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SPECIAL SECTION: RESTORATION BENEFITS IN GULF OF MEXICO

Standardizing Estimates of Biomass at Recruitment and Productivity for Fin- and Shellfish in Coastal Habitats

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Abstract

Assessing the biomass and productivity of fin- and shellfish supported by coastal ecosystems is important to develop plans for the conservation and restoration of these ecosystems, but such assessments are not easy to obtain. We developed a protocol that, from density data, quantifies biomass at recruitment for species where information exists to derive life history tables, and productivity where such information does not exist. Our protocol also assesses the variability (i.e., variance) for the calculated biomass and productivity values. For relatively well-reported species, inferences regarding differences among habitats or species can be suggested. For instance, application of our protocol to juvenile pinfish confirms its well-known preference for structured habitats. Mud crabs also seem to reach higher productivity levels in structured than open bottom habitats. For poorly reported species, only a general idea can be gleaned. However, larger data sets of fin- and shellfish density in shallow coastal systems are needed to increase the accuracy, precision, and comprehensiveness of the estimates of biomass at recruitment and productivity generated with our protocol. With such larger data sets and the use of statistical tools such as Bayesian methods, the protocol can significantly help improve our understanding and management of fisheries productivity in coastal systems.

Keywords Fish · Invertebrates · Estuaries · Recruitment · Biomass · Productivity

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Introduction

Coastal ecosystems lie at the interface between the land and ocean, and include estuaries and other types of coasts that are not at the confluence of rivers and oceans (Valiela 2006). Foundational components, such as marshlands, seagrass beds, biogenic reefs, and sediment flats, form these ecosystems. Coastal ecosystems generate many benefits for humankind and wildlife. They provide habitat for a plethora of species, including fin- and shellfish, birds, and mammals. They can also act as filters of land-derived pollution before it enters the open ocean. Primary producers, through nutrient uptake, and microorganisms, through denitrification and other microbial processes, may significantly reduce nutrient loading from land into the open ocean (Tobias et al. 2001, Sparks et al. 2015). Coastal ecosystems can also be large carbon sinks and help mitigate anthropogenic CO_2 accumulation and climate change (Duarte et al. 2005, Fourqurean et al. 2012). Coastal ecosystems can buffer wave energy substantially and protect the coastline against storms (Manis et al. 2015, Sharma et al. 2016).

The habitat role of coastal ecosystems has received much attention. Many species of fin- and shellfish with commercial and recreational importance utilize these ecosystems. Most of such species, however, reside in the shallower parts of coastal ecosystems as juveniles and pre-adults, while adults move to deeper parts of the coastal ecosystem, or even to farther offshore waters, and do not return to the shallow waters to which they recruited (Rozas et al. 2012, McDonald et al. 2016). In some other species, adults may temporarily (e.g., a few months per year) return to shallow waters (Sheaves et al. 2015). More than 90% of all commercial fish landings in the Gulf of Mexico are species that use shallow coastal waters during some portion of their life cycle (Kennish 1999, Lellis-Dibble et al. 2008). Exported production from shallow to deeper waters through juvenile migration represents prey for fish in the deeper waters. In turn, the invertebrate and fish species that reside permanently in the shallow waters of coastal ecosystems constitute prey for juveniles, pre-adults, and adults of temporary residents. All together, these various species of fin- and shellfish that occur in shallow waters of coastal ecosystems represent a prolific trophic resource for large apex predators that frequently visit these waters, such as sharks, and for permanent and migratory waterfowl, many of which are targeted for conservation and recreation (e.g., bird watching). Endangered megafauna, such as manatees and sea turtles, may also forage in the shallow parts of coastal ecosystems (Aven et al. 2015). Therefore, coastal ecosystems have many economic and societal ramifications and are often the object of highly debated management policies.

The need for effective management of coastal ecosystems has been heightened by the major losses and degradation that these ecosystems have endured in recent decades. Human activities are often the cause of such degradation. As humans develop the coast, maritime forests and wetlands are removed and replaced with urban landscapes. The conversion of natural into developed coastal land often results in increased sediment and nutrient inputs into coastal waters, which can severely impair water quality and cause the decline of important habitats such as seagrass beds and biogenic reefs (Valiela 2006). Human overexploitation of coastal resources may accelerate the degradation of these habitats. Past reports have estimated coastal habitat losses amounting to 29% for seagrass beds (Waycott et al. 2009), 67% for marshlands (Lotze et al. 2006), and 85% for oyster reefs (Beck et al. 2011) over large areas across the world. Large losses of these habitats have also been reported for the Gulf of Mexico (Handley et al. 2007, Zu Ermgassen et al. 2012, Sparks et al. 2013). Much effort is ongoing to offset these losses through conservation, restoration, and mitigation practices.

Two key metrics to gauge the habitat value of coastal ecosystems are fin- and shellfish biomass (generically defined as mass per bottom area unit, for instance dry weight per square meter of bottom) and productivity (generically defined as the gain in biomass over time, for instance dry weight of fish biomass produced in a year per square meter of bottom) in these ecosystems. This information can help develop management policies for coastal ecosystems, for instance by setting quantitative estimates of fisheries productivity that can be maintained or enhanced through habitat conservation and restoration (Lellis-Dibble et al. 2008, Sheaves et al. 2015). However, these metrics are difficult to measure, their availability in the published literature is limited, and the information available covers varying and often discrepant taxonomic diversity, habitats, time periods, and gear types. In addition, many available estimates are subject to several assumptions and, in some instances, considerable uncertainty that is often not well quantified (Peterson et al. 2003, French McCay et al. 2015). This limits our understanding of the habitat role of coastal ecosystems as well as our ability to efficiently manage these ecosystems.

