. Coen, B. Dumbauld, S. Geiger, J.H. Grabowski, R. Grizzle, M. Luckenbach, K. McGraw, and W. Rodney. 2012. Historical ecology with real numbers: Past and present extent and biomass of an imperilled estuarine habitat. *Proceedings of the Royal Society B: Biological Sciences* 279(1742):3393–3400.

Supplemental Tables

Table S1. Estimated means, number of individuals/m^2, (± 1 SE) of total nekton density (sum of crustacean and fish species), total crustacean density, total fish density, and densities of individual crustacean and fish species in open-water NVB (“near” and “far”) and marsh (“edge” and “interior”) habitats during the spring and fall in the saline zone. Means are presented for two or more observations. The total number of samples (N) is also provided.

			Open-water NVB						Marsh					
			Far			Near			Edge			Interior		
Family	Common name	Scientific name	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Spring														
–	**Nekton – total**	–	**14.13**	**3.05**	**13**	**31.96**	**8.22**	**25**	**89.13**	**13.57**	**32**	**47.09**	**8**	**10**
–	**Crustaceans – total**	–	**4.49**	**0.96**	**13**	**9.35**	**3.83**	**26**	**76.33**	**12.98**	**32**	**41.5**	**7.73**	**10**
Alpheidae	Bigclaw snapping shrimp	*Alpheus heterochaelis*				0.12	0.35	8	0.44	0.3	11			1
Portunidae	Blue crab, bluepoint	*Callinectes sapidus*	0.32	0.21	23	0.6	0.19	32	3.44	0.39	40	1.23	0.51	10
Diogenidae	Thinstripe hermit	*Clibanarius vittatus*				1.24	0.8	17	1.49	0.4	18	1.71	1.5	5
Panopeidae	Gulf grassflat crab	*Dyspanopeus texanus*				0.15	0.28	13	0.11	0.35	8	0	0.71	2
Panopeidae	Flatback mud crab	*Eurypanopeus depressus*			1	0.06	0.32	10	0.42	0.41	6			1
Panopeidae	Ridgeback mud crab	*Eurypanopeus turgidus*							0.15	0.38	7			
Penaeidae	Brown shrimp, golden shrimp, northern brown shrimp, red shrimp, redtail shrimp	*Farfantepenaeus aztecus*	1.91	0.35	35	3	0.41	29	13.41	1.37	45	4.56	1.56	10
Penaeidae	Bait shrimp, northern pink shrimp, pink shrimp, spotted shrimp	*Farfantepenaeus duorarum*	0.04	0.58	3			1	0.18	0.38	7			
Penaeidae	Northern white shrimp, white shrimp	*Litopenaeus setiferus*	0.04	0.5	4	0.61	0.32	16	0.31	0.21	22	0.4	0.5	4
Menippidae	Gulf stone crab	*Menippe adina*						1						
Menippidae	Florida stone crab	*Menippe mercenaria*				0	0.58	3						
Palaemonidae	Brackish grass shrimp	*Palaemonetes intermedius*	0	0.58	3	0.05	0.29	12	3.37	1.78	19	0	0.58	3
Palaemonidae	Eastern grass shrimp, riverine grass shrimp	*Palaemonetes paludosus*												
Palaemonidae	Daggerblade grass shrimp	*Palaemonetes pugio*	0.32	0.2	24	2.45	1.92	29	44.05	9.69	41	25.12	6.73	10
Palaemonidae	Common American prawn, common grass shrimp, marsh grass shrimp, marsh shrimp	*Palaemonetes vulgaris*				0	0.38	7	0.19	0.29	12	0.29	0.58	3
Panopeidae	Atlantic mud crab	*Panopeus herbstii*				0.22	0.45	5	0.12	0.32	10			1
Porcellanidae	Green porcelain crab	*Petrolisthes armatus*			1	0.22	0.71	2			1			

			Open-water NVB						Marsh					
			Far			Near			Edge			Interior		
Family	Common name	Scientific name	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Panopeidae	Harris mud crab, estuarine mud crab	*Rhithropanopeus harrisii*				0.17	0.3	11	0.29	0.41	6	0.07	0.58	3
Sesarmidae	Heavy marsh crab, purple marsh crab	*Sesarma reticulatum*	0	0.41	6	0	0.33	9	3.68	2.12	15	1.77	1.35	3
Ocypodidae	–	*Uca* spp.							6.73	6.73	2	1.16	1.22	2
Xanthidae	Mud crabs, pebble crabs, rubble crabs	Xanthidae spp.						1			1			
–	**Fish – total**	**–**	**9.63**	**2.44**	**13**	**19.49**	**6.45**	**29**	**11.34**	**2.14**	**36**	**5.6**	**1.39**	**10**
Fundulidae	Diamond killifish	*Adinia xenica*			1	0	0.3	11	0.37	0.32	10	1.32	0.85	4
Engraulidae	Bay anchovy	*Anchoa mitchilli*			1	5.19	3.23	21	0.49	0.32	18	0.23	0.5	4
Sparidae	Sheepshead	*Archosargus probatocephalus*			1	0	0.5	4			1			
Ariidae	Hardhead catfish	*Ariopsis felis*				0.09	0.28	13	0	0.5	4	0	0.58	3
Clupeidae	Gulf menhaden, largescale menhaden	*Brevoortia patronus*	8.12	1.97	18	12.45	6.18	28	3.13	2.03	28	0.7	0.63	8
Blenniidae	Striped blenny	*Chasmodes bosquianus*							0	0.71	2			
Gobiidae	Darter goby	*Ctenogobius boleosoma*			1	0.51	0.36	17	4.68	2.71	18	1.14	1.22	2
Sciaenidae	Sand seatrout	*Cynoscion arenarius*				0.05	0.41	6	0	0.58	3			1
Sciaenidae	Spotted seatrout	*Cynoscion nebulosus*			1	0	0.28	13	0.01	0.32	10			1
Cyprinodontidae	Sheepshead minnow, sheepshead pupfish	*Cyprinodon variegatus*			1	0.1	0.24	18	0.29	0.24	17	1.76	0.75	5
Fundulidae	Gulf killifish	*Fundulus grandis*	0	0.5	4	0.01	0.21	22	0.25	0.21	23	0.85	0.41	6
Fundulidae	Bayou killifish	*Fundulus pulvereus*									1	0.22	1.22	2
Poeciliidae	Mosquitofish, western mosquitofish	*Gambusia affinis*									1	0	1.22	2
Gobiesocidae	Skilletfish	*Gobiesox strumosus*				0.38	0.32	10	1.31	1.08	6	0	0.58	3
Gobiidae	Naked goby	*Gobiosoma bosc*	0.18	0.5	4	0.77	0.44	22	0.7	0.35	20	0	0.5	4
Sparidae	Pinfish	*Lagodon rhomboides*	0.34	0.2	25	0.19	0.2	26	4.23	0.65	37	1.5	0.91	6
Sciaenidae	Spot	*Leiostomus xanthurus*	0.49	0.28	13	0.35	0.2	24	0.33	0.18	30	0.04	0.45	5
Fundulidae	Rainwater killifish	*Lucania parva*			1	0	0.41	6	0.52	0.34	11	0.07	1.22	2

Family	Common name	Scientific name	Open-water NVB						Marsh					
			Far			Near			Edge			Interior		
			Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Atherinopsidae	Inland silverside, tidewater silverside	*Menidia beryllina*	0.11	0.5	4	0.94	0.32	25	0.74	0.3	20	0.17	0.41	6
Sciaenidae	Atlantic croaker	*Micropogonias undulatus*	0.64	0.5	4	0.38	0.23	19	0.02	0.26	15	0.06	0.5	4
Mugilidae	Striped mullet, gray mullet, black mullet	*Mugil cephalus*	0.02	0.38	7	0.15	0.21	22	0.4	0.21	22	0.74	0.35	8
Ophichthidae	Speckled worm eel	*Myrophis punctatus*				0.13	0.24	17	0.23	0.28	13	0.12	0.58	3
Batrachoididae	Gulf toadfish	*Opsanus beta*			1	0.12	0.32	10	0.03	0.35	8			1
Paralichthyidae	Southern flounder	*Paralichthys lethostigma*			1	0.05	0.24	17	0.09	0.29	12	0	0.71	2
Poeciliidae	Sailfin molly	*Poecilia latipinna*				0	0.71	2			1	0	1.22	2
Sciaenidae	Black drum	*Pogonias cromis*			1	0.09	0.38	7	0	0.5	4			
Sciaenidae	Red drum	*Sciaenops ocellatus*			1	0.04	0.25	16	0	0.33	9			1
Tetraodontidae	Least puffer	*Sphoeroides parvus*				0.09	0.33	9	0.12	0.58	3	0	0.71	2
Cynoglossidae	Blackcheek tonguefish	*Symphurus plagiusa*	0.69	0.5	4	0.04	0.26	15	0	0.32	10			1
Fall														
–	**Nekton – total**	**–**	**8.47**	**1.19**	**16**	**21.8**	**5.44**	**25**	**103.06**	**9.57**	**27**	**55.91**	**11.74**	**9**
–	**Crustaceans – total**	**–**	**4.35**	**0.63**	**16**	**12.83**	**4.85**	**25**	**93.79**	**10.16**	**27**	**45.63**	**10.53**	**9**
Alpheidae	Bigclaw snapping shrimp	*Alpheus heterochaelis*	0.1	0.5	4	0.08	0.35	8	4.73	2.78	4			
Portunidae	Blue crab, bluepoint	*Callinectes sapidus*	1.49	0.19	38	2.64	0.76	28	11.53	1.22	41	3.69	1.04	11
Diogenidae	Thinstripe hermit	*Clibanarius vittatus*				0.13	0.29	12	1.57	0.96	8	2.63	2.58	3
Panopeidae	Gulf grassflat crab	*Dyspanopeus texanus*				0.19	0.29	12	0.56	0.71	2	0	0.71	2
Panopeidae	Flatback mud crab	*Eurypanopeus depressus*				0	0.5	4	4.29	4.29	2			
Panopeidae	Ridgeback mud crab	*Eurypanopeus turgidus*									1			
Penaeidae	Brown shrimp, golden shrimp, northern brown shrimp, red shrimp, redtail shrimp	*Farfantepenaeus aztecus*	0.47	0.2	26	0.72	0.2	26	7.36	1.31	31	1.07	0.37	9
Penaeidae	Bait shrimp, northern pink shrimp, pink shrimp, spotted shrimp	*Farfantepenaeus duorarum*	0.54	0.2	25	0.37	0.25	16	3.22	0.62	23	0.18	0.71	2
Penaeidae	Northern white shrimp, white shrimp	*Litopenaeus setiferus*	1.11	0.31	38	4.84	1.92	26	17.77	2.73	38	4.93	2.06	11
Menippidae	Gulf stone crab	*Menippe adina*									1			
Menippidae	Florida stone crab	*Menippe mercenaria*						1						

			Open-water NVB						Marsh					
			Far			Near			Edge			Interior		
Family	Common name	Scientific name	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Palaemonidae	Brackish grass shrimp	*Palaemonetes intermedius*	0.01	0.41	6	0.03	0.24	17	5	2.11	20	0.85	0.38	7
Palaemonidae	Eastern grass shrimp, riverine grass shrimp	*Palaemonetes paludosus*									1			
Palaemonidae	Daggerblade grass shrimp	*Palaemonetes pugio*	0.21	0.26	15	2.98	1.43	26	43.1	6.4	27	24.77	6.61	11
Palaemonidae	Common American prawn, common grass shrimp, marsh grass shrimp, marsh shrimp	*Palaemonetes vulgaris*	0.16	0.38	7	0.07	0.24	17	4.56	1.99	15	0.18	0.38	7
Panopeidae	Atlantic mud crab	*Panopeus herbstii*				0.07	0.29	12	0	0.71	2			1
Porcellanidae	Green porcelain crab	*Petrolisthes armatus*				0	0.71	2			1			
Panopeidae	Harris mud crab, estuarine mud crab	*Rhithropanopeus harrisii*	0.74	0.58	3	0.08	0.33	9	1.1	0.58	6	0.07	0.58	3
Sesarmidae	Heavy marsh crab, purple marsh crab	*Sesarma reticulatum*	0.04	0.58	3	0	0.25	16	4.42	3.2	9	1.28	1.09	4
Ocypodidae	–	*Uca* spp.				0	0.71	2	1.45	1.22	2	0.07	1.22	2
Xanthidae	Mud crabs, pebble crabs, rubble crabs	Xanthidae spp.				0	0.41	6	0.04	0.58	3	0	0.71	2
–	**Fish – total**	**–**	**4.12**	**0.97**	**16**	**8.39**	**1.73**	**27**	**8.84**	**1.54**	**29**	**10.27**	**3.1**	**9**
Fundulidae	Diamond killifish	*Adinia xenica*	0	0.71	2	0.23	0.38	7	2.21	1.91	4	2.93	0.5	4
Engraulidae	Bay anchovy	*Anchoa mitchilli*	3.65	0.94	26	5.21	1.72	25	0.28	0.2	25	0.07	0.41	6
Sparidae	Sheepshead	*Archosargus probatocephalus*	0	0.71	2	0.04	0.58	3						
Ariidae	Hardhead catfish	*Ariopsis felis*				0.03	0.45	5						
Clupeidae	Gulf menhaden, largescale menhaden	*Brevoortia patronus*			1	0.01	0.38	7	0.08	0.35	8	0	1.22	2
Blenniidae	Striped blenny	*Chasmodes bosquianus*									1			
Gobiidae	Darter goby	*Ctenogobius boleosoma*	0.41	0.3	11	0.5	0.24	26	2.44	1.05	22	0.6	0.41	6
Sciaenidae	Sand seatrout	*Cynoscion arenarius*				0.01	0.71	2			1			
Sciaenidae	Spotted seatrout	*Cynoscion nebulosus*			1	0.14	0.16	40	0.41	0.26	15	0.09	0.38	7
Cyprinodontidae	Sheepshead minnow, sheepshead pupfish	*Cyprinodon variegatus*	0.06	0.38	7	0.65	0.48	17	0.61	0.35	13	2.78	0.84	7
Fundulidae	Gulf killifish	*Fundulus grandis*	0.11	0.5	4	0.02	0.24	17	0.43	0.24	17	1.35	0.43	7

			Open-water NVB						Marsh					
			Far			Near			Edge			Interior		
Family	Common name	Scientific name	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Fundulidae	Bayou killifish	*Fundulus pulvereus*			1	0	0.3	11	0.7	0.7	3	0.4	0.5	4
Poeciliidae	Mosquitofish, western mosquitofish	*Gambusia affinis*									1	0	1.22	2
Gobiesocidae	Skilletfish	*Gobiesox strumosus*	0	0.71	2	0	0.5	4			1			
Gobiidae	Naked goby	*Gobiosoma bosc*	0.91	0.39	13	1.18	0.39	26	3.85	1.25	23	5.75	4.29	6
Sparidae	Pinfish	*Lagodon rhomboides*	0.02	0.45	5	0.02	0.3	11	0.49	0.35	13			1
Sciaenidae	Spot	*Leiostomus xanthurus*	0.14	0.58	3	0.05	0.29	12	0	0.35	8			1
Fundulidae	Rainwater killifish	*Lucania parva*	0	0.71	2	0	0.5	4	2.01	0.87	9	0.7	0.71	2
Atherinopsidae	Inland silverside, tidewater silverside	*Menidia beryllina*	0.01	0.58	3	0.53	0.22	20	0.16	0.26	15	0.2	0.38	7
Sciaenidae	Atlantic croaker	*Micropogonias undulatus*	0.64	0.71	2	0.47	0.19	31	0.04	0.33	9	0	0.71	2
Mugilidae	Striped mullet, gray mullet, black mullet	*Mugil cephalus*	0.72	0.72	2	0.18	0.25	16	0.13	0.26	15	0.32	0.35	8
Ophichthidae	Speckled worm eel	*Myrophis punctatus*	0	0.71	2	0.08	0.41	6	0.06	0.41	6			
Batrachoididae	Gulf toadfish	*Opsanus beta*	0	0.58	3	0.03	0.5	4	0	0.5	4			
Paralichthyidae	Southern flounder	*Paralichthys lethostigma*	0	0.71	2	0.04	0.32	10	0.02	0.35	8	0	0.71	2
Poeciliidae	Sailfin molly	*Poecilia latipinna*	0	0.71	2	0	0.5	4			1	2.4	1.22	2
Sciaenidae	Black drum	*Pogonias cromis*				0	0.5	4	0	0.71	2			
Sciaenidae	Red drum	*Sciaenops ocellatus*	0.1	0.71	2	0.16	0.19	27	0.24	0.38	7	0.13	1.22	2
Tetraodontidae	Least puffer	*Sphoeroides parvus*				0.03	0.33	9						
Cynoglossidae	Blackcheek tonguefish	*Symphurus plagiusa*	0.68	0.32	10	0.48	0.2	26	0.38	0.23	19	0.1	0.38	7

Table S2. Estimated means, number of individuals/m^2, (± 1 SE) of total nekton density (sum of crustacean and fish species), total crustacean density, total fish density, and densities of crustacean and fish species in saline, brackish, and intermediate marsh during the spring and fall. Means are presented for two or more observations. The total number of samples (N) is also provided.

Family	Common name	Scientific name	Saline marsh			Brackish marsh			Intermediate marsh		
			Mean	SE	N	Mean	SE	N	Mean	SE	N
Spring											
–	**Nekton – total**	**–**	**88.67**	**10.23**	**65**	**41.14**	**15.12**	**11**	**44.24**	**9.72**	**14**
–	**Crustaceans – total**	**–**	**79.15**	**10**	**65**	**30.02**	**14.48**	**11**	**24.11**	**11.4**	**10**
Alpheidae	Bigclaw snapping shrimp	*Alpheus heterochaelis*	0.45	0.22	20			1			1
Portunidae	Blue crab, bluepoint	*Callinectes sapidus*	2.89	0.29	61	1.85	0.6	11	0.46	0.28	13
Diogenidae	Thinstripe hermit	*Clibanarius vittatus*	1.34	0.32	33	0	0.58	3			1
Panopeidae	Gulf grassflat crab	*Dyspanopeus texanus*	0.45	0.22	20	0.2	0.5	4			
Panopeidae	Flatback mud crab	*Eurypanopeus depressus*	0.21	0.26	15			1			1
Panopeidae	Ridgeback mud crab	*Eurypanopeus turgidus*	0.15	0.38	7						
Penaeidae	Brown shrimp, golden shrimp, northern brown shrimp, red shrimp, redtail shrimp	*Farfantepenaeus aztecus*	12.96	1.15	66	1.85	0.75	10	0.12	0.41	6
Penaeidae	Bait shrimp, northern pink shrimp, pink shrimp, spotted shrimp	*Farfantepenaeus duorarum*	0.18	0.38	7			1			1
Penaeidae	Northern white shrimp, white shrimp	*Litopenaeus setiferus*	1.9	0.89	34	0	0.58	3			1
Menippidae	Gulf stone crab	*Menippe adina*							0.02	0.71	2
Menippidae	Florida stone crab	*Menippe mercenaria*	0.03	0.45	5						
Palaemonidae	Brackish grass shrimp	*Palaemonetes intermedius*	2.71	1.16	30	0.32	0.45	5			1
Palaemonidae	Eastern grass shrimp, riverine grass shrimp	*Palaemonetes paludosus*							15.31	6.51	10
Palaemonidae	Daggerblade grass shrimp	*Palaemonetes pugio*	50.98	8.54	62	25.08	13.83	11	2.31	1.79	7
Palaemonidae	Common American prawn, common grass shrimp, marsh grass shrimp, marsh shrimp	*Palaemonetes vulgaris*	1.45	1.29	23	0	0.5	4			
Panopeidae	Atlantic mud crab	*Panopeus herbstii*	0.15	0.25	16			1			1
Porcellanidae	Green porcelain crab	*Petrolisthes armatus*			1						
Panopeidae	Harris mud crab, estuarine mud crab	*Rhithropanopeus harrisii*	0.17	0.28	13	0.69	0.56	6	1.61	0.98	6
Sesarmidae	Heavy marsh crab, purple marsh crab	*Sesarma reticulatum*	2.2	1.15	26			1			1
Ocypodidae	–	*Uca* spp.	4.86	4.3	4	1.37	0.69	5	0.06	0.5	4
Xanthidae	Mud crabs, pebble crabs, rubble crabs	Xanthidae spp.			1			1	3.71	3.71	2
–	**Fish – total**	**–**	**8.95**	**1.27**	**69**	**11.12**	**3.58**	**11**	**19.87**	**5.18**	**10**

Family	Common name	Scientific name	Saline marsh			Brackish marsh			Intermediate marsh		
			Mean	SE	N	Mean	SE	N	Mean	SE	N
Fundulidae	Diamond killifish	*Adinia xenica*	0.52	0.28	18	0.63	0.37	10	0.09	0.5	4
Engraulidae	Bay anchovy	*Anchoa mitchilli*	0.41	0.2	30	5.81	4.01	6	0.06	0.5	4
Sparidae	Sheepshead	*Archosargus probatocephalus*	0.1	0.41	6						
Ariidae	Hardhead catfish	*Ariopsis felis*	0.02	0.28	13	0.03	0.5	4	0.01	0.71	2
Clupeidae	Gulf menhaden, largescale menhaden	*Brevoortia patronus*	2.02	1.24	46	0.38	0.41	6	24.28	24.35	6
Blenniidae	Striped blenny	*Chasmodes bosquianus*	0	0.71	2			1			1
Gobiidae	Darter goby	*Ctenogobius boleosoma*	3.27	1.84	26	0.51	0.71	2	0.06	0.71	2
Gobiidae	Freshwater goby	*Ctenogobius shufeldti*									1
Sciaenidae	Sand seatrout	*Cynoscion arenarius*	0	0.38	7			1			1
Sciaenidae	Spotted seatrout	*Cynoscion nebulosus*	0.01	0.27	14	0.29	0.71	2			
Cyprinodontidae	Sheepshead minnow, sheepshead pupfish	*Cyprinodon variegatus*	0.47	0.18	30	2.66	1.52	9	5.25	3.12	10
Fundulidae	Gulf killifish	*Fundulus grandis*	0.4	0.16	40	0.62	0.3	11	0.06	0.71	2
Fundulidae	Bayou killifish	*Fundulus pulvereus*	0.49	0.58	3	1.45	0.54	6	0.57	0.33	9
Poeciliidae	Mosquitofish, western mosquitofish	*Gambusia affinis*	0.04	0.58	3	0.05	0.41	6	2.1	1.03	9
Gobiesocidae	Skilletfish	*Gobiesox strumosus*	0.68	0.55	12	0.54	0.54	5			1
Gobiidae	Naked goby	*Gobiosoma bosc*	0.74	0.23	33	2.19	1.51	6	0.27	0.38	7
Sparidae	Pinfish	*Lagodon rhomboides*	3.18	0.49	54	0.45	0.41	6	0.17	0.71	2
Sciaenidae	Spot	*Leiostomus xanthurus*	0.23	0.15	46	0.1	0.38	7	0.04	0.58	3
Fundulidae	Rainwater killifish	*Lucania parva*	0.41	0.27	14	0.58	0.6	6	7.32	1.58	12
Atherinopsidae	Inland silverside, tidewater silverside	*Menidia beryllina*	0.56	0.19	37	0.11	0.32	10	0.39	0.41	6
Sciaenidae	Atlantic croaker	*Micropogonias undulatus*	0.02	0.21	22	0.05	0.38	7	0	0.5	4
Mugilidae	Striped mullet, gray mullet, black mullet	*Mugil cephalus*	0.41	0.16	38	0.04	0.3	11	0	0.71	2
Ophichthidae	Speckled worm eel	*Myrophis punctatus*	0.18	0.21	22	0.07	0.38	7	0.08	0.58	3
Batrachoididae	Gulf toadfish	*Opsanus beta*	0.03	0.29	12	0	0.58	3			1
Paralichthyidae	Southern flounder	*Paralichthys lethostigma*	0.12	0.2	25	0.03	0.45	5	0	0.71	2
Poeciliidae	Sailfin molly	*Poecilia latipinna*	0	0.58	3	0.09	0.45	5	0.87	0.39	8
Sciaenidae	Black drum	*Pogonias cromis*	0	0.5	4						
Sciaenidae	Red drum	*Sciaenops ocellatus*	0	0.25	16	0.04	0.58	3			1
Tetraodontidae	Least puffer	*Sphoeroides parvus*	0.04	0.35	8	0	0.45	5			1
Cynoglossidae	Blackcheek tonguefish	*Symphurus plagiusa*	0.01	0.24	17	0	0.71	2			1

Family	Common name	Scientific name	Saline marsh			Brackish marsh			Intermediate marsh		
			Mean	SE	N	Mean	SE	N	Mean	SE	N
Fall											
–	**Nekton – total**	**–**	**115.12**	**10.62**	**59**	**90.38**	**36.84**	**11**	**67.12**	**49.09**	**3**
–	**Crustaceans – total**	**–**	**104.36**	**10.26**	**59**	**71.87**	**37.66**	**11**	**45.61**	**45.27**	**3**
Alpheidae	Bigclaw snapping shrimp	*Alpheus heterochaelis*	2.11	1.05	12			1			
Portunidae	Blue crab, bluepoint	*Callinectes sapidus*	12.93	2.18	63	10.06	5.26	11	2.56	1.44	4
Diogenidae	Thinstripe hermit	*Clibanarius vittatus*	1.3	0.46	21			1			1
Panopeidae	Gulf grassflat crab	*Dyspanopeus texanus*	2.9	1.31	13	0.64	0.46	6			1
Panopeidae	Flatback mud crab	*Eurypanopeus depressus*	1.13	1.07	8			1			
Panopeidae	Ridgeback mud crab	*Eurypanopeus turgidus*			1						
Penaeidae	Brown shrimp, golden shrimp, northern brown shrimp, red shrimp, redtail shrimp	*Farfantepenaeus aztecus*	6.04	0.9	51	1.36	0.46	7	0	0.71	2
Penaeidae	Bait shrimp, northern pink shrimp, pink shrimp, spotted shrimp	*Farfantepenaeus duorarum*	5	0.72	36	1.24	0.68	7	0	0.71	2
Penaeidae	Northern white shrimp, white shrimp	*Litopenaeus setiferus*	12.9	1.95	60	0.85	0.33	11	1.42	1.17	4
Menippidae	Gulf stone crab	*Menippe adina*			1						
Menippidae	Florida stone crab	*Menippe mercenaria*			1			1			
Palaemonidae	Brackish grass shrimp	*Palaemonetes intermedius*	3.44	1.14	38	2.85	2.29	6	0.29	0.71	2
Palaemonidae	Eastern grass shrimp, riverine grass shrimp	*Palaemonetes paludosus*			1			1	3.08	3.08	2
Palaemonidae	Daggerblade grass shrimp	*Palaemonetes pugio*	43.7	5.57	49	50.19	27.85	11	8.44	5.19	4
Palaemonidae	Common American prawn, common grass shrimp, marsh grass shrimp, marsh shrimp	*Palaemonetes vulgaris*	4.73	1.36	33	9.91	9.84	4	2.24	1.65	3
Panopeidae	Atlantic mud crab	*Panopeus herbstii*	0.03	0.29	12	0.07	0.58	3			
Porcellanidae	Green porcelain crab	*Petrolisthes armatus*	0.07	0.58	3						
Panopeidae	Harris mud crab, estuarine mud crab	*Rhithropanopeus harrisii*	0.62	0.31	12	0.45	0.38	7	12.97	12.48	4
Sesarmidae	Heavy marsh crab, purple marsh crab	*Sesarma reticulatum*	2.17	1.41	21	0.37	0.45	5			1
Ocypodidae	–	*Uca* spp.	0.56	0.49	6	0.29	0.45	5			1
Xanthidae	Mud crabs, pebble crabs, rubble crabs	Xanthidae spp.	0.02	0.41	6	0.14	0.41	6	24.43	24.49	2
–	**Fish – total**	**–**	**10.47**	**1.34**	**61**	**18.5**	**4.27**	**11**	**21.51**	**4.11**	**3**
Fundulidae	Diamond killifish	*Adinia xenica*	1.64	0.68	13	3.82	0.45	5			1
Engraulidae	Bay anchovy	*Anchoa mitchilli*	0.4	0.15	42	1.55	0.84	7	0	0.58	3
Sparidae	Sheepshead	*Archosargus probatocephalus*	0	0.58	3						

Family	Common name	Scientific name	Saline marsh			Brackish marsh			Intermediate marsh		
			Mean	SE	N	Mean	SE	N	Mean	SE	N
Ariidae	Hardhead catfish	*Ariopsis felis*	0.04	0.58	3						
Clupeidae	Gulf menhaden, largescale menhaden	*Brevoortia patronus*	0.06	0.32	10						
Blenniidae	Striped blenny	*Chasmodes bosquianus*			1						
Gobiidae	Darter goby	*Ctenogobius boleosoma*	2.04	0.65	39	0	0.41	6	0.64	0.71	2
Gobiidae	Freshwater goby	*Ctenogobius shufeldti*									
Sciaenidae	Sand seatrout	*Cynoscion arenarius*			1			1			1
Sciaenidae	Spotted seatrout	*Cynoscion nebulosus*	0.31	0.17	33	0.05	0.3	11	0	0.71	2
Cyprinodontidae	Sheepshead minnow, sheepshead pupfish	*Cyprinodon variegatus*	0.99	0.32	27	1.75	1.16	10	9.35	4.71	2
Fundulidae	Gulf killifish	*Fundulus grandis*	0.9	0.22	32	0.36	0.3	11	0.64	0.71	2
Fundulidae	Bayou killifish	*Fundulus pulvereus*	0.3	0.27	14	2.21	1.14	10	3.54	3.54	2
Poeciliidae	Mosquitofish, western mosquitofish	*Gambusia affinis*	0	0.58	3	0.67	0.45	5			1
Gobiesocidae	Skilletfish	*Gobiesox strumosus*	0.11	0.38	7			1			
Gobiidae	Naked goby	*Gobiosoma bosc*	6.19	1.55	40	11.77	2.8	6	2.67	2.12	3
Sparidae	Pinfish	*Lagodon rhomboides*	0.35	0.25	18	0	0.71	2			
Sciaenidae	Spot	*Leiostomus xanthurus*	0	0.27	14	0	0.58	3			1
Fundulidae	Rainwater killifish	*Lucania parva*	1.77	0.73	11	6.27	6.27	2	4.61	2.04	4
Atherinopsidae	Inland silverside, tidewater silverside	*Menidia beryllina*	0.15	0.18	30	0.06	0.32	10			1
Sciaenidae	Atlantic croaker	*Micropogonias undulatus*	0.04	0.26	15	0.06	0.41	6			1
Mugilidae	Striped mullet, gray mullet, black mullet	*Mugil cephalus*	0.16	0.18	31	0.01	0.33	9	0.58	0.58	3
Ophichthidae	Speckled worm eel	*Myrophis punctatus*	0.22	0.29	12	0	0.71	2	1.45	1.45	2
Batrachoididae	Gulf toadfish	*Opsanus beta*	0.03	0.45	5	0	0.71	2			1
Paralichthyidae	Southern flounder	*Paralichthys lethostigma*	0.02	0.26	15	0.07	0.45	5			
Poeciliidae	Sailfin molly	*Poecilia latipinna*	1.78	1.05	5	4.8	1.88	5			1
Sciaenidae	Black drum	*Pogonias cromis*	0	0.71	2						
Sciaenidae	Red drum	*Sciaenops ocellatus*	0.16	0.29	12			1			
Tetraodontidae	Least puffer	*Sphoeroides parvus*	0.04	0.33	9			1			
Cynoglossidae	Blackcheek tonguefish	*Symphurus plagiusa*	0.37	0.16	37	0.67	0.62	5			

Table S3. Estimated means, number of individuals/m², (± 1 SE) of total nekton density (sum of crustacean and fish species), total crustacean density, total fish density, and densities of individual crustacean and fish species in marsh habitat during the spring, summer, fall, and winter in the saline zone. Means are presented for two or more observations. The total number of samples (N) is also provided.

Family	Common name	Scientific name	Spring			Summer			Fall			Winter		
			Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
–	**Nekton – total**	–	88.67	10.23	65	87.21	16.21	11	115.12	10.62	59	39.81	8.78	5
–	**Crustaceans – total**	–	79.15	10	65	79.28	16.64	11	104.36	10.26	59	37.99	9.49	5
Alpheidae	Bigclaw snapping shrimp	*Alpheus heterochaelis*	0.45	0.22	20	1.16	0.89	3	2.11	1.05	12			1
Portunidae	Blue crab, bluepoint	*Callinectes sapidus*	2.89	0.29	61	4.48	0.97	16	12.93	2.18	63	3.74	1.21	7
Diogenidae	Thinstripe hermit	*Clibanarius vittatus*	1.34	0.32	33	0.99	0.5	4	1.3	0.46	21			1
Panopeidae	Gulf grassflat crab	*Dyspanopeus texanus*	0.45	0.22	20	0.07	0.41	6	2.9	1.31	13			
Panopeidae	Flatback mud crab	*Eurypanopeus depressus*	0.21	0.26	15	3.56	3.56	3	1.13	1.07	8	0	0.71	2
Panopeidae	Ridgeback mud crab	*Eurypanopeus turgidus*	0.15	0.38	7						1			
Penaeidae	Brown shrimp, golden shrimp, northern brown shrimp, red shrimp, redtail shrimp	*Farfantepenaeus aztecus*	12.96	1.15	66	9.1	1.98	16	6.04	0.9	51	0.66	0.38	7
Penaeidae	Bait shrimp, northern pink shrimp, pink shrimp, spotted shrimp	*Farfantepenaeus duorarum*	0.18	0.38	7	1.46	0.85	6	5	0.72	36	0	0.5	4
Penaeidae	Northern white shrimp, white shrimp	*Litopenaeus setiferus*	1.9	0.89	34	8.13	2.92	16	12.9	1.95	60	0.72	0.54	7
Menippidae	Gulf stone crab	*Menippe adina*									1			
Menippidae	Florida stone crab	*Menippe mercenaria*	0.03	0.45	5	0.09	0.58	3			1			1
Palaemonidae	Brackish grass shrimp	*Palaemonetes intermedius*	2.71	1.16	30	0.72	0.32	10	3.44	1.14	38	1.74	1.21	3
Palaemonidae	Eastern grass shrimp, riverine grass shrimp	*Palaemonetes paludosus*									1			
Palaemonidae	Daggerblade grass shrimp	*Palaemonetes pugio*	50.98	8.54	62	55.83	9.7	14	43.7	5.57	49	40.05	4.36	6
Palaemonidae	Common American prawn, common grass shrimp, marsh grass shrimp, marsh shrimp	*Palaemonetes vulgaris*	1.45	1.29	23	0.67	0.35	10	4.73	1.36	33	0.4	0.5	4
Panopeidae	Atlantic mud crab	*Panopeus herbstii*	0.15	0.25	16	0.1	0.58	3	0.03	0.29	12	0.02	0.71	2
Porcellanidae	Green porcelain crab	*Petrolisthes armatus*			1	0.1	0.5	4	0.07	0.58	3	0.2	0.71	2
Panopeidae	Harris mud crab, estuarine mud crab	*Rhithropanopeus harrisii*	0.17	0.28	13	0.16	0.58	3	0.62	0.31	12			