In this paper, we develop a protocol that, departing from density values (expressed in number of individuals per square meter of bottom), derives two kinds of estimates. The first kind is estimates of biomass at recruitment. In these calculations, recruitment corresponds to the post-larvae or early juveniles that settle in the shallow parts of coastal ecosystems. The calculations can be applied to permanent resident (i.e., all life cycle stages-eggs, larvae, juveniles, and adults remain in the shallow parts) and temporary resident species (i.e., large juveniles, pre-adults, or adults migrate to deeper coastal or farther offshore waters) of shallow parts of coastal ecosystems. Biomass at recruitment (expressed in grams of dry weight per square meter of bottom) corresponds to the biomass of post-larvae or juveniles of the given species that settle in the shallow coastal system at the time of recruitment. The calculation of estimates of biomass at recruitment following our protocol is contingent upon information provided by life history tables, which can be derived for most finfish species, and for some shellfish species, that permanently or temporarily utilize

the shallow parts of coastal systems (Jensen et al. 1988, French McCay et al. 2003a, French McCay et al. 2015).

However, for a few fin- and many shellfish species that permanently or temporarily utilize the shallow parts of coastal ecosystems, information to initialize and validate life history tables, and thus derive them with rigor, does not exist. In these cases, the protocol generates estimates of productivity for the given fin- or shellfish species. These estimates (expressed in grams of dry weight per square meter of bottom per year) correspond to the new biomass generated by the species over one year per bottom square meter in the shallow coastal system. The productivity estimates include the new biomass generated by all different species' life cycle stages as they naturally occur in the system. For both types of estimates (i.e., biomass at recruitment and productivity), we borrow from established methods to build a cohesive construct for their derivation, and importantly we also present how to quantify the uncertainty of the estimates. Our protocol allows for the derivation of estimates of biomass and productivity of fin- and shellfish species targeted for economic, recreation, or conservation purposes in coastal habitats, as well the quantification of uncertainty around such estimates. It can also help develop estimates of fisheries productivity under various scenarios of coastal habitat conservation and restoration. Thus, the protocol presented here can improve our capacity to effectively manage coastal ecosystems.

Methods

Derivation of Life History Tables

Here, we focus on the first year of life for the estimation of biomass at recruitment. Our protocol relies on comprehensive and detailed information of how fish size and mortality evolve throughout that first year of life (i.e., daily or, at most, weekly intervals). However, comprehensive records of species-specific measurements of growth and mortality rates during the first year of life directly obtained in the field are seldom available. Instead, where adequate information exists for model initialization and validation, detailed life history tables for the first year of life can be derived using well established equations. Life history tables assess how fin- and shellfish individual length, mass, and mortality rates change with individual age. The equations are different for larval and juvenile stages, and they are combined to provide estimates of daily growth (length) and mortality rates throughout the first year. Standard weight-length conversions are used as appropriate. Here, we utilize estimates of mortality rates (as per day) and individual fresh weight (as grams of fresh weight per individual) over daily time intervals throughout the first year of life. The derivation of these estimates is explained in Appendix 1 (for further elaboration see French McCay et al. 2015) and the actual estimates provided in Appendix 2.

Species Studied

Species with Derived Life History Tables

We have chosen two fish species as examples, pinfish (*Lagodon rhomboides*) and black drum (*Pogonias cromis*). Species-specific values for model initialization and validation to derive the life history tables are obtained from Nelson (2002) for pinfish and Murphy and Muller (1995) for black drum. These species represent fish that recruit to shallow parts of coastal ecosystems, where they reside through their pre-adult stage and subsequently migrate to deeper waters as they become adults. Numerous records of fish density in coastal waters exist for pinfish; however, the number of density records for black drum in coastal waters is drastically lower. Thus, this comparison allows us to gauge how our calculations fare for well vs. poorly reported density data sets.

Pinfish is a widespread species in coastal ecosystems extending from Massachusetts (although rare north of Maryland) to the Yucatan Peninsula, and to Bermuda, and the Gulf of Mexico (Muncy 1984). Juveniles typically reside in the shallow parts of coastal systems from late winter to late fall, pre-adults move to deeper waters of coastal systems, and adults move farther offshore. The species is not commercially harvested, but it serves as an important consumer of invertebrates (as juveniles) and plants (as large juveniles and adults; Hoss 1974, Stoner 1982), and as prey (both as juveniles and adults) for harvested fish species (Jordan et al. 1996, Nelson et al. 2013). Pinfish has been extensively studied and its density in coastal ecosystems along the Gulf of Mexico is well documented.

Black drum inhabits a wider geographical range than pinfish extending from the Bay of Fundy to the North Atlantic and Gulf coasts to the South Atlantic coast (Argentina) (Sutter et al. 1986). The species occur in coastal habitats along this range, and it is common in the Gulf of Mexico. Juveniles stay in the shallower parts of coastal ecosystems from mid spring to mid fall, pre-adults (typically up to 2 years old) reside in deeper areas of coastal waters, and adults may move to even deeper areas farther from the coastline (Osburn and Matlock 1984, Cody et al. 1985). The species plays significant trophic roles as prey and predator. In addition, it constitutes important commercial and recreational fisheries in the Gulf of Mexico (Leard et al. 1993). In spite of this, there are relatively few reports of density for this species in coastal ecosystems along the Gulf of Mexico.

Species Without Derived Life History Tables

We have chosen two invertebrate species as examples, the mud crab *(Rhithropanopeus harrisii)* and the Gulf stone crab (*Menippe adina*). Life history tables cannot be derived with rigor for these species since information to initialize and

validate them is not available. These two species reside in shallow parts of coastal ecosystems throughout their entire