Family	Common name	Scientific name	Spring			Summer			Fall			Winter		
			Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Sesarmidae	Heavy marsh crab, purple marsh crab	*Sesarma reticulatum*	2.2	1.15	26	0.19	0.58	3	2.17	1.41	21			
Ocypodidae	–	*Uca* spp.	4.86	4.3	4			1	0.56	0.49	6			1
Xanthidae	Mud crabs, pebble crabs, rubble crabs	Xanthidae spp.			1			1	0.02	0.41	6			
–	**Fish – total**	**–**	**8.95**	**1.27**	**69**	**6.43**	**2.3**	**14**	**10.47**	**1.34**	**61**	**1.48**	**0.74**	**7**
Fundulidae	Diamond killifish	*Adinia xenica*	0.52	0.28	18	0.19	0.58	3	1.64	0.68	13			
Engraulidae	Bay anchovy	*Anchoa mitchilli*	0.41	0.2	30	0.11	0.28	13	0.4	0.15	42	0	0.45	5
Sparidae	Sheepshead	*Archosargus probatocephalus*	0	0.41	6	0.1	0.41	6				0.42	0.58	3
Ariidae	Hardhead catfish	*Ariopsis felis*	0.06	0.24	18	0.02	0.28	13						1
Sparidae	Sheepshead	*Archosargus probatocephalus*	0.1	0.41	6	0	0.45	5	0	0.58	3			
Ariidae	Hardhead catfish	*Ariopsis felis*	0.02	0.28	13			1	0.04	0.58	3			
Clupeidae	Gulf menhaden, largescale menhaden	*Brevoortia patronus*	2.02	1.24	46	2.84	2.8	10	0.06	0.32	10	0.38	0.41	6
Blenniidae	Striped blenny	*Chasmodes bosquianus*	0	0.71	2			1			1			1
Gobiidae	Darter goby	*Ctenogobius boleosoma*	3.27	1.84	26	0.08	0.35	8	2.04	0.65	39	0	0.41	6
Sciaenidae	Sand seatrout	*Cynoscion arenarius*	0	0.38	7						1			
Sciaenidae	Spotted seatrout	*Cynoscion nebulosus*	0.01	0.27	14	0.33	0.3	11	0.31	0.17	33	0.01	0.41	6
Cyprinodontidae	Sheepshead minnow, sheepshead pupfish	*Cyprinodon variegatus*	0.47	0.18	30	0.62	0.42	9	0.99	0.32	27	0.12	0.58	3
Fundulidae	Gulf killifish	*Fundulus grandis*	0.4	0.16	40	0.25	0.28	13	0.9	0.22	32	0.05	0.38	7
Fundulidae	Bayou killifish	*Fundulus pulvereus*	0.49	0.58	3	0.4	0.71	2	0.3	0.27	14			1
Poeciliidae	Mosquitofish, western mosquitofish	*Gambusia affinis*	0.04	0.58	3	0.07	0.71	2	0	0.58	3			
Gobiesocidae	Skilletfish	*Gobiesox strumosus*	0.68	0.55	12	0.04	0.45	5	0.11	0.38	7			1
Sciaenidae	Spot	*Leiostomus xanthurus*	1.77	0.58	54	0.23	0.15	46			1	0.34	0.27	14
Gobiidae	Naked goby	*Gobiosoma bosc*	0.74	0.23	33	0.91	0.31	14	6.19	1.55	40	0.1	0.41	6
Sparidae	Pinfish	*Lagodon rhomboides*	3.18	0.49	54	0.66	0.28	13	0.35	0.25	18	0.24	0.38	7
Sciaenidae	Spot	*Leiostomus xanthurus*	0.23	0.15	46	0	0.3	11	0	0.27	14	0.26	0.41	6
Fundulidae	Rainwater killifish	*Lucania parva*	0.41	0.27	14	0.03	0.5	4	1.77	0.73	11	0	0.71	2

Family	Common name	Scientific name	Spring			Summer			Fall			Winter		
			Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Atherinopsidae	Inland silverside, tidewater silverside	*Menidia beryllina*	0.56	0.19	37	0.91	0.63	13	0.15	0.18	30	0	0.45	5
Sciaenidae	Atlantic croaker	*Micropogonias undulatus*	0.02	0.21	22	0.01	0.35	8	0.04	0.26	15	0.14	0.45	5
Mugilidae	Striped mullet, gray mullet, black mullet	*Mugil cephalus*	0.41	0.16	38	0.26	0.28	13	0.16	0.18	31	0.02	0.45	5
Ophichthidae	Speckled worm eel	*Myrophis punctatus*	0.18	0.21	22	0.18	0.29	12	0.22	0.29	12	0	0.45	5
Batrachoididae	Gulf toadfish	*Opsanus beta*	0.03	0.29	12	0.04	0.38	7	0.03	0.45	5	0	0.71	2
Paralichthyidae	Southern flounder	*Paralichthys lethostigma*	0.12	0.2	25	0.02	0.28	13	0.02	0.26	15	0	0.45	5
Poeciliidae	Sailfin molly	*Poecilia latipinna*	0	0.58	3				1.78	1.05	5			
Sciaenidae	Black drum	*Pogonias cromis*	0	0.5	4	0	0.58	3	0	0.71	2	0	0.71	2
Sciaenidae	Red drum	*Sciaenops ocellatus*	0	0.25	16	0	0.38	7	0.16	0.29	12	0.05	0.45	5
Tetraodontidae	Least puffer	*Sphoeroides parvus*	0.04	0.35	8			1	0.04	0.33	9			
Cynoglossidae	Blackcheek tonguefish	*Symphurus plagiusa*	0.01	0.24	17	0.05	0.32	10	0.37	0.16	37	0	0.41	6

Table S4. Estimated means, number of individuals/m², (± 1 SE) of total nekton density (sum of crustacean and fish species), total crustacean density, total fish density, and densities of individual crustacean and fish species in open-water NVB, marsh, oyster reefs, and SAV habitats during the spring and fall in the saline zone. Means are presented for two or more observations. The total number of samples (N) is also provided.

			Open-water NVB			Marsh			Oyster reefs			SAV		
Family	Common name	Scientific name	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Spring														
–	**Nekton – total**	**–**	**23.57**	**4.58**	**49**	**88.67**	**10.23**	**65**	**266.71**	**119.52**	**4**	**63.92**	**18.01**	**24**
–	**Crustaceans – total**	**–**	**7.02**	**2.03**	**50**	**79.15**	**10**	**65**	**323.72**	**187.75**	**2**	**58.39**	**19.24**	**20**
Alpheidae	Bigclaw snapping shrimp	*Alpheus heterochaelis*	0.08	0.28	13	0.45	0.22	20	10.3	2.31	14	0.65	0.3	15
Portunidae	Blue crab, bluepoint	*Callinectes sapidus*	0.46	0.12	67	2.89	0.29	61	2.08	0.61	16	2.54	0.69	20
Diogenidae	Thinstripe hermit	*Clibanarius vittatus*	1.05	0.64	21	1.34	0.32	33	0.82	0.41	13	0.35	0.58	3
Panopeidae	Gulf grassflat crab	*Dyspanopeus texanus*	0.15	0.28	13	0.45	0.22	20			1	3.98	2.61	14
Panopeidae	Flatback mud crab	*Eurypanopeus depressus*	0.68	0.53	16	0.21	0.26	15	30.54	21.83	18	0	0.71	2
Panopeidae	Ridgeback mud crab	*Eurypanopeus turgidus*				0.15	0.38	7			1	0.33	0.71	2
Penaeidae	Brown shrimp, golden shrimp, northern brown shrimp, red shrimp, redtail shrimp	*Farfantepenaeus aztecus*	2.35	0.26	76	12.96	1.15	66	6.94	1.72	2	12.09	4.1	9
Penaeidae	Bait shrimp, northern pink shrimp, pink shrimp, spotted shrimp	*Farfantepenaeus duorarum*	0.05	0.32	10	0.18	0.38	7			1	1.32	0.32	10
Penaeidae	Northern white shrimp, white shrimp	*Litopenaeus setiferus*	0.39	0.19	27	1.9	0.89	34			1	4.93	1.52	7
Menippidae	Gulf stone crab	*Menippe adina*			1				0	0.29	12			
Menippidae	Florida stone crab	*Menippe mercenaria*	0	0.58	3	0.03	0.45	5						
Palaemonidae	Brackish grass shrimp	*Palaemonetes intermedius*	0.1	0.21	23	2.71	1.16	30			1	32.76	22.74	9
Palaemonidae	Eastern grass shrimp, riverine grass shrimp	*Palaemonetes paludosus*												
Palaemonidae	Daggerblade grass shrimp	*Palaemonetes pugio*	1.41	0.93	66	50.98	8.54	62	36.71	23.2	14	30.06	14.47	14
Palaemonidae	Common American prawn, common grass shrimp, marsh grass shrimp, marsh shrimp	*Palaemonetes vulgaris*	0.01	0.28	13	1.45	1.29	23						1
Panopeidae	Atlantic mud crab	*Panopeus herbstii*	0.25	0.35	8	0.15	0.25	16	317.29	79.61	14	0.18	0.38	7
Porcellanidae	Green porcelain crab	*Petrolisthes armatus*	3.74	3.57	4			1	18.56	7.42	16			1

Family	Common name	Scientific name	Open-water NVB			Marsh			Oyster reefs			SAV		
			Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Panopeidae	Harris mud crab, estuarine mud crab	*Rhithropanopeus harrisii*	0.27	0.26	15	0.17	0.28	13			1	2.94	1.76	3
Sesarmidae	Heavy marsh crab, purple marsh crab	*Sesarma reticulatum*	0.01	0.24	18	2.2	1.15	26						
Ocypodidae	–	*Uca* spp.			1	4.86	4.3	4	0	0.32	10			
Xanthidae	Mud crabs, pebble crabs, rubble crabs	Xanthidae spp.	2.46	0.71	2			1				0.59	0.58	3
–	**Fish – total**	**–**	**14.44**	**3.67**	**53**	**8.95**	**1.27**	**69**	**60.52**	**35.07**	**2**	**8.22**	**2.7**	**31**
Fundulidae	Diamond killifish	*Adinia xenica*	0	0.28	13	0.52	0.28	18				0.05	0.58	3
Engraulidae	Bay anchovy	*Anchoa mitchilli*	3.89	2.03	34	0.41	0.2	30	0.02	0.71	2	0.51	0.44	6
Sparidae	Sheepshead	*Archosargus probatocephalus*	0	0.41	6	0.1	0.41	6				0.42	0.58	3
Ariidae	Hardhead catfish	*Ariopsis felis*	0.06	0.24	18	0.02	0.28	13						1
Clupeidae	Gulf menhaden, largescale menhaden	*Brevoortia patronus*	9.13	3.35	55	2.02	1.24	46				2.19	1.58	8
Blenniidae	Striped blenny	*Chasmodes bosquianus*			1	0	0.71	2	0.28	0.28	13			1
Gobiidae	Darter goby	*Ctenogobius boleosoma*	0.39	0.28	22	3.27	1.84	26	9.58	9.3	13	6.65	3.42	15
Sciaenidae	Sand seatrout	*Cynoscion arenarius*	0.03	0.33	9	0	0.38	7						
Sciaenidae	Spotted seatrout	*Cynoscion nebulosus*	0.01	0.24	17	0.01	0.27	14			1	0.13	0.45	5
Cyprinodontidae	Sheepshead minnow, sheepshead pupfish	*Cyprinodon variegatus*	0.39	0.31	23	0.47	0.18	30				0.51	0.44	9
Fundulidae	Gulf killifish	*Fundulus grandis*	0.01	0.18	32	0.4	0.16	40	0.26	0.28	13	0.05	0.41	6
Fundulidae	Bayou killifish	*Fundulus pulvereus*			1	0.49	0.58	3						
Poeciliidae	Mosquitofish, western mosquitofish	*Gambusia affinis*			1	0.04	0.58	3						
Gobiesocidae	Skilletfish	*Gobiesox strumosus*	0.68	0.33	13	0.68	0.55	12	0	0.29	12			
Gobiidae	Naked goby	*Gobiosoma bosc*	0.63	0.3	34	0.74	0.23	33	0.86	0.55	14	1.19	0.92	5
Sparidae	Pinfish	*Lagodon rhomboides*	0.59	0.21	64	3.18	0.49	54	5.46	2.35	2	5.73	2.55	35
Sciaenidae	Spot	*Leiostomus xanthurus*	1.77	0.58	54	0.23	0.15	46			1	0.34	0.27	14
Fundulidae	Rainwater killifish	*Lucania parva*	0.61	0.61	8	0.41	0.27	14				1.48	1.19	13
Atherinopsidae	Inland silverside, tidewater silverside	*Menidia beryllina*	0.78	0.22	37	0.56	0.19	37	3.88	3.88	2	1.12	0.99	11

Family	Common name	Scientific name	Open-water NVB			Marsh			Oyster reefs			SAV		
			Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Sciaenidae	Atlantic croaker	*Micropogonias undulatus*	0.33	0.18	32	0.02	0.21	22			1	0.12	0.41	6
Mugilidae	Striped mullet, gray mullet, black mullet	*Mugil cephalus*	0.11	0.17	36	0.41	0.16	38			1	0	0.45	5
Ophichthidae	Speckled worm eel	*Myrophis punctatus*	0.14	0.22	21	0.18	0.21	22	0.28	0.29	12			1
Batrachoididae	Gulf toadfish	*Opsanus beta*	0.1	0.29	12	0.03	0.29	12	2.84	1.38	14	0	0.45	5
Paralichthyidae	Southern flounder	*Paralichthys lethostigma*	0.05	0.2	24	0.12	0.2	25				0.03	0.45	5
Poeciliidae	Sailfin molly	*Poecilia latipinna*	0	0.58	3	0	0.58	3						
Sciaenidae	Black drum	*Pogonias cromis*	0.08	0.35	8	0	0.5	4				0.07	0.71	2
Sciaenidae	Red drum	*Sciaenops ocellatus*	0.03	0.22	21	0	0.25	16				0	0.71	2
Tetraodontidae	Least puffer	*Sphoeroides parvus*	0.06	0.28	13	0.04	0.35	8						
Cynoglossidae	Blackcheek tonguefish	*Symphurus plagiusa*	0.16	0.21	22	0.01	0.24	17				0.22	0.45	5
Fall														
–	**Nekton – total**	**–**	**16.07**	**3.06**	**47**	**115.12**	**10.62**	**59**	**102.95**	**79.64**	**6**	**74.67**	**10.54**	**26**
–	**Crustaceans – total**	**–**	**9.05**	**2.59**	**48**	**104.36**	**10.26**	**59**	**86.35**	**67.84**	**6**	**68.01**	**10.79**	**22**
Alpheidae	Bigclaw snapping shrimp	*Alpheus heterochaelis*	0.17	0.27	14	2.11	1.05	12	4.99	2.34	11	4.01	1.09	21
Portunidae	Blue crab, bluepoint	*Callinectes sapidus*	1.94	0.34	74	12.93	2.18	63	8.05	4.4	13	6.42	2.13	30
Diogenidae	Thinstripe hermit	*Clibanarius vittatus*	0.12	0.28	13	1.3	0.46	21	3.3	2.23	7	0.41	0.71	2
Panopeidae	Gulf grassflat crab	*Dyspanopeus texanus*	0.19	0.29	12	2.9	1.31	13				8.3	3.54	9
Panopeidae	Flatback mud crab	*Eurypanopeus depressus*	0.22	0.45	5	1.13	1.07	8	4.63	3.7	8			1
Panopeidae	Ridgeback mud crab	*Eurypanopeus turgidus*						1			1	0.1	0.71	2
Penaeidae	Brown shrimp, golden shrimp, northern brown shrimp, red shrimp, redtail shrimp	*Farfantepenaeus aztecus*	0.61	0.13	59	6.04	0.9	51	0.65	0.41	6	2.83	0.72	15
Penaeidae	Bait shrimp, northern pink shrimp, pink shrimp, spotted shrimp	*Farfantepenaeus duorarum*	0.52	0.14	49	5	0.72	36			1	9.51	2.56	15
Penaeidae	Northern white shrimp, white shrimp	*Litopenaeus setiferus*	2.77	0.84	70	12.9	1.95	60	6.59	4.88	7	9.93	3.62	9
Menippidae	Gulf stone crab	*Menippe adina*						1	0.51	0.46	7			1
Menippidae	Florida stone crab	*Menippe mercenaria*			1			1						
Palaemonidae	Brackish grass shrimp	*Palaemonetes intermedius*	0.04	0.18	30	3.44	1.14	38				11.95	2.44	9

Family	Common name	Scientific name	Open-water NVB			Marsh			Oyster reefs			SAV		
			Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Palaemonidae	Eastern grass shrimp, riverine grass shrimp	*Palaemonetes paludosus*			1			1						
Palaemonidae	Daggerblade grass shrimp	*Palaemonetes pugio*	1.75	0.78	49	43.7	5.57	49	1.19	0.78	11	24.4	8.09	15
Palaemonidae	Common American prawn, common grass shrimp, marsh grass shrimp, marsh shrimp	*Palaemonetes vulgaris*	0.08	0.19	29	4.73	1.36	33				4.26	3.04	7
Panopeidae	Atlantic mud crab	*Panopeus herbstii*	0.07	0.29	12	0.03	0.29	12	161.24	65.42	7	0.14	0.41	6
Porcellanidae	Green porcelain crab	*Petrolisthes armatus*	0	0.71	2	0.07	0.58	3	0.11	0.38	7			1
Panopeidae	Harris mud crab, estuarine mud crab	*Rhithropanopeus harrisii*	0.44	0.27	14	0.62	0.31	12				0.38	0.71	2
Sesarmidae	Heavy marsh crab, purple marsh crab	*Sesarma reticulatum*	0.01	0.22	20	2.17	1.41	21						
Ocypodidae	–	*Uca* spp.	0	0.58	3	0.56	0.49	6	1.13	0.56	6			
Xanthidae	Mud crabs, pebble crabs, rubble crabs	Xanthidae spp.	0.08	0.38	7	0.02	0.41	6				0.17	0.71	2
–	**Fish – total**	**–**	**6.11**	**0.98**	**54**	**10.47**	**1.34**	**61**	**16.03**	**7.88**	**6**	**8.92**	**1.56**	**35**
Fundulidae	Diamond killifish	*Adinia xenica*	0.13	0.29	12	1.64	0.68	13				0.09	0.45	5
Engraulidae	Bay anchovy	*Anchoa mitchilli*	3.97	0.86	61	0.4	0.15	42			1	0.08	0.33	9
Sparidae	Sheepshead	*Archosargus probatocephalus*	0.02	0.38	7	0	0.58	3	0.25	0.5	4			
Ariidae	Hardhead catfish	*Ariopsis felis*	0.02	0.38	7	0.04	0.58	3						1
Clupeidae	Gulf menhaden, largescale menhaden	*Brevoortia patronus*	0.01	0.3	11	0.06	0.32	10			1	0.02	0.58	3
Blenniidae	Striped blenny	*Chasmodes bosquianus*						1	0.11	0.38	7			1
Gobiidae	Darter goby	*Ctenogobius boleosoma*	0.45	0.15	42	2.04	0.65	39	5.2	4.77	12	6.23	1.33	19
Sciaenidae	Sand seatrout	*Cynoscion arenarius*	0.01	0.58	3			1						
Sciaenidae	Spotted seatrout	*Cynoscion nebulosus*	0.13	0.15	46	0.31	0.17	33				0.23	0.41	6
Cyprinodontidae	Sheepshead minnow, sheepshead pupfish	*Cyprinodon variegatus*	0.44	0.31	26	0.99	0.32	27	0.16	0.45	5	1.59	0.8	14
Fundulidae	Gulf killifish	*Fundulus grandis*	0.03	0.19	28	0.9	0.22	32	0	0.41	6	0.33	0.5	4
Fundulidae	Bayou killifish	*Fundulus pulvereus*	0	0.28	13	0.3	0.27	14				0	0.71	2
Poeciliidae	Mosquitofish, western mosquitofish	*Gambusia affinis*			1	0	0.58	3						

Family	Common name	Scientific name	Open-water NVB			Marsh			Oyster reefs			SAV		
			Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Gobiesocidae	Skilletfish	*Gobiesox strumosus*	0	0.41	6	0.11	0.38	7	0.38	0.32	10			
Gobiidae	Naked goby	*Gobiosoma bosc*	1.15	0.29	45	6.19	1.55	40	1.23	0.46	12	2.13	1.05	9
Sparidae	Pinfish	*Lagodon rhomboides*	0.02	0.2	24	0.35	0.25	18			1	0.59	0.16	37
Sciaenidae	Spot	*Leiostomus xanthurus*	0.13	0.21	23	0	0.27	14				0.05	0.5	4
Fundulidae	Rainwater killifish	*Lucania parva*	0	0.33	9	1.77	0.73	11				1.36	0.43	18
Atherinopsidae	Inland silverside, tidewater silverside	*Menidia beryllina*	0.5	0.19	29	0.15	0.18	30			1	0.25	0.32	10
Sciaenidae	Atlantic croaker	*Micropogonias undulatus*	0.43	0.16	37	0.04	0.26	15			1	0.14	0.58	3
Mugilidae	Striped mullet, gray mullet, black mullet	*Mugil cephalus*	0.18	0.2	24	0.16	0.18	31	0	0.5	4			
Ophichthidae	Speckled worm eel	*Myrophis punctatus*	0.08	0.29	12	0.22	0.29	12	0.16	0.32	10			1
Batrachoididae	Gulf toadfish	*Opsanus beta*	0.02	0.35	8	0.03	0.45	5	0.68	0.62	11	0.05	0.41	6
Paralichthyidae	Southern flounder	*Paralichthys lethostigma*	0.03	0.26	15	0.02	0.26	15	0	0.5	4			
Poeciliidae	Sailfin molly	*Poecilia latipinna*	0	0.33	9	1.78	1.05	5				0.33	0.5	4
Sciaenidae	Black drum	*Pogonias cromis*	0	0.5	4	0	0.71	2						
Sciaenidae	Red drum	*Sciaenops ocellatus*	0.15	0.18	32	0.16	0.29	12				0.23	0.32	10
Tetraodontidae	Least puffer	*Sphoeroides parvus*	0.03	0.33	9	0.04	0.33	9						
Cynoglossidae	Blackcheek tonguefish	*Symphurus plagiusa*	0.53	0.16	39	0.37	0.16	37	0.22	0.45	5	1.02	0.45	8

A. Nekton Data Compilation

A.1 Overview

Data related to nekton density and abundance reported in the scientific and grey (e.g., theses, dissertations, reports) literature were compiled to evaluate nekton use of estuarine habitats in the northern Gulf of Mexico. In particular, an extensive literature search was conducted consisting of a keyword search, an author-based search, and supplemental searches (Section A.2). Papers were reviewed for relevant data on nekton densities of estuarine habitats in the northern Gulf of Mexico (Section A.3); and the relevant data were extracted and compiled, and a 100% quality control (QC) check was performed to verify correct data entry (Section A.4). The following sections describe in more detail the methods used.

A.2 Literature Search

A.2.1 Keyword Search

A keyword search was conducted in 12 databases available through the ProQuest service (http://www.proquest.com/). The selected databases included:

1. Aquatic Sciences and Fisheries Abstracts
2. Biosis Previews
3. Conference Papers Index
4. Ecology Abstracts
5. Ei Compendex
6. Environment Abstracts
7. Environmental Engineering Abstracts
8. Meteorological and Geoastrophysical Abstracts
9. National Technical Information Service
10. Oceanic Abstracts
11. ProQuest Dissertations and Theses
12. SciSearch.

Out of the more than 90 databases that ProQuest offers, these 12 databases were selected because, in the experience of the research team, they provide the most relevant information for searches concerning ecological research.

To identify potentially relevant documents in each of the databases listed above, the following four sets of search terms were used:

- Set 1: Marsh? Or wetland? Or barrier island? Or oyster? Or SAV?[1] Or seagrass? Or mangrove?
- Set 2: Producti?[2] Or utiliz?[3] Or densit?[4] Or abundance? Or biomass? Or CPUE?[5] Or weight? Or number?

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1. Submerged aquatic vegetation.
2. Includes words such as production, productivity, etc.
3. Includes words such as utilize, utilization, etc.
4. Includes words such as density, densities, etc.
5. Catch-per-unit effort.

- Set 3: Louisiana? Or Gulf Coast? Or Gulf of Mexico? Or Texas? Or Alabama? Or Mississippi? Or Florida?
- Set 4: Fish? Or nekton? Or macrofauna? Or crustacean? Or decapod?

The combined statement used in the literature search consisted of the following combination: Set 1, Set 2, Set 3, and Set 4.

The keyword search, which was completed April 24, 2014, was updated May 17, 2017 and January 26, 2018 to identify articles published since the original search.

A.2.2 Author-Based Search

In addition to the keyword search, an author-based literature search was conducted targeting the more prolific authors who were identified in the keyword search. The number of appearances for each author were counted, no matter where in the list of authors his or her name appeared. If an author appeared four times or more in the results of the keyword search, he or she was included in a focused author search. Three additional authors were selected who appeared three times in the keyword search and who wrote papers the research team previously found relevant. The list of authors included in the author search appears in Table A.1.

The author search was conducted in the same 12 databases listed in Section A.2.1. The authors' names were searched with no additional limiters. The author-based search was completed May 29, 2014.

Table A.1. List of 18 authors included in the author-based literature search. An asterisk (*) indicates authors who appeared four or more times in the keyword search. Authors without an asterisk appeared three times in the keyword search.

#	Authors	* Appeared four or more times
1	Baltz, D.M.	*
2	Boswell, K.M.	*
3	Caldwell, P.	*
4	Cowan Jr., J.H.	*
5	Heck Jr., K.L.	*
6	Holmquist, J.G.	*
7	Johnson, M.W.	*
8	La Peyre, M.	
9	Minello, T.J.	*
10	Nyman, J.A.	
11	Rakocinski, C.	*
12	Rooker, J.R.	*
13	Rozas, L.P.	*
14	Sheridan, P.	
15	Stunz, G.W.	*
16	Thayer, G.W.	*
17	Wilson, C.A.	*
18	Zimmerman, R.J.	*

A.2.3 Supplemental Searches

To ensure that a comprehensive list of relevant publications was identified, similar searches were conducted using online search engines (e.g., Google Scholar, Louisiana State University Electronic Thesis and Dissertation Library) and publications already familiar to the research team from previous related work (including publications cataloged in the in-house library of the principal investigators) were reviewed.

A.3 Publication Screening

A.3.1 Literature Screening Criteria

To determine whether identified publications contained relevant information on nekton use of estuarine habitats in the northern Gulf of Mexico, an initial screening protocol was developed consisting of five criteria:

1. Studies that occurred along the U.S. coast of the Gulf of Mexico, extending from Laguna Madre in southern Texas to the Caloosahatchee River in southern Florida
2. Studies that were located in one or more of the following habitats: marsh; mangroves; oyster reefs; SAV; or open-water, non-vegetated bottom (NVB)
3. Studies that were located in a natural or restored habitat (i.e., not substantially impacted or degraded, as characterized by the author)
4. Studies that contained field-collected nekton data (i.e., not laboratory-based studies)
5. Studies that reported density, abundance, biomass, length, or CPUE for all nekton, all fish, all crustaceans, or by species for at least three nekton species.

If all five criteria were met, the documents were retained for additional review and data extraction. Papers that did not meet all five criteria were excluded from further review. The excluded papers included, but were not limited to, studies located outside of the area of interest, studies conducted in an impacted or degraded habitat, studies reporting only presence/absence data, and studies reporting only data for one or two species of interest.

A.3.2 Literature Screening Results

A total of 952 documents were originally identified using the search methods listed above (Figure A.1). Of these documents, 135 passed the screening criteria. In some cases, two papers contained duplicate data from the same study, such as a chapter in a dissertation that also appeared in a scientific journal. For these papers, data from the most recent document were compiled. Overall, data were compiled from 119 documents. Table A.2 provides the list of documents that passed the screening criteria.

Figure A.1. Flow chart representing the literature search, document screening, and data compilation process.

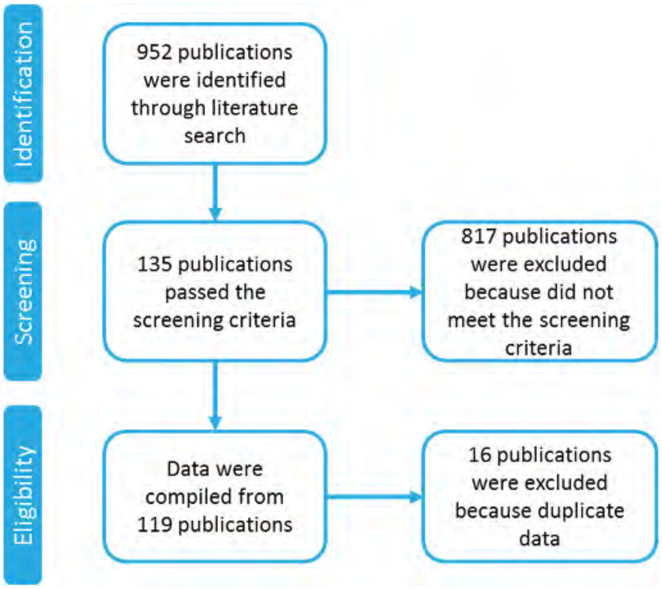

Table A.2. List of publications that passed the screening criteria. This table also indicates whether the publication was compiled in the database. Publications that contained data duplicated in another paper were not compiled in the database.

#	Publications	Compiled in database?
1	Able, K.W., P.C. López-Duarte, F.J. Fodrie, O.P. Jensen, C.W. Martin, B.J. Roberts, J. Valenti, K. O'Connor, and S.C. Halbert. 2015. Fish assemblages in Louisiana salt marshes: Effects of the Macondo oil spill. *Estuaries and Coasts* 38(5):1385–1398.	Yes
2	Allen, R.L. and D.M. Baltz. 1997. Distribution and microhabitat use by flatfishes in a Louisiana estuary. *Environmental Biology of Fishes* 50(1):85–103.	Yes
3	Anton, A., J. Cebrian, C.M. Duarte, K.L. Heck Jr., and J. Goff. 2009. Low impact of Hurricane Katrina on seagrass community structure and functioning in the northern Gulf of Mexico. *Bulletin of Marine Science* 85(1):45–59.	Yes
4	Armitage, A.R., C.-K. Ho, E.N. Madrid, M.T. Bell, and A. Quigg. 2014. The influence of habitat construction technique on the ecological characteristics of a restored brackish marsh. *Ecological Engineering* 62:33–42.	Yes
5	Baltz, D.M. and R.F. Jones. 2003. Temporal and spatial patterns of microhabitat use by fishes and decapod crustaceans in a Louisiana estuary. *Transactions of the American Fisheries Society* 132(4):662–678.	Yes
6	Baltz, D.M., C. Rakocinski, and J.W. Fleeger. 1993. Microhabitat use by marsh-edge fishes in a Louisiana estuary. *Environmental Biology of Fishes* 36:109–126.	Yes
7	Beck, S.L. 2012. The Effects of Oyster Harvest on Resident Oyster Reef Communities and Reef Structure in Coastal Louisiana. MS Thesis, Louisiana State University.	Yes
8	Beck, S. and M.K. La Peyre. 2015. Effects of oyster harvest activities on Louisiana reef habitat and resident nekton communities. *Fishery Bulletin* 113(3):327–340.	Yes
9	Bell, M.T. 2011. Aquatic Macrophyte and Animal Communities in a Recently Restored Brackish Marsh: Possible Influences of Restoration Design and the Invasive Plant Species *Myriophyllum spicatum*. MS Thesis, Texas A&M University.	Yes
10	Birdsong, T.W. 2004. Complexity and Nekton Use of Marsh Edge Habitats in Barataria Bay, Louisiana. MS Thesis, Louisiana State University.	No; duplicate data

#	Publications	Compiled in database?
11	Bologna, P.A.X. and K.L. Heck Jr. 1999. Macrofaunal associations with seagrass epiphytes: Relative importance of trophic and structural characteristics. *Journal of Experimental Marine Biology & Ecology* 242:21–39.	Yes
12	Boswell, K.M., M.P. Wilson, P.S.D. MacRae, C.A. Wilson, and J.H. Cowan Jr. 2010. Seasonal estimates of fish biomass and length distributions using acoustics and traditional nets to identify estuarine habitat preferences in Barataria Bay, Louisiana. *Marine and Coastal Fisheries: Dynamics, Management and Ecosystem Science* 2:83–97.	Yes
13	Burfeind, D.D. and G.W. Stunz. 2006. The effects of boat propeller scarring intensity on nekton abundance in subtropical seagrass meadows. *Marine Biology* 148:953–962.	Yes
14	Bush, C.S. 2003. Nekton Utilization of Restored Habitat in a Louisiana Marsh. MS Thesis, Louisiana State University.	Yes
15	Castellanos, D.L. 1997. Nekton Use of Submerged Aquatic Vegetation, Marsh, and Shallow Unvegetated Bottom in a Louisiana Tidal Freshwater Ecosystem. MS Thesis, University of Southern Louisiana.	No; duplicate data
16	Castellanos, D.L. and L.P. Rozas. 2001. Nekton use of submerged aquatic vegetation, marsh, and shallow unvegetated bottom in the Atchafalaya River Delta, a Louisiana tidal freshwater ecosystem. *Estuaries* 24:184–197.	Yes
17	Caudill, M.C. 2005. Nekton Utilization of Black Mangrove (*Avicennia germinans*) and Smooth Cordgrass (*Spartina alterniflora*) Sites in Southwestern Caminada Bay, Louisiana. MS Thesis, Louisiana State University.	Yes
18	Cebrian, J., G.A. Miller, J.P. Stutes, A.L. Stutes, M.E. Miller, and K.L. Sheehan. 2009. A comparison of fish populations in shallow coastal lagoons with contrasting shoalgrass (*Halodule wrightii*) cover in the north central Gulf of Mexico. *Gulf and Caribbean Research* 21:1–5.	Yes
19	Day, J.W., W.G. Smith, P.R. Wagner, and W.C. Stowe. 1973. *Community Structure and Carbon Budget of a Salt Marsh and Shallow Bay Estuarine System in Louisiana*. Publication No. LSU-SG-72-04. Prepared by the Center for Wetland Resources, Louisiana State University. May.	Yes
20	De Angelo, J.A., P.W. Stevens, D.A. Blewett, and T.S. Switzer. 2014. Fish assemblages of shoal-and shoreline-associated seagrass beds in eastern Gulf of Mexico estuaries. *Transactions of the American Fisheries Society* 143(4):1037–1048.	Yes
21	Duffy, K.C. and D.M. Baltz. 1998. Comparison of fish assemblages associated with native and exotic submerged macrophytes in the Lake Pontchartrain estuary, USA. *Journal of Experimental Marine Biology & Ecology* 223:199–221.	Yes
22	Duque, G. 2004. Influence of the Marsh Edge on the Structure and Trophic Ecology of the Fish and Macroinvertebrate Community in a Louisiana Estuarine Ecosystem. PhD Dissertation, Louisiana State University.	Yes
23	Felley, J.D. 1987. Nekton assemblages of three tributaries to the Calcasieu Estuary, Louisiana. *Estuaries* 10(4):321–329.	Yes
24	Fodrie, F.J. and K.L. Heck. 2011. Response of coastal fishes to the Gulf of Mexico oil disaster. *PLoS ONE* 6(7):e21609.	Yes
25	Furlong, J.N. 2012. Artificial Oyster Reefs in the Northern Gulf of Mexico: Management, Material, and Faunal Effects. MS Thesis, Louisiana State University.	Yes
26	Gain, I. 2009. Oyster Reefs as Nekton Habitat in Estuarine Ecosystems. MS Thesis, Texas A&M University.	Yes
27	Gain, I.E., R.A. Brewton, M.M.R. Robillard, K.D. Johnson, D.L. Smee, and G.W. Stunz. 2017. Macrofauna using intertidal oyster reef varies in relation to position within the estuarine habitat mosaic. *Marine Biology* 164(1):8.	No; duplicate data
28	Geary, B.W., J.R. Rooker, and J.W. Webb. 2001. Utilization of saltmarsh shorelines by newly settled sciaenids in a Texas estuary. *Gulf and Caribbean Research* 13:37–50.	Yes
29	George, L.M., K. De Santiago, T.A. Palmer, and J.B. Pollack. 2015. Oyster reef restoration: Effect of alternative substrates on oyster recruitment and nekton habitat use. *Journal of Coastal Conservation* 19(1):13–22.	Yes

#	Publications	Compiled in database?
30	Geraldi, N.R., S.P. Powers, K.L. Heck, and J. Cebrian. 2009. Can habitat restoration be redundant? Response of mobile fishes and crustaceans to oyster reef restoration in marsh tidal creeks. *Marine Ecology Progress Series* 389:171–180.	Yes
31	Glancy, T.P., T.K. Frazer, C.E. Cichra, and W.J. Lingberg. 2003. Comparative patterns of occupancy by decapod crustaceans in seagrass, oyster, and marsh-edge habitats in a northeast Gulf of Mexico estuary. *Estuaries* 26(5):1291–1301.	Yes
32	Gordon, J.A. 2010. Impacts of Marsh Loss and Fragmentation on Microhabitat Use by Estuarine Nekton in Southwest Louisiana. MS Thesis, Louisiana State University.	Yes
33	Gossman, B.P. 2005. Use of Terraced Marsh Habitats by Estuarine Nekton in Southwestern Louisiana. MS Thesis, Louisiana State University.	No; duplicate data
34	Granados-Dieseldorff, P. 2006. Habitat Use by Nekton in a Saltmarsh Estuary along a Stream-Order Gradient in Northeastern Barataria Bay, Louisiana. MS Thesis, Louisiana State University.	Yes
35	Gregalis, K.C., M.W. Johnson, and S.P. Powers. 2009. Restored oyster reef location and design affect responses of resident and transient fish, crab, and shellfish species in Mobile Bay, Alabama. *Transactions of the American Fisheries Society* 138:314–327.	Yes
36	Herke, W.H., E.E. Knudsen, P.A. Knudsen, and B.D. Rogers. 1992. Effects of semi-impoundment of Louisiana marsh on fish and crustacean nursery use and export. *North American Journal of Fisheries Management* 12(1):151–160.	Yes
37	Hitch, A.T., K.M. Purcell, S.B. Martin, P.L. Klerks, and P.L. Leberg. 2011. Interactions of salinity, marsh fragmentation and submerged aquatic vegetation on resident nekton assemblages of coastal marsh ponds. *Estuaries and Coasts* 34:653–662.	Yes
38	Hoese, H.D. and R.S. Jones. 1963. Seasonality of larger animals in a Texas turtle grass community. In *Publications of the Institute of Marine Science of the University of Texas*, Volume 9, 37–47. Port Aransas, TX.	Yes
39	Homer, M. 1975. Seasonal Abundance, Biomass, Diversity, and Trophic Structure of Fish in a Saltmarsh Tidal Creek Affected by a Coastal Power Plant. ERDA 2nd Thermal Ecology Symposium, Atlanta, GA.	Yes
40	Humphries, A.T. 2010. Effects of Habitat Structural Complexity on Nekton Assemblages: Lab and Field Observations in Southern Louisiana. MS Thesis, Louisiana State University.	No; duplicate data
41	Humphries, A.T., M.K. La Peyre, M.E. Kimball, and L.P. Rozas. 2011. Testing the effect of habitat structure and complexity on nekton assemblages using experimental oyster reefs. *Journal of Experimental Marine Biology & Ecology* 409(1–2):172–179.	Yes
42	Jones, R.F., D.M. Baltz, and R.L. Allen. 2002. Patterns of resource use by fishes and macroinvertebrates in Barataria Bay, Louisiana. *Marine Ecology Progress Series* 237:271–289.	Yes
43	Kang, S.-R. 2011. Aquatic Macroinvertebrate and Nekton Community Structure in a Chenier Marsh Ecosystem: Implications for Whooping Crane Prey Availability. PhD Dissertation, Louisiana State University.	No; duplicate data
44	Kang, S.-R. and S.L. King. 2013. Effects of hydrologic connectivity and environmental variables on nekton assemblage in a coastal marsh system. *Wetlands* 33:321–334.	Yes
45	Kanouse, S., M.K. La Peyre, and J.A. Nyman. 2006. Nekton use of *Ruppia maritima* and non-vegetated bottom habitat types within brackish marsh ponds. *Marine Ecology Progress Series* 327:61–69.	No; duplicate data
46	Kanouse, S.C. 2003. Nekton Use and Growth in Three Brackish Marsh Pond Microhabitats. MS Thesis, Louisiana State University.	Yes
47	Kelley Jr., J.R. 1965. A Taxonomic Survey of the Fishes of Delta National Wildlife Refuge with Emphasis upon Distribution and Abundance. MS Thesis, Louisiana State University.	Yes
48	Kimball, M.E., L.P. Rozas, K.M. Boswell, and J.H. Cowan Jr. 2010. Evaluating the effect of slot size and environmental variables on the passage of estuarine nekton through a water control structure. *Journal of Experimental Marine Biology & Ecology* 395:181–190.	Yes
49	King, S.P. and P. Sheridan. 2006. Nekton of new seagrass habitats colonizing a subsided salt marsh in Galveston Bay, Texas. *Estuaries* 29(2):286–296.	Yes

#	Publications	Compiled in database?
50	Kinney, E.L., A. Quigg, and A.R. Armitage. 2014. Acute effects of drought on emergent and aquatic communities in a brackish marsh. *Estuaries and Coasts* 37(3):636–645.	Yes
51	Kurz, R.C., R.W. Fenwick, and K.A. Davis. 1997. A comparison of fish communities in restored and natural salt marshes in Tampa Bay, Florida. In *Proceedings of the 24th Annual Conference on Ecosystems Restoration and Creation,* P.J. Cannizzaro (ed.). pp. 38–51. May.	Yes
52	La Peyre, M.K. and T.W. Birdsong. 2008. Physical variation of non-vegetated marsh edge habitats, and use patterns by nekton in Barataria Bay, Louisiana, USA. *Marine Ecology Progress Series* 356:51–61.	Yes
53	La Peyre, M.K. and J. Gordon. 2012. Nekton density patterns and hurricane recovery in submerged aquatic vegetation, and along non-vegetated natural and created edge habitats. *Estuarine, Coastal and Shelf Science* 98:108–118.	Yes
54	La Peyre, M.K., B. Gossman, and J.A. Nyman. 2007. Assessing functional equivalency of nekton habitat in enhanced habitats: Comparison of terraced and unterraced marsh ponds. *Estuaries and Coasts* 30(3):526–536.	Yes
55	La Peyre, M.K., L. Schwarting, and S. Miller. 2013a. Baseline Data for Evaluating the Development Trajectory and Provision of Ecosystem Services by Created Fringing Oyster Reefs in Vermilion Bay, Louisiana. U.S. Geological Survey Open-File Report 2013-1053.	Yes
56	La Peyre, M.K., L. Schwarting, and S. Miller. 2013b. Preliminary Assessment of Bioengineered Fringing Shoreline Reefs in Grand Isle and Breton Sound, Louisiana. U.S. Geological Survey Open-File Report 2013-1040.	Yes
57	La Peyre, M.K., A.T. Humphries, S.M. Casas, and J.F. La Peyre. 2014. Temporal variation in development of ecosystem services from oyster reef restoration. *Ecological Engineering* 63:34–44.	Yes
58	Llewellyn, C. and M. La Peyre. 2011. Evaluating ecological equivalence of created marshes: Comparing structural indicators with stable isotope indicators of blue crab trophic support. *Estuaries and Coasts* 34:172–184.	Yes
59	MacRae, P.S.D. 2006. A Community Approach to Identifying Essential Fish Habitat of Spotted Seatrout, *Cynoscion nebulosus*, in Barataria Bay, LA. PhD Dissertation, Louisiana State University.	Yes
60	Maiaro, J.L. 2007. Disturbance Effects on Nekton Communities of Seagrass and Bare Substrates in Biloxi Marsh, Louisiana. MS Thesis, Louisiana State University.	Yes
61	Matich, P., W.B. Godwin, and M. Fisher. 2016. Long-term trends in fish community composition across coastal bays and lakes in the Lavaca-Colorado Estuary. *Canadian Journal of Zoology* 94(12):871–884.	Yes
62	Merino, J.H., L.P. Rozas, T.J. Minello, and P.F. Sheridan. 2010. Effects of marsh terracing on nekton abundance at two locations in Galveston Bay, Texas. *Wetlands* 30:693–704.	Yes
63	Minello, T.J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat. *American Fisheries Society Symposium* 22:43–75.	Yes
64	Minello, T.J. 2000. Temporal development of salt marsh value for nekton and epifauna: Utilization of dredged material marshes in Galveston Bay, Texas, USA. *Wetlands Ecology and Management* 8:327–341.	Yes
65	Minello, T.J. and L.P. Rozas. 2002. Nekton in Gulf Coast wetlands: Fine-scale distributions, landscape patterns, and restoration implications. *Ecological Applications* 12(2):441–455.	Yes
66	Minello, T.J. and J.W. Webb. 1997. Use of natural and created *Spartina alterniflora* salt marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. *Marine Ecology Progress Series* 151:165–179.	Yes
67	Minello, T.J. and R.J. Zimmerman. 1992. Utilization of natural and transplanted Texas salt marshes by fish and decapod crustaceans. *Marine Ecology Progress Series* 90:273–285.	Yes
68	Minello, T.J., G.A. Matthews, and P.A. Caldwell. 2008. Population and production estimates for decapod crustaceans in wetlands of Galveston Bay, Texas. *Transactions of the American Fisheries Society* 137:129–146.	Yes
69	Minello, T.J., R.J. Zimmerman, and R. Medina. 1994. The importance of edge for natant macrofauna in a created salt marsh. *Wetlands* 14(3):184–198.	Yes

#	Publications	Compiled in database?
70	Minello, T.J., J.W. Webb Jr., R.J. Zimmerman, R.B. Wooten, J.L. Martinez, T.J. Baumer, and M.C. Pattillo. 1991. Habitat Availability and Utilization by Benthos and Nekton in Hall's Lake and West Galveston Bay. NOAA Technical Memorandum NMFS-SEFC-275.	Yes
71	Nevins, J.A., J.B. Pollack, and G.W. Stunz. 2014. Characterizing nekton use of the largest unfished oyster reef in the United States compared with adjacent estuarine habitats. *Journal of Shellfish Research* 33(1):227–238.	Yes
72	O'Connell, J.L. and J.A. Nyman. 2010. Marsh terraces in coastal Louisiana increase marsh edge and densities of waterbirds. *Wetlands* 30:125–135.	Yes
73	Peterson, G.W. and R.E. Turner. 1994. The value of salt marsh edge vs interior as a habitat for fish and decapod crustaceans in a Louisiana tidal marsh. *Estuaries* 17(18):235–262.	Yes
74	Peterson, M.S. and A.G. Stricklin. 2008. Restoration and Faunal Composition of Patchy, Small Intertidal *Crassostrea virginica* Oyster Reefs within the Grand Bay National Estuarine Research Reserve, North-Central Gulf of Mexico. Fisheries Ecology Laboratory, University of Southern Mississippi, Mobile, AL. Prepared for The Nature Conservancy, Alabama Coastal Program.	Yes
75	Peterson, M.S., C.F. Rakocinski, and B.H. Comyns. 2000. Nekton Densities in the Pascagoula River Estuary: Anthropogenic Effects on Essential Fish Habitat. Final Technical Report. Mississippi-Alabama Sea Grant Consortium. September 15.	Yes
76	Piazza, B.P. 2009. The Role of Climate Variability and Riverine Pulsing in the Community Dynamics of Estuarine Nekton in Breton Sound, Louisiana. PhD Dissertation, Louisiana State University.	Yes
77	Piazza, B.P. and M.K. La Peyre. 2007. Restoration of the annual flood pulse in Breton Sound, Louisiana, USA: Habitat change and nekton community response. *Aquatic Biology* 1:109–119.	No; duplicate data
78	Piazza, B.P. and M.K. La Peyre. 2009. The effect of Hurricane Katrina on nekton communities in the tidal freshwater marshes of Breton Sound, Louisiana, USA. *Estuarine, Coastal and Shelf Science* 83(1):97–104.	Yes
79	Plunket, J. and M.K. La Peyre. 2005. Oyster beds as fish and macroinvertebrate habitat in Barataria Bay, Louisiana. *Bulletin of Marine Science* 77(1):155–164.	Yes
80	Plunket, J.T. 2003. A Comparison of Finfish Assemblages on Subtidal Oyster Shell (Cultched Oyster Lease) and Mud Bottom in Barataria Bay, Louisiana. MS Thesis, Louisiana State University.	No; duplicate data
81	Poulakis, G.R., D.A. Blewett, and M.E. Mitchell. 2003. The effects of season and proximity to fringing mangroves on seagrass-associated fish communities in Charlotte Harbor, Florida. *Gulf of Mexico Science* 21(2):171–184.	Yes
82	Rakocinski, C.F., D.M. Baltz, and J.W. Fleeger. 1992. Correspondence between environmental gradients and the community structure of marsh-edge fishes in a Louisiana estuary. *Marine Ecology Progress Series* 80:135–148.	Yes
83	Reed, D.J., M.S. Peterson, and B.J. Lezina. 2006. Reducing the effects of dredged material levees on coastal marsh function: Sediment deposition and nekton utilization. *Environmental Management* 37(5):671–685.	Yes
84	Reed, D.J., A. Beall, L. Martinez, T.J. Minello, A.M.U. O'Conell, L.P. Rozas, S. Penland, R.C. Cashner, and A.M. Commagere. 2007. Modeling Relationships between the Abundance of Fishery Species, Coastal Wetland, Landscapes, and Salinity in the Barataria Basin, Louisiana. Prepared for NOAA, NMFS, and the Louisiana Coastal Wetlands Conservation and Restoration Task Force. December.	Yes
85	Reese, M.M., G.W. Stunz, and A.M. Bushon. 2008. Recruitment of estuarine-dependent nekton through a new tidal inlet: The opening of Packery Channel in Corpus Christi, TX, USA. *Estuaries and Coasts* 31:1143–1157.	Yes
86	Robillard, M.M.R., G.W. Stunz, and J. Simons. 2010. Relative value of deep subtidal oyster reefs to other estuarine habitat types using a novel sampling method. *Journal of Shellfish Research* 29(2):291–302.	Yes
87	Rooker, J.R., S.A. Holt, M.A. Soto, and G.J. Holt. 1998. Postsettlement patterns of habitat use by sciaenid fishes in subtropical seagrass meadows. *Estuaries* 21(2):318–327.	Yes

#	Publications	Compiled in database?
88	Roth, A.-M.F. 2009. Anthropogenic and Natural Perturbations on Lower Barataria Bay, Louisiana: Detecting Responses of Marsh-Edge Fishes and Decapod Crustaceans. PhD Dissertation, Louisiana State University.	Yes
89	Roth, A.-M.F. and D.M. Baltz. 2009. Short-term effects of an oil spill on marsh-edge fishes and decapod crustaceans. *Estuaries and Coasts* 32:565–572.	Yes
90	Rozas, L.P. 1992. Bottomless lift net for quantitatively sampling nekton on intertidal marshes. *Marine Ecology Progress Series* 89:287–292.	No; duplicate data
91	Rozas, L.P. and T.J. Minello. 1997. Structural Marsh Management Effects on Habitat Selection by Nekton. National Marine Fisheries Service, Silver Spring, MD.	No; duplicate data
92	Rozas, L.P. and T.J. Minello. 1998. Nekton use of salt marsh, seagrass, and nonvegetated habitats in a south Texas (USA) estuary. *Bulletin of Marine Science* 63(3):481–501.	Yes
93	Rozas, L.P. and T.J. Minello. 1999. Effects of structural marsh management on fishery species and other nekton before and during a spring drawdown. *Wetlands Ecology and Management* 7:121–139.	Yes
94	Rozas, L.P. and T.J. Minello. 2001. Marsh terracing as a wetland restoration tool for creating fishery habitat. *Wetlands* 21(3):327–341.	Yes
95	Rozas, L.P. and T.J. Minello. 2006. Nekton use of *Vallisneria americana Michx.* (wild celery) beds and adjacent habitats in coastal Louisiana. *Estuaries and Coasts* 29(2):297–310.	Yes
96	Rozas, L.P. and T.J. Minello. 2007. Restoring coastal habitat using marsh terracing: The effect of cell size on nekton use. *Wetlands* 27(3):595–609.	Yes
97	Rozas, L.P. and T.J. Minello. 2010. Nekton density patterns in tidal ponds and adjacent wetlands related to pond size and salinity. *Estuaries and Coasts* 33:652–667.	No; duplicate data
98	Rozas, L.P. and T.J. Minello. 2015. Small-scale nekton density and growth patterns across a saltmarsh landscape in Barataria Bay, Louisiana. *Estuaries and Coasts* 38(6):2000–2018.	Yes
99	Rozas, L.P. and D.J. Reed. 1993. Nekton use of marsh-surface habitats in Louisiana (USA) deltaic salt marshes undergoing submergence. *Marine Ecology Progress Series* 96:147–157.	Yes
100	Rozas, L.P. and R.J. Zimmerman. 2000. Small-scale patterns of nekton use among marsh and adjacent shallow nonvegetated areas of the Galveston Bay Estuary, Texas (USA). *Marine Ecology Progress Series* 193:217–239.	Yes
101	Rozas, L.P., C.W. Martin, and J.F. Valentine. 2013. Effects of reduced hydrological connectivity on the nursery use of shallow estuarine habitats within a river delta. *Marine Ecology Progress Series* 492:9–20.	Yes
102	Rozas, L.P., T.J. Minello, and D.D. Dantin. 2012. Use of shallow lagoon habitats by nekton of the northeastern Gulf of Mexico. *Estuaries and Coasts* 35:572–586.	Yes
103	Rozas, L.P., T.J. Minello, R.J. Zimmerman, and P. Caldwell. 2007. Nekton populations, long-term wetland loss, and the effect of recent habitat restoration in Galveston Bay, Texas. *Marine Ecology Progress Series* 344:119–130.	Yes
104	Rozas, L.P., T.J. Minello, I. Munuera-Fernandez, B. Fry, and B. Wissel. 2005. Macrofaunal distributions and habitat change following winter-spring releases of freshwater into the Breton Sound estuary, Louisiana (USA). *Estuarine, Coastal and Shelf Science* 65:319–336.	Yes
105	Scott, E. 1998. Utilization of Submerged Aquatic Vegetation Habitats by Fishes and Decapods in the Galveston Bay Ecosystem, Texas. MS Thesis, Texas A&M University.	Yes
106	Scyphers, S.B., S.P. Powers, K.L. Heck Jr., and D. Byron. 2011. Oyster reefs as natural breakwaters mitigate shoreline loss and facilitate fisheries. *PLoS ONE* 6(8):e22396.	Yes
107	Sheridan, P. 2004. Comparison of restored and natural seagrass beds near Corpus Christi, Texas. *Estuaries* 27(5):781–792.	Yes
108	Sheridan, P. and T.J. Minello. 2003. Nekton use of different habitat types in seagrass beds of lower Laguna Madre, Texas. *Bulletin of Marine Science* 72(1):37–61.	Yes
109	Sheridan, P., C. Henderson, and G. McMahan. 2003. Fauna of natural seagrass and transplanted *Halodule wrightii* (shoalgrass) beds in Galveston Bay, Texas. *Restoration Ecology* 11(2):139–154.	Yes

#	Publications	Compiled in database?
110	Shervette, V.R. and F. Gelwick. 2008. Seasonal and spatial variations in fish and macroinvertebrate communities of oyster and adjacent habitats in a Mississippi estuary. *Estuaries and Coasts* 31:584–596.	Yes
111	Shervette, V.R., F. Gelwick, and N. Hadley. 2011. Decapod utilization of adjacent oyster, vegetated marsh, and non-vegetated bottom habitats in a Gulf of Mexico estuary. *Journal of Crustacean Biology* 31(4):660–667.	Yes
112	Simonsen, K. and J.H. Cowan Jr. 2007. Sport fish utilization of an inshore artificial oyster reef in Barataria Bay, Louisiana. In *Proceedings of the 60th Gulf and Caribbean Fisheries Institute.* pp. 398–406. Punta Cana, Dominican Republic. November 5–9.	No; duplicate data
113	Simonsen, K.A. 2008. The Effect of an Inshore Artificial Reef on the Community Structure and Feeding Ecology of Estuarine Fishes in Barataria Bay, Louisiana. MS Thesis, Louisiana State University.	Yes
114	Smee, D.L., J.A. Sanchez, M. Diskin, and C. Trettin. 2017. Mangrove expansion into salt marshes alters associated faunal communities. *Estuarine, Coastal and Shelf Science* 187:306–313.	Yes
115	Stallings, C.D., J.P. Brower, J.M.H. Loch, and A. Mickle. 2014. Catch comparison between otter and rollerframe trawls: Implications for sampling in seagrass beds. *Fisheries Research* 155:177–184.	Yes
116	Stein III, W. 2013. Fish and Decapod Community Structure in Estuarine Habitats of the New Orleans Land Bridge, Including a Description of the Life Cycle of Tarpon (*Megalops atlanticus*) in Southeastern Louisiana. PhD Dissertation, University of New Orleans.	Yes
117	Stoner, A.W. 1983. Distribution of fishes in seagrass meadows: Role of macrophyte biomass and species composition. *Fishery Bulletin* 81(4):837–846.	Yes
118	Stunz, G., M. Reese, and A. Bushon. 2006. Impacts of a New Tidal Inlet on Estuarine Nekton: The Opening of Packery Channel in Corpus Christi Texas. Final report to Coastal Bend Bays & Estuaries Program, Corpus Christi, TX. August 17.	No; duplicate data
119	Stunz, G.W., T.J. Minello, and L.P. Rozas. 2010. Relative value of oyster reef as habitat for estuarine nekton in Galveston Bay, Texas. *Marine Ecology Progress Series* 406:147–159.	Yes
120	Subrahmanyam, C.B. and C.L. Coultas. 1980. Studies on the animal communities in two north Florida salt marshes Part III: Seasonal fluctuations of fish and macroinvertebrates. *Bulletin of Marine Science* 30(4):790–818.	Yes
121	Subrahmanyam, C.B. and S.H. Drake. 1975. Studies on the animal communities in two north Florida salt marshes. Part I: Fish communities. *Bulletin of Marine Science* 25(4):445–465.	Yes
122	Thom, C.S.B., M.K.G. La Peyre, and J.A. Nyman. 2004. Evaluation of nekton use and habitat characteristics of restored Louisiana marsh. *Ecological Engineering* 23:63–75.	No; duplicate data
123	Tolley, S.G. and A.K. Volety. 2005. The role of oysters in habitat use of oyster reefs by resident fishes and decapod crustaceans. *Journal of Shellfish Research* 24(4):1007–1012.	Yes
124	Tolley, S.G., A.K. Volety, M. Savarese, L.D. Walls, C. Linardich, and E.M. Everham III. 2006. Impacts of salinity and freshwater inflow on oyster-reef communities in Southwest Florida. *Aquatic Living Resources* 19(4):371–387.	Yes
125	Valentine, J.F. and K.L. Heck Jr. 1993. Mussels in seagrass meadows: Their influence on macroinvertebrate abundance and secondary production in the northern Gulf of Mexico. *Marine Ecology Progress Series* 96:63–74.	Yes
126	Vose, F.E. and S.S. Bell. 1994. Resident fishes and macrobenthos in mangrove-rimmed habitats: Evaluation of habitat restoration by hydrologic modification. *Estuaries* 17(3):585–596.	Yes
127	Wedge, M. and C.J. Anderson. 2017. Urban land use affects resident fish communities and associated salt marsh habitat in Alabama and West Florida, USA. *Wetlands* 37(4):715–727.	Yes
128	Williams, P.R. 1998. Nekton Assemblages Associated with the Barrier Island Aquatic Habitats of East Timbalier Island, Louisiana. MS Thesis, Louisiana State University.	Yes
129	Yeldell, N.A., M.K. La Peyre, and S. Beck. 2011. Testing the Effect of Live Oyster Presence and Structural Diversity on Nekton Abundance and Diversity. Louisiana Sea Grant Undergraduate Research Opportunities Program.	Yes

#	Publications	Compiled in database?
130	Zeug, S.C., V.R. Shervette, D.J. Hoeinghaus, and S.E.I. Davis. 2007. Nekton assemblage structure in natural and created marsh-edge habitats of the Guadalupe Estuary, Texas, USA. *Estuarine, Coastal and Shelf Science* 71:457–466.	Yes
131	Zimmerman, R., T. Minello, T. Baumer, and M. Castiglione. 1989. Oyster Reef as Habitat for Estuarine Macrofauna. NOAA Technical Memorandum NMFS-SEFC-249.	Yes
132	Zimmerman, R.J. and T.J. Minello. 1984. Densities of *Penaeus aztecus, Penaeus setiferus,* and other natant macrofauna in a Texas salt marsh. *Estuaries* 7(4A):421–433.	Yes
133	Zimmerman, R.J., T.J. Minello, M. Castiglione, and D. Smith. Undated. Use of Marsh Habitats by Fishery Organisms along a Salinity Gradient in Galveston Bay. Southeast Fisheries Center, Galveston, TX. Report to Texas Parks and Wildlife Department Environmental Protection Division, Austin, TX.	No; duplicate data
134	Zimmerman, R.J., T.J. Minello, M.C. Castiglione, and D.L. Smith. 1990a. Utilization of Marsh and Associated Habitats along a Salinity Gradient in Galveston Bay. NOAA Technical Memorandum NMFS-SEFC-250.	Yes
135	Zimmerman, R.J., T.J. Minello, D.L. Smith, and J. Kostera. 1990b. The Use of *Juncus* and *Spartina* Marshes by Fisheries Species in Lavaca Bay, Texas, with Reference to Effects of Floods. NOAA Technical Memorandum NMFS-SEFC-251.	Yes

A.4 Data Extraction, Compilation, and QC Methods

A.4.1 Data Extraction

Nekton density, abundance, biomass, length, and CPUE data were extracted from documents that passed the screening criteria. Data tables were extracted from the papers using Able2Extract Professional 8 software (http://www.investintech.com/), which converts data in formatted tables (typically in PDF format) into Excel. The extracted data from the Excel tables were input into a separate worksheet for each document. Using DataThief III software (Tummers, 2006), data presented in the figures were extracted and saved in a table format in the appropriate worksheet for each document. Similarly, data presented in the text were copied into a table format. Basic information about each study was also recorded, such as location, habitat, restoration method (if applicable), vegetation type, sampling season, and gear type.

A.4.2 Data Compilation

After extraction, the data were compiled into an Excel workbook. A separate worksheet was created for each document to help facilitate data tracking and QC. After all data were extracted, compiled, and a QC check performed, a single Access database was created with all of the data compiled in one table. Some data fields were standardized to ensure consistency in the data field entries and to aid in data queries.

A.4.2.1 Data Compilation Process Guidelines

A set of process guidelines were developed for compiling the data to ensure that the methods were consistent and transparent during the compilation process. First, all data were compiled as reported in the original document. For example, if the paper reported the data by technique, season, site, habitat, transect, elevation, or other site characteristic, this reporting method was retained. In some cases, calculations or other numerical manipulations were conducted, as noted in the database and described below.

- Density was standardized to the number of individuals per m^2. For example, some papers reported density as the number of individuals per 2.6 m^2. In this case, the reported density was divided by 2.6.
- Density (number of individuals per m^2) was calculated if abundance and sampling area were reported but density was not calculated by the author(s).
- Biomass per area (g wet weight per m^2, g dry weight per m^2, or g ash-free dry weight per m^2) was calculated if biomass and sampling area were reported but biomass per area was not calculated by the author(s).
- Biomass per individual (g wet weight per individual, g dry weight per individual, or g ash-free dry weight per individual) was calculated if biomass and the number of individuals were reported but biomass per individual was not calculated by the author(s).
- A total value for a group of species (e.g., total nekton density) was calculated if the authors had not calculated a total and provided information to allow this calculation (e.g., reported mean densities of all species collected, or reported total crustacean density and total fish density).

A.4.2.2 Data Compilation Process Decisions

Occasionally, the data presented in the documents required additional decisions to classify the data appropriately in the database. Those additional decisions are described below.

Value – reference site and restored site

Nekton data were compiled from restored and natural estuarine habitats in the Gulf of Mexico. For papers reporting restoration data, the data of the restored site were compiled in the "value – restored site" data field. If the paper also reported data for a reference site and identified it as such, the data were compiled in the "value – reference site" data field. For papers not reporting restoration data, the data were compiled in the "value – reference site" data field. The data were only compiled if the habitat appeared to be natural (i.e., the paper did not indicate that the site was restored or managed in any way). A single period (".") was reported, signifying a blank, in the "value – restored site" or "value – reference site" data field if the study did not collect data from that respective habitat.

For papers reporting data from restored and unrestored sites that were combined, the data were compiled in the "value – restored site" data field. For these studies, the restoration type was recorded as "combined" in the "restoration type" data field [e.g., "oyster reef and unrestored (combined)"] and a note was added in the "data notes" field.

If the original document included blank data points, and information in the paper allowed us to clearly interpret the blank as a zero (e.g., no observation of a species reported for a given data point), the blank was recorded as a "0." If the blank could not be interpreted as a zero, the blank was recorded as a single period (".").

For restoration data, some studies reported results from multiple reference sites without any clear pairing to the restored sites. For these studies, the data were recorded two different ways. First, an average of the reference site data was taken and the average value was used as a pairing to the restored site. Second, the data for each reference site were recorded individually, and the reference site was not linked to a restored site.

Standard Error – restored site and reference site

As discussed in Section A.4.2.1, a total value was calculated for a group of species if the authors had not calculated a total but provided information that allowed this calculation. When mean densities of all species were reported, the values were summed to obtain the mean total nekton density, referred to as $\bar{y}_{TOTAL}$. When only total crustacean density ($\bar{y}_C$) and total fish density ($\bar{y}_F$) were reported, the total nekton density ($\bar{y}_{TOTAL}$) was calculated by summing:

$$\bar{y}_{TOTAL} = \bar{y}_C + \bar{y}_F.$$

If the standard errors (SEs) for the two groups of organisms were provided, the SE of the combined total was calculated using:

$$SE\left(\widehat{Total}\right) = \sqrt{SE_C^2 + SE_F^2}.$$

We were comfortable assuming independence because the Spearman's rank correlation between the two densities was negligible [r = 0.06, sample number (N) = 246] using records that contained both total crustacean density and total fish density.

Sample number – restored site and reference site

The sample numbers associated with each value in the database were identified and compiled. If the document did not explicitly present the sample number associated with the values and errors (SE or standard deviation) in the tables and figures, which was a common occurrence, the methods section was reviewed to determine the sample number. In a few cases, the methods section did not present sufficient information to determine the sample number. If possible, the primary author was contacted to ask for clarification; if we were unable to contact the author or if it was otherwise not possible to verify the sample number, a single period (".") was recorded, signifying a blank.

Restoration type

For restoration data, the type of restoration project was recorded. The following definitions were used when classifying the restoration type:

- ***Created***: large-scale creation of marsh using dredged material or nearby sediment
- ***Terrace***: creation of narrow strips of marsh using dredged material or nearby sediment
- ***Diversion***: controlled large-scale sediment or water diversion
- ***Hydrologic***: uncontrolled smaller-scale hydrologic modification, such as removing a culvert or gapping a levee
- ***Oyster cultch***: placement of unconsolidated oyster cultch material, such as oyster shell, limestone rock, or crushed concrete, on the bay bottom
- ***Oyster reef***: placement of consolidated reef material, such as bagged oyster shell, reef balls, or reef blocks, on the bay bottom
- ***Seagrass***: restoration of seagrass via plantings.

As noted above, for papers reporting combined data from restored and unrestored sites, the "restoration type" was recorded as combined [e.g., "oyster reef and unrestored (combined)"].

Marsh type given in paper

For sampling sites located in oyster, SAV, or open-water NVB habitats, the "marsh type given in paper" data field was recorded based on the adjacent marsh characteristics if the paper provided this information.

Vegetation type assigned

In the "vegetation type assigned" data field, a vegetation type was assigned based on the vegetation community at the site as reported by the author(s), following the classification scheme outlined in Visser et al. (1998, 2000, 2002), Enwright et al. (2014), and Sasser et al. (2014). If the vegetation community was not reported, the project location was cross-referenced with available vegetation maps, including the vegetation layers displayed in the Coastwide Reference Monitoring System online viewer (http://lacoast.gov/crms2/home.aspx), and state-specific maps for Louisiana (Sasser et al., 2014) and Texas (Enwright et al., 2014). The site was recorded as "combined" if the paper reported data for multiple vegetation types. For sampling sites located in oyster, SAV, or open-water NVB habitats, the "vegetation type assigned" data field was recorded based on adjacent marsh characteristics.

Landscape position_1

For sampling sites that were located on barrier islands, the site was recorded as "barrier island" in the "landscape position_1" data field. The site was not recorded as a barrier island if the island appeared to be significantly developed with roads and houses, such as Galveston Island, Texas; in these cases, the landscape position_1 data field was recorded with a single period ("."), signifying a blank.

Landscape position_2

For marsh and mangrove habitats, the site was recorded as either "edge" or "interior" in the "landscape position_2" data field if this information was reported by the author(s). The habitat was recorded as "edge" if the sampling site was located on the vegetated surface, extending from the open water/emergent vegetation interface to < 5 m on the vegetated surface. The habitat was recorded as "interior" if the sampling site was on the vegetated surface and located ≥ 5 m from the open water/emergent vegetation interface. If the paper reported data for sites at both edge and interior locations, the landscape position_2 data field was recorded as "edge and interior (combined)." If the paper did not provide information on the sampling location, the landscape position_2 data field was recorded as "not specified." These classifications were established based on studies examining patterns of nekton use of marsh edge habitats in the Gulf of Mexico (e.g., Minello and Rozas, 2002; Minello et al., 2008).

For open-water NVB habitats, the site was recorded as either "near" or "far" if this information was reported by the author(s). The habitat was recorded as "near" if the sampling site was located in the open water, extending from the open water/emergent vegetation interface to < 5 m into the open water. The habitat was recorded as "far" if the sampling site was located within the open water and ≥ 5 from the open water/emergent vegetation interface. If the paper reported data for sites at both near and far locations, the "landscape position_2" data field was recorded as "near and far (combined)." If the paper did not provide information on the sampling location, the "landscape position_2" data field was recorded as "not specified."

For oyster habitat, the site was recorded as either "subtidal" or "intertidal" if the paper provided this information. The "landscape position_2" data field was recorded as "not specified" if the paper did not provide this information.

For SAV and combined habitats, the "landscape position_2" data field was recorded with a single period ("."), signifying a blank.

Vegetation species included in dominance – restored and reference

For marsh and mangrove habitats, *Spartina alterniflora*, *S. patens*, *Phragmites*, or black mangrove (*Avicennia germinans*) was recorded in the "vegetation species included in dominance" data field if the paper reported any of these species as dominant vegetation. If the paper reported both *S. alterniflora* and *S. patens* as the dominant species, and the authors did not indicate whether one was more abundant than the other, the dominant species was recorded as "*Spartina* spp." The dominant species was recorded as "combined" if the paper reported data from multiple sites or locations, and the dominant vegetation was not the same across sites or locations. If the paper reported a species other than those listed above as dominant, and none of the species listed above were identified as having a significant presence, the dominant vegetation was recorded as "other."

For SAV habitat, *Thalassia testudinum*, *Halodule wrightii*, *Ruppia maritima*, *Vallisneria americana*, or *Syringodium filiforme* was recorded in the "vegetation species included in dominance" data field if the paper reported the species as dominant vegetation. If the paper reported both *Halodule wrightii* and *Thalassia testudinum* as the dominant species, and the authors did not indicate whether one was more abundant than the other, the dominant species were recorded as "*Halodule wrightii* and *Thalassia testudinum*." If the paper reported both *Ruppia maritima* and *Halodule wrightii* as the dominant species, and the authors did not indicate whether one was more abundant than the other, the dominant species were recorded as "*Ruppia maritima* and *Halodule wrightii*." If the paper reported both *Ruppia maritima* and *Vallisneria americana* as the dominant species, and the authors did not indicate whether one was more abundant than the other, the dominant species were recorded as "*Ruppia maritima* and *Vallisneria americana*." The dominant species were recorded as "combined" if the paper reported data from multiple sites or locations, and the dominant vegetation was not the same across sites or locations. If the paper reported a species other than those listed above as dominant, and none of the species listed above were identified as having a significant presence, the dominant vegetation was recorded as "other."

For oyster and open-water NVB habitats, "open water/unvegetated" was recorded in the "vegetation species included in dominance" data field.

If the paper did not report vegetation, "not specified" was recorded in the "vegetation species included in dominance" data field.

Standardized season sampled

The season in the "standardized season sampled" data field was recorded based on the timing of sampling: March, April, and May (spring); June, July, and August (summer); September, October, and November (fall); and December, January, and February (winter). If the sampling occurred across seasons, all of the seasons sampled were recorded [e.g., "spring and fall (combined)"]. In some cases, the author(s) conducted sampling during a short timeframe that extended over two seasons. For example, the author(s) conducted the sampling over five days that extended from the end of May to early June (May 29–June 2), and reported the season as "spring." In these cases, the standardized season was recorded consistent with how the author(s) reported it (i.e., ”spring”).

Standardized month sampled

The month in the “standardized month sampled” data field was recorded based on the timing of the sampling. If the sampling occurred over two or three consecutive months, all months were recorded (e.g., May and June). If the sample occurred over four or greater consecutive months or over multiple months that were not consecutive, the month was recorded as “combined.” If the sampling month was not reported in the paper, “not specified” was recorded in the data field.

Time of day sampled

The “time of day sampled” data field was recorded from a standardized list, including “day,” “night,” “day and night,” and “not specified.” For passive sampling devices that were deployed and collected days to weeks later (e.g., substrate tray), the time of day was recorded based on when the sampling device was retrieved.

Year sampled

For restoration data, if the sampling extended over two or three years and the paper reported the data as a single average for the entire sampling period, the “year sampled” was recorded as the middle point to facilitate the later calculation of a restoration age. For example, if the sampling occurred in years 1994 through 1995, the year sampled was recorded as “1994.5.” If the sampling extended for three or more years, the full timeframe of the sampling was recorded (e.g., 1994–1997).

For non-restoration data, the full timeframe of the sampling was recorded in the “year sampled” data field. For example, if sampling occurred in years 1994 through 1995, the year was recorded as “1994–1995.”

Year restored, year sampled, and age

For restoration data, if the post-restoration sampling data were collected within the same year as the restoration action, the “year restored” and “year sampled” were recorded on a monthly basis. For example, if the restoration was finalized in June 2010 and the sampling was conducted in October 2010, the year restored was recorded as “2010.5” (2010 and 6/12ths) and the year sampled was recorded as “2010.83” (2010 and 10/12ths). Thus, the “age” of the restoration project was recorded as “0.33 years.”

If a study conducted sampling at a restoration site before the restoration action(s) occurred (e.g., to collect pre-restoration baseline conditions), “pre” was recorded for these data in the “age” data field.

Nekton sampler mesh size

The “nekton sampler mesh size” data field was recorded as it was reported in the paper. For nekton samplers that were not made of mesh (e.g., drop sampler), the size of the dip net or pump/filter unit that was used to collect the nekton after the sampler was retrieved was recorded.

Metric

A standardized list of terms were used to populate the “metric” data field (Table A.3).

Table A.3. Data parameters compiled under each standardized metric.

Metric	Parameters compiled under "metric" data field
Abundance	Number of individuals
Biomass	Total biomass, biomass per individual, biomass per m^2
Density	Number of individuals per m^2, CPUE
Size	Length

A.4.2.3 Summary of Data Fields and Standardized Parameter Lists

Appendix B summarizes the data that were compiled and provides a brief description of each data field.

A.4.3 QC Methods

A 100% QC check was conducted to ensure that data extraction and compilation accurately captured data from the documents included in the database. The data and associated information (e.g., site, restoration type, habitat type) in the compiled database were compared directly to the data presented in the appropriate document. If the person conducting the QC check identified a discrepancy, he or she flagged it for technical staff to review. Data discrepancies could originate with the data-extraction software, be caused if the person visually extracting the data made a mistake, occur if a value was difficult or impossible to decipher, or arise if the person compiling the data erred. If the review uncovered an error, any discrepancies were corrected in both the compiled database and in the Excel workbook where the data were originally extracted. The correction was then double-checked.

A.5 References

Enwright, N.M., S.B. Hartley, M.G. Brasher, J.M. Visser, M.K. Mitchell, B.M. Ballard, M.W. Parr, B.R. Couvillion, and B.C. Wilson. 2014. Delineation of Marsh Types of the Texas Coast from Corpus Christi Bay to the Sabine River in 2010. U.S. Geological Survey Scientific Investigations Report 2014-5110.

Minello, T.J. and L.P. Rozas. 2002. Nekton in Gulf Coast wetlands: Fine-scale distributions, landscape patterns, and restoration implications. *Ecological Applications* 12(2):441–455.

Minello, T.J., G.A. Matthews, and P.A. Caldwell. 2008. Population and production estimates for decapod crustaceans in wetlands of Galveston Bay, Texas. *Transactions of the American Fisheries Society* 137:129–146.

Sasser, C.E., J.M. Visser, E. Mouton, J. Linscombe, and S.B. Hartley. 2014. Vegetation Types in Coastal Louisiana in 2013. U.S. Scientific Investigations Map 3290.

Tummers, B. 2006. DataThief III. Available: http://download.cnet.com/DataThief/3000-2053_4-80439.html. Accessed August 1, 2014.

Visser, J.M., C.E. Sasser, R.H. Chabreck, and R.G. Linscombe. 2002. The impact of a severe drought on the vegetation of a subtropical estuary. *Estuaries* 25(6A):1184–1195.

Visser, J.M., C.E. Visser, R.H. Chabreck, and R.G. Linscombe. 1998. Marsh vegetation types of the Mississippi River Deltaic Plain. *Estuaries* 21(4B):818–828.

Visser, J.M., C.E. Visser, R.H. Chabreck, and R.G. Linscombe. 2000. Marsh vegetation types of the Chenier Plain, Louisiana, USA. *Estuaries* 23(3):318–327.

B. Nekton Database

B.1 Preface

Information related to nekton density and abundance reported in the scientific and grey (e.g., theses, dissertations, reports) literature was compiled to evaluate nekton use of estuarine habitats in the northern Gulf of Mexico. This appendix provides an overview and summary of the data fields in the compiled nekton database.

B.2 Overview of Database

Version 2.0 of the nekton database ("Nekton_Database_V2_Dec_2019.accdb"), which was finalized in December 2019, is a Microsoft Access database that consists of four main tables:

1. "tbl_NektonData": This primary data table includes nekton density data and associated site/sampling information.
2. "tbl_EnvironmentalVariables": This data table provides the environmental data (e.g., temperature, salinity, dissolved oxygen, distance to marsh edge) for the studies in the nekton data table, which are linked by the "Sampling ID" data field.
3. "tbl_MasterSpeciesList": This data table provides taxonomic information for the species listed in the nekton data table, which are linked by the "Taxa ID" data field.
4. "tbl_References": This data table provides full references for the citations listed in the nekton data table, which are linked by the "Ref ID" data field.

Additional information on the data fields in each of the data tables is provided in the sections below.

B.3 Summary of Data Fields

B.3.1 Nekton Data

The nekton data table is the primary data table that includes the nekton density data and associated site/sampling information. Table B.1 summarizes the data that were compiled and provides a brief description of each data field. In addition, Table B.1 includes the standardized lists of parameters that were developed for some data entry fields to maintain consistency in data entry.

Table B.1. Summary of compiled data fields in the nekton data table.

Field name	Description	Parameter list
Study information		
Source	Citation, including author(s) and year of publication.	As given
Ref ID	Reference identification (ID) number. This field links to the references data table.	As given (e.g., 10001)
Sampling ID	The sampling ID number. This field links to the environmental variables data table. Only provides a sampling ID number for studies included in the environmental variables data table.	Developed using the Ref ID and the sampling event number (e.g., 10001-01)
Location	Location of the study (e.g., Galveston Bay).	As given
Site	Name/description of the sampling site within the study location (e.g., marsh edge).	As given
State	State the study is located in.	Standardized list: AL, FL, LA, MS, or TX

Field name	Description	Parameter list
Longitude	Global positioning system (GPS) coordinates of the study location (longitude).	As given (in decimal degrees), or “combined” if multiple locations were reported
Latitude	GPS coordinates of the study location (latitude).	As given (in decimal degrees), or “combined” if multiple locations were reported
Restoration information (applicable to papers reporting information from restored sites; if a paper did not report information from a restored site, all fields were filled out as N/A)		
Restoration type	Type of restoration project.	Standardized list: created, diversion, hydrologic, oyster cultch, oyster reef, seagrass, terrace, or N/A
Size of restored site (ha)	Size of the restoration project, in hectares.	As given (in hectares), “not specified” if not reported, or N/A
Active revegetation?	Information on whether active revegetation (e.g., planting) was a component of the restoration project.	Standardized list: yes, no, mixed, not specified, or N/A
Offsite dredged material?	Information on whether the use of offsite dredged material was a component of the restoration project.	Standardized list: yes, no, mixed, not specified, or N/A
Onsite or offsite reference site?	Information on whether the reference site was onsite or offsite. Onsite was defined as a reference area included within an experimental area, such as in a block design. Offsite was defined as adjacent or nearby but outside the restored or experimental area.	Standardized list: onsite, offsite, not specified, or N/A
Pumped sediment is greater than 50% sand?	Information about the type of substrate used in created or thin-layer marsh restoration projects.	Standardized list: yes, no, combined, not specified, or N/A
Unique or multiple reference site?	Information on whether the reference site was unique or multiple. Unique was defined as either a single reference site for one or more restored sites, or one reference site specifically paired with one restored site. Multiple was defined as more than one reference site used for a study but not paired with an individual reference site.	Standardized list: unique, multiple, not specified, or N/A
Year restored	The year of the restoration project.	As given (YYYY), or N/A
Age (years)	Age of the restored site at time of the sampling.	As given (YYYY), or N/A
Habitat information		
Habitat type	Information on the habitat type of the sampling site.	Standardized list: mangrove, marsh, open water/unvegetated, oyster, or SAV
Marsh type given in paper	Description of the marsh type given in the paper.	As given, or “not specified” if not reported
Vegetation type assigned	The assigned vegetation type based on the vegetation community (Visser et al., 1998, 2000, 2002; Sasser et al., 2014).	Standardized list: saline, brackish, intermediate, fresh, or combined
Landscape position_1	Additional information on the sampling site.	Standardized list: barrier island or not specified
Landscape position_2	Additional information on the sampling site.	Standardized list: edge, interior, near, far, subtidal, intertidal, or not specified
Vegetation species included in dominance – restored	The dominant vegetation type(s) of the restored site, if applicable.	Standardized list: *Spartina alterniflora*, *Spartina patens*, *Spartina* spp., *Phragmites*, black mangrove, *Halodule wrightii*, *Ruppia maritima*, *Syringodium filiforme*, *Thalassia testudinum*, *Vallisneria americana*, open water/unvegetated, other, combined, not specified, or N/A

Field name	Description	Parameter list
Vegetation species included in dominance – reference	The dominant vegetation type(s) of the reference site, if applicable.	Standardized list: *Spartina alterniflora*, *Spartina patens*, *Spartina* spp., *Phragmites*, black mangrove, *Halodule wrightii*, *Ruppia maritima*, *Syringodium filiforme*, *Thalassia testudinum*, *Vallisneria americana*, open water/unvegetated, other, combined, not specified, or N/A
Sampling season and year		
Season sampled	The season of the sampling, as reported in the paper.	As given
Standardized season sampled	The season of the sampling, from a standardized list.	Standardized list: spring, summer, fall, winter, or not specified
Standardized month sampled	The month of the sampling, from a standardized list.	Standardized list: January, February, March, April, May, June, July, August, September, October, November, December, combined, or not specified
Time of day sampled	The time of day the sampling was conducted.	Standardized list: day, night, or not specified
Year sampled	The year or years of the sampling. In some cases for the restoration data, a fraction of the year was recorded (e.g., 2004.5; see Appendix A, Section A.4.2.2 for more information).	As given (YYYY, YYYY–YYYY, or YYYY.Y)
Nekton gear type		
Nekton sampler	The type of sampler that was used to collect nekton, if applicable.	Standardized list: beam trawl, block net, cast net, drop net, drop sampler, epibenthic sled, flume net, gill net, hand trawl, lift net, otter trawl, passive trap, push trawl, rollerframe trawl, seine, substrate tray, suction sampler, throw trap, trap, trawl, multiple, or N/A
Nekton sampler mesh size	The mesh size of the nekton sampler or the gear used to collect the nekton from the nekton sampler (e.g., dip net), if applicable.	As given, "not specified" if not reported, or N/A
Organism information		
Functional group	The organism group that was sampled.	Standardized list: nekton
Organism	More detailed information on the organism or group of organisms that were sampled (e.g., white shrimp), if provided. If not provided, the functional group was used.	As given
Taxa ID	The taxonomic name of the fish or invertebrate species or group of species, from a standardized list. This field links to the master species list data table.	Standardized list of fish and invertebrate species or group of species (see "tbl_MasterSpeciesList" table)
Field data		
Metric	The general type of parameter that was measured.	Standardized list: abundance, biomass, density, or size
Parameter	More detailed information on the specific parameter that was measured.	As given
Unit	The specific unit of the parameter.	As given

Field name	Description	Parameter list
Standardized parameter and unit	The specific parameter and unit, from a standardized list.	Standardized list: abundance (# of individuals), biomass per area (g ww/m^2), biomass per area (g dw/m^2), biomass per area (g afdw/m^2), biomass per individual (g ww/individual), biomass per individual (g dw/individual), biomass per individual (g afdw/individual), density (# of individuals/m^2), length (mm), total biomass (g ww), total biomass (g dw), or total biomass (g afdw)
Value – restored site	The value of the restored site, if applicable.	As given
SE – restored site	The SE associated with the restored site value, if provided.	As given
SD – restored site	The SD associated with the restored site value, if provided.	As given
Sample number (N) – restored site	The sample number associated with the restored site value, if provided.	As given
Value – reference site	The value of the reference site or natural habitat site, if provided.	As given
SE – reference site	The SE associated with the reference site value, if provided.	As given
SD – reference site	The SD associated with the reference site value, if provided.	As given
Sample number (N) – reference site	The sample number associated with the reference site value, if provided.	As given
Other data fields		
Table/Figure/ Page	The table, figure, or page the data originated from.	As given
Data reported or calculated?	Indicates whether the data were recorded as reported in the paper, or were calculated (e.g., calculated density using abundance and sampling area) or standardized (e.g., changed density from units of #/2.6 m^2 to #/m^2).	Standardized list: reported, calculated, or standardized
Species list complete or incomplete?	Indicates whether the species list is complete (i.e., all species are reported) or incomplete (i.e., only a subset of species is reported).	Standardized list: complete or incomplete
Data notes	Additional notes on the data.	As given
GPS = global positioning system, ID = identification, N/A = not applicable, SAV = submerged aquatic vegetation, SD = standard deviation, SE = standard error.		

B.3.2 Environmental Variables

The environmental variables data table provides the environmental data for the studies included in the nekton data table. Table B.2 summarizes the data that were compiled and provides a brief description of each data field. In addition, Table B.2 includes the standardized lists of parameters that were developed for some data entry fields to maintain consistency in data entry.

Table B.2. Summary of compiled data fields in the environmental variables data table.

Field name	Description	Parameter list
Study information		
Source	Same as Table B.1.	Same as Table B.1
Ref ID	Same as Table B.1.	Same as Table B.1
Sampling ID	The sampling ID number. This field links to the nekton data table.	Developed using the Ref ID and the sampling event number (e.g., 10001-01)
Location	Same as Table B.1.	Same as Table B.1
Site	Same as Table B.1.	Same as Table B.1
State	Same as Table B.1.	Same as Table B.1
Restoration information (applicable to papers reporting information from restored sites; if a paper did not report information from a restored site, all fields were filled out as N/A)		
Restoration type	Same as Table B.1.	Same as Table B.1
Year restored	Same as Table B.1.	Same as Table B.1
Age	Same as Table B.1.	Same as Table B.1
Habitat information		
Habitat type	Same as Table B.1.	Same as Table B.1
Vegetation type assigned	Same as Table B.1.	Same as Table B.1
Landscape position_1	Same as Table B.1.	Same as Table B.1
Landscape position_2	Same as Table B.1.	Same as Table B.1
Sampling season and year		
Season sampled	Same as Table B.1.	Same as Table B.1
Standardized season sampled	Same as Table B.1.	Same as Table B.1
Standardized month sampled	Same as Table B.1.	Same as Table B.1
Time of day sampled	Same as Table B.1.	Same as Table B.1
Year sampled	Same as Table B.1.	Same as Table B.1
Nekton gear type		
Nekton sampler	Same as Table B.1.	Same as Table B.1
Field data		
Parameter	The specific parameter that was measured.	As given
Unit	The specific unit of the parameter.	As given
Standardized parameter and unit	The specific parameter and unit, from a standardized list.	Standardized list: dissolved oxygen – ppm or mg/L; dissolved oxygen – µL/L; distance to marsh edge – m; distance to SAV edge – m; elevation – cm; marsh aboveground biomass – g dw/m^2; marsh cover – %; marsh stem density – stems/m^2; oyster cover (%) – value; oyster density (#/m^2) – value; salinity – PSU or ppt; sand content – %; SAV aboveground biomass – g dw/m^2; SAV cover – %; SAV stem density – stems/m^2; sediment macro-organic matter – g dry wt/m^2; soil organic content – %; temperature – degree C; total organic carbon – mg/L; total suspended solids – mg/L; turbidity – NTU or FTU; water depth – cm; water depth – m
Value – restored site	The value of the restored site, if applicable.	As given
SE – restored site	The SE associated with the restored site value, if provided.	As given

Field name	Description	Parameter list
SD – restored site	The SD associated with the restored site value, if provided.	As given
Sample number (N) – restored site	The sample number associated with the restored site value, if provided.	As given
Value – reference site	The value of the reference site or natural habitat site, if provided.	As given
SE – reference site	The SE associated with the reference site value, if provided.	As given
SD – reference site	The SD associated with the reference site value, if provided.	As given
Sample number (N) – reference site	The sample number associated with the reference site value, if provided.	As given
Other data fields		
Table/Figure/Page	The table, figure, or page the data originated from.	As given
Data notes	Additional notes on the data.	As given

B.3.3 Master Species List

The master species list data table presents the standardized list of fish and invertebrate species names that were used to populate the "Taxa ID" data field in the nekton data table. The Taxa ID was validated using the Integrated Taxonomic Information System (ITIS; www.itis.gov/). Table B.3 presents a summary of the data fields in the master species list data table. The taxonomic information for each taxa was pulled from the ITIS database.

Table B.3. Summary of compiled data fields in the master species list data table.

Field name	Description	Parameter list
Taxa ID	The taxonomic name of the fish or invertebrate species or group of species, from a standardized list. This field links to the nekton data table.	Standardized list of fish and invertebrate species or group of species (validated using the ITIS database)
Organism group	The general group of fish or invertebrate.	Standardized list: crustacean, elasmobranch, fish, mollusc, other
Phylum	The phylum of the taxa.	As provided in the ITIS database
Subphylum	The subphylum of the taxa.	As provided in the ITIS database
Class	The class of the taxa.	As provided in the ITIS database
Subclass	The subclass of the taxa.	As provided in the ITIS database
Order	The order of the taxa.	As provided in the ITIS database
Family	The family of the taxa.	As provided in the ITIS database
Genus	The genus of the taxa.	As provided in the ITIS database
Common name	The common name of the taxa.	As provided in the ITIS database

B.3.4 References

The references data table provides the full references for citations listed in the nekton data table. Table B.4 presents a summary of the data fields in the references data table.

Table B.4. Summary of compiled data fields in the references data table.

Field name	Description	Parameter list
RefID	Reference ID number. This field links to the references data table.	As given
Reference	Full document reference.	As given

B.4 References

Sasser, C.E., J.M. Visser, E. Mouton, J. Linscombe, and S.B. Hartley. 2014. Vegetation Types in Coastal Louisiana in 2013. U.S. Scientific Investigations Map 3290.

Visser, J.M., C.E. Sasser, R.H. Chabreck, and R.G. Linscombe. 2002. The impact of a severe drought on the vegetation of a subtropical estuary. *Estuaries* 25(6A):1184–1195.

Visser, J.M., C.E. Visser, R.H. Chabreck, and R.G. Linscombe. 1998. Marsh vegetation types of the Mississippi River Deltaic Plain. *Estuaries* 21(4B):818–828.

Visser, J.M., C.E. Visser, R.H. Chabreck, and R.G. Linscombe. 2000. Marsh vegetation types of the Chenier Plain, Louisiana, USA. *Estuaries* 23(3):318–327.

C. Analysis Methods

C.1 Preface

Information related to nekton density and abundance reported in the scientific and grey (e.g., theses, dissertations, reports) literature was compiled to evaluate nekton use of estuarine habitats in the northern Gulf of Mexico. This appendix provides an overview of the analysis methods that were conducted to:

1. Summarize species assemblages within estuarine habitats (Section C.2)
2. Understand general patterns of nekton use across and within estuarine habitats (Section C.3)
3. Understand the effects of key environmental factors on nekton use within marsh and adjacent open-water, non-vegetated bottom (NVB) habitat (Section C.4)
4. Evaluate recovery of nekton following marsh restoration (Section C.5)
5. Understand how nekton composition varies across the four estuarine habitat types (Section C.6).

C.2 Summary of Species Assemblages within Estuarine Habitats

This analysis was conducted to summarize species assemblages within each of the four estuarine habitats, including marsh, oyster reef, submerged aquatic vegetation (SAV), and open-water NVB. To accomplish this, species-level density data from both restored and reference sites reported in the nekton database were aggregated across studies to determine the total density range and relative density values across season (i.e., spring, summer, fall, and winter) and salinity zone (i.e., saline, brackish, and intermediate) for each estuarine habitat type. High relative density was defined as 76–100% of observed season or vegetation-type maximum, medium relative density was defined as 25.0–75.9% of observed maximum, low relative density was defined as 1.0–24.9% of observed maximum, and not present was defined as < 1% of observed maximum. Density values were not corrected for gear efficiency in this analysis.

C.3 Nekton Use across and within Estuarine Habitats

This analysis was conducted to understand general patterns of nekton use across and within the four estuarine habitat types (i.e., marsh, oyster reef, SAV, and open-water NVB). Using both restored and reference site data from the database, mean densities for selected taxa were estimated using a meta-analytic approach. First, standard errors (SEs) that were not reported in the literature for the associated reported densities were imputed where possible using a regression approach. Second, each reported density was corrected for gear efficiency in order to standardize densities and allow for comparisons. Finally, a meta-analysis was preformed to provide weighted average densities for each selected taxa within a given habitat (i.e., combination of habitat type and vegetation type) and season.

Due to the available records in the final compiled database, analyses were focused on comparing:

1. Nekton densities in marsh, oyster reef, SAV, and open-water NVB habitats in the saline zone during spring and fall
2. Nekton densities across the transition zone between marsh and open-water NVB (i.e., marsh edge, marsh interior, open-water far, open-water near) in the saline zone during spring and fall
3. Nekton densities in saline, brackish, and intermediate marsh during spring and fall
4. Nekton densities in saline marsh during spring, summer, fall, and winter.

These analyses were conducted for total nekton (sum of crustacean and fish species), total crustacean, total fish, and 50 fish and crustacean taxa. Of the close to 300 species in the database, these 50 taxa were selected due to their high densities, high sample numbers, and/or commercial/recreational importance. Of the 119 papers that were compiled, data from 47 publications were included in the meta-analysis. The majority of these studies were located in Louisiana and Texas. See Hollweg et al. (2019b) for more information on the analytical methods.

C.4 Environmental Factors that Affect Nekton Use

Two sets of meta-analyses were conducted to understand the effects of key environmental factors on nekton use within marsh and adjacent open-water, NVB habitat. One analysis looked at the interplay of salinity and temperature on density, and the other used distance from the marsh edge as a predictor of taxon density. The meta-analyses were performed on selected taxa in fall and spring for marsh and open-water, NVB habitat in the saline zone.

Similar to the other meta-analyses, the approach used gear-corrected densities and weights based on SEs of the gear-corrected densities; the environmental variables were treated as continuous rather than categorical. Hence, the meta-analyses for the environmental data are a weighted regression approach where individual observations were inversely weighted by the square of their SE before fitting the regression model. Initial analyses indicated that a square root transformation of the response variable was required before conducting the weighted regression analysis, and so all subsequent analyses were based on the square root of the corrected density and its calculated SE. See Cebrian et al. (2019) for more details on the model fitting.

For the study of the relationship of the square-root transformed corrected density, and temperature and salinity, the model included salinity (S) and temperature (T) as main effects, and the interaction of the two variables (T x S). Hypothesis tests of the statistical significance of the variables (T, S, and T x S) to predict the mean square-root transformed corrected density were performed hierarchically (i.e., the interaction was tested first and removed only if it was not statistically significant at a type I error of 0.10).

For the study of the relationship of square-root transformed corrected density to distance from marsh edge, the few observations with very large distances from the marsh edge that were also not close in value to the remaining data were removed before the meta-regression model was fit. A hypothesis test of the relationship between distance and the square-root transformed corrected density was done using a type I error of 0.10.

For purposes of display in the main text of the guidebook, the predicted values from the significant regressions were back-transformed to the original scale. The results of the meta-regression analyses on the square-root scale and related tests of the relationships are given in Tables C.1 and C.2.

Table C.1. Results of the meta-regression analyses on the square-root transformed corrected density on temperature, salinity, and their interaction. The regression equations show the estimated coefficients; the SE of each coefficient is given in parentheses ( ) after the estimated value of the coefficient.

Taxon	Habitat type	Season	Estimated regression equation	Salinity p-value	Temperature p-value	Salinity x temperature p-value
Nekton – total	Marsh	Spring	-32.06 + 1.74(0.29) x S + 1.39(0.25) x T – 0.06(0.01) x S x T	< 0.0001	< 0.0001	< 0.0001
		Fall	-30.09 + 1.21(0.49) x S + 1.48(0.44) x T – 0.05(0.02) x S x T	0.022	0.002	0.019
	Open	Spring	8.25 – 0.1(0.31) x S – 0.21(0.25) x T + 0.01(0.01) x S x T	0.760	0.405	0.654
		Fall	19.19 – 0.79(0.31) x S – 0.57(0.29) x T + 0.03(0.01) x S x T	0.018	0.057	0.028
Crustacea – total	Marsh	Spring	-44.31 + 2.3(0.27) x S + 1.81(0.24) x T – 0.08(0.01) x S x T	< 0.0001	< 0.0001	< 0.0001
		Fall	-48.45 + 1.75(0.64) x S + 2.19(0.55) x T – 0.07(0.02) x S x T	0.011	0	0.007
	Open	Spring	24.39 – 0.94(0.12) x S – 0.83(0.10) x T + 0.03(0) x S x T	< 0.0001	< 0.0001	< 0.0001
		Fall	16.14 – 0.69(0.22) x S – 0.55(0.18) x T + 0.03(0.01) x S x T	0.003	0.004	0.002
Callinectes sapidus	Marsh	Spring	-0.2 + 0.11(0.09) x S + 0.05(0.07) x T + 0(0) x S x T	0.220	0.532	0.324
		Fall	6.35 – 0.21(0.28) x S – 0.05(0.23) x T + 0(0.01) x S x T	0.465	0.843	0.661
	Open	Spring	9.15 – 0.3(0.08) x S – 0.32(0.07) x T + 0.01(0) x S x T	0	< 0.0001	0
		Fall	9.08 – 0.33(0.13) x S – 0.3(0.11) x T + 0.01(0) x S x T	0.016	0.009	0.013
Farfantepenaeus aztecus	Marsh	Spring	-18.27 + 1.13(0.13) x S + 0.67(0.11) x T – 0.04(0) x S x T	< 0.0001	< 0.0001	< 0.0001
	Open	Spring	16.9 – 0.69(0.11) x S – 0.59(0.09) x T + 0.03(0) x S x T	< 0.0001	< 0.0001	< 0.0001
Litopenaeus setiferus	Marsh	Fall	56.14 – 2.74(0.36) x S – 1.88(0.30) x T + 0.1(0.01) x S x T	< 0.0001	< 0.0001	< 0.0001
	Open	Fall	9.37 – 0.45(0.18) x S – 0.35(0.15) x T + 0.02(0.01) x S x T	0.017	0.025	0.008
Palaemonetes pugio	Marsh	Spring	-17.98 + 1.23(0.20) x S + 0.8(0.17) x T – 0.04(0.01) x S x T	< 0.0001	< 0.0001	< 0.0001
		Fall	-52.91 + 2.18(0.66) x S + 2.1(0.54) x T – 0.08(0.02) x S x T	0.003	0.001	0.003
	Open	Spring	7.52 – 0.21(0.22) x S – 0.23(0.19) x T + 0.01(0.01) x S x T	0.366	0.252	0.439
		Fall	-4.28 + 0.23(0.23) x S + 0.18(0.21) x T – 0.01(0.01) x S x T	0.324	0.413	0.342
Fish – total	Marsh	Spring	-3.83 + 0.27(0.16) x S + 0.25(0.13) x T – 0.01(0.01) x S x T	0.114	0.066	0.100
		Fall	-26.81 + 0.94(0.28) x S + 1.12(0.25) x T – 0.04(0.01) x S x T	0.003	0	0.001
	Open	Spring	2.06 + 0.07(0.28) x S – 0.04(0.23) x T + 0(0.01) x S x T	0.811	0.870	0.927
		Fall	10.67 – 0.55(0.20) x S – 0.28(0.17) x T + 0.02(0.01) x S x T	0.010	0.121	0.021
Anchoa mitchilli	Marsh	Spring	2.22 – 0.13(0.60) x S – 0.08(0.48) x T + 0.01(0.02) x S x T	0.861	0.895	0.845
		Fall	-8.32 + 0.42(0.18) x S + 0.33(0.16) x T – 0.02(0.01) x S x T	0.037	0.054	0.030
	Open	Spring	12.83 – 0.44(0.69) x S – 0.66(0.63) x T + 0.03(0.03) x S x T	0.534	0.315	0.356
		Fall	9.33 – 0.45(0.26) x S – 0.22(0.21) x T + 0.01(0.01) x S x T	0.089	0.306	0.183

Taxon	Habitat type	Season	Estimated regression equation	Salinity p-value	Temperature p-value	Salinity x temperature p-value
Brevoortia patronus	Marsh	Spring	9.46 – 0.48(0.23) x S – 0.35(0.21) x T + 0.02(0.01) x S x T	0.048	0.106	0.058
	Open	Spring	-5.35 + 0.23(0.42) x S + 0.24(0.36) x T – 0.01(0.02) x S x T	0.595	0.511	0.618
Lagodon rhomboides	Marsh	Spring	-17.63 + 0.97(0.20) x S + 0.69(0.17) x T – 0.03(0.01) x S x T	< 0.0001	0	< 0.0001
	Open	Spring	3 – 0.04(0.12) x S – 0.11(0.10) x T + 0(0) x S x T	0.744	0.277	0.642
Mugil cephalus	Marsh	Spring	-6.69 + 0.3(0.06) x S + 0.25(0.05) x T – 0.01(0) x S x T	< 0.0001	< 0.0001	< 0.0001
	Open	Spring	-0.03 + 0(0.01) x S + 0(0.01) x T + 0(0) x S x T	0.820	0.928	0.820

Table C.2. Estimated regression equations for the relationship between distance to marsh edge and the square root of corrected taxon density.

Taxon	Habitat type	Season	Estimated regression equation	SE of slope estimate	p-value for test of slope
Nekton – total	Marsh	Spring	6.5642 – 0.0077 x D	0.0835	0.9280
	Marsh	Fall	9.1744 – 0.2891 x D	0.1098	0.0219
	Open	Spring	5.4367 – 0.02018 x D	0.0115	0.1022
	Open	Fall	3.5923 – 0.01284 x D	0.0037	0.0131
Crustacea – total	Marsh	Spring	5.6014 – 0.1818 x D	0.0889	0.0603
	Marsh	Fall	8.683 – 0.7959 x D	0.1670	3.00E-04
	Open	Spring	3.5313 – 0.00885 x D	0.0025	0.0023
	Open	Fall	2.7603 – 0.01344 x D	0.0029	6.00E-04
Callinectes sapidus	Marsh	Spring	1.4418 – 0.08246 x D	0.0193	5.00E-04
	Marsh	Fall	2.4727 – 0.07203 x D	0.0305	0.0295
	Open	Spring	1.0881 – 0.00304 x D	0.0019	0.1270
	Open	Fall	1.4057 – 0.00739 x D	0.0021	0.0033
Farfantepenaeus aztecus	Marsh	Spring	3.0589 – 0.3156 x D	0.0287	< 0.0001
	Open	Spring	1.4657 – 0.00758 x D	0.0025	0.0074
Litopenaeus setiferus	Marsh	Fall	4.4231 – 0.3703 x D	0.0464	< 0.0001
	Open	Fall	1.5357 – 0.01 x D	0.0027	0.0021
Palaemonetes pugio	Marsh	Spring	3.5637 – 0.2388 x D	0.0494	1.00E-04
	Marsh	Fall	4.8175 – 0.06759 x D	0.0744	0.3782
	Open	Spring	2.55 – 0.01551 x D	0.0063	0.0254
	Open	Fall	0.5003 – 0.0019 x D	0.0013	0.3841
Fish – total	Marsh	Spring	1.9797 + 0.07598 x D	0.0393	0.0738
	Marsh	Fall	2.2592 + 0.1437 x D	0.0614	0.0347
	Open	Spring	2.7624 – 0.01185 x D	0.0054	0.0415
	Open	Fall	2.3117 – 0.00749 x D	0.0032	0.0337
Anchoa mitchilli	Marsh	Spring	0 + 0 x D	0.5065	1.0000
	Marsh	Fall	0.412 – 0.08751 x D	0.1459	0.6561
	Open	Spring	0.5258 – 0.00045 x D	0.0047	0.9403
	Open	Fall	1.4333 – 0.01073 x D	0.0031	0.0032
Brevoortia patronus	Marsh	Spring	0.3652 – 0.03242 x D	0.0972	0.7451
	Open	Spring	1.7353 – 0.00887 x D	0.0089	0.3359
Lagodon rhomboides	Marsh	Spring	1.492 + 0.8623 x D	0.5717	0.2286
	Open	Spring	0.2968 + 0.002451 x D	0.0016	0.3658
Mugil cephalus	Marsh	Spring	0.1863 + 0.06666 x D	0.0216	0.0129
	Open	Spring	0.03848 – 0.00234 x D	0.0021	0.4666

C.5 Nekton Recovery Following Marsh Restoration

This meta-analysis was conducted to evaluate nekton recovery following marsh restoration in the northern Gulf of Mexico. Due to data availability, this meta-analysis focused on two common marsh restoration techniques: (1) a large-scale marsh creation that consisted of establishing marsh in open-water or fragmented habitat, and (2) the construction of marsh terraces using onsite subtidal sediment or offsite dredged material.

For this analysis, nekton densities at restored marshes were compared to densities at paired reference marshes for selected taxa. Hence, only studies that included a paired reference marsh were used in these analyses. Each restored and reference data pair was from the same study, collected during the same time period, using the same gear type.

To compare restored and reference site densities, a response ratio (RR) was first calculated:

$$RR_i = \ln\left(\frac{Restored\ Mean\ Density\ + 0.01}{Reference\ Mean\ Density\ + 0.01}\right)_i$$

where ln is the natural logarithm function and i indexes the i^{th} record. The SE of each response ratio was calculated using the Delta method (Casella and Berger, 2002) and then applying Goodman's (1960) approach. This response ratio is similar to one used in a meta-analysis by Moreno-Mateos et al. (2012).

For purposes of display in the main text of the guidebook, the model-estimated mean response ratios were back-transformed to the original scale. The back-transformed values x 100% are interpreted as the mean percentages of density in restored marshes compared to those in reference marshes:

$$\%\ of\ reference = \frac{Restored\ Mean\ Density}{Reference\ Mean\ Density} x\ 100\%.$$

A value less than 100% indicates the restored site density is less than the reference site density; and a value greater than 100% indicates the restored site density is greater than the reference site density.

Two sets of analyses were performed to assess recovery. The first analysis binned restored site data into two groups, either classified as an "early" time period (equal to or less than five years following restoration) or a "late" time period (greater than five years following restoration). A five-year threshold was used because existing literature suggests that aboveground biomass at restored sites generally recovers within two–five years following restoration (Craft et al., 2002, 2003; Strange et al., 2002; Ebbets et al., 2019). The second analysis investigated recovery trends over time based on the age of the restored site.

This analysis included nekton density data from 13 studies located within Louisiana or Texas, and included saline to intermediate vegetation types (Figure C.1). Restored sites included both large-scale marsh creation and construction of marsh terraces, and varied in age from 1 year to more than 30 years. See Hollweg et al. (2019a) for more information on the paired analysis methods.

Figure C.1. Geographic distribution of sampling locations included in the analyses. Paired analyses included studies that were conducted in marsh, SAV, or NVB during any season and across any vegetation type. Since some studies conducted sampling at multiple locations, they may contain more than one marker. In addition, some studies may have combined data across sampling locations.

C.6 Nekton Composition of Estuarine Habitats

This analysis was conducted to understand how nekton composition varies across the four estuarine habitat types. Using mean density values estimated by the meta-analysis (Section C.3), relative densities were calculated at the family-level for each habitat in the saline zone during spring and fall. Analyses were separated between crustacean and fish, and the proportional densities of each crustacean and fish family relative to the summed total density for that group of species within each habitat was calculated.

C.7 References

Casella, G. and R.L. Berger. 2002. *Statistical Inference* (Vol. 2). Duxbury, Pacific Grove, CA.

Cebrian, J., H. Liu, M. Christman, T. Hollweg, D. French McCay, R. Balouskus, C. McManus, H. Ballestero, J. White, S. Friedman, and K. Benson. 2019. Standardizing estimates of biomass at recruitment and productivity for fin- and shellfish in coastal habitats. Accepted in Special Issue in *Estuaries and Coasts*.

Craft, C., S. Broome, and C. Campbell. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. *Restoration Ecology* 10(2):248–258.

Craft, C., P. Megonigal, S. Broome, J. Stevenson, R. Freese, J. Cornell, L. Zheng, and J. Sacco. 2003. The pace of ecosystem development of constructed *Spartina alterniflora* marshes. *Ecological Applications* 13(5):1417–1432.

Ebbets, A.L., D.R. Lane, P. Dixon, T.A. Hollweg, M.T. Huisenga, and J. Gurevitch. 2019. Using meta-analysis to develop evidence-based recovery trajectories of vegetation and soils in restored wetlands in the northern Gulf of Mexico. *Estuaries and Coasts*. Available: https://doi.org/10.1007/s12237-019-00536-y. Accessed November 4, 2019.

Goodman, L.A. 1960. On the exact variance of products. *Journal of the American Statistical Association* 55(292):708–713.

Hollweg, T.A., M.C. Christman, J. Lipton, B.P. Wallace, M.T. Huisenga, D.R. Lane, and K.G. Benson. 2019a. Meta-analysis of nekton recovery following marsh restoration in the northern Gulf of Mexico. *Estuaries and Coasts*. Available: https://link.springer.com/article/10.1007%2Fs12237-019-00630-1. Accessed November 4, 2019.

Hollweg, T.A., M.C. Christman, J. Cebrian, B.P. Wallace, S.L. Friedman, H.R. Ballestero, M.T. Huisenga, and K.G. Benson. 2019b. Meta-analysis of nekton utilization of coastal habitats in the northern Gulf of Mexico. *Estuaries and Coasts*. Available: https://link.springer.com/article/10.1007/s12237-019-00633-y. Accessed November 4, 2019.

Moreno-Mateos, D., M.E. Power, F.A. Comin, and R. Yockteng. 2012. Structural and functional loss in restored wetland ecosystems. *PLOS Biology* 10(1):e1001247. doi: 10.1371/journal.pbio.1001247.

Strange, E., H. Galbraith, S. Bickel, D. Mills, D. Beltman, and J. Lipton. 2002. Determining ecological equivalence in service-to-service scaling of salt marsh restoration. *Environmental Management* 29(2):290–300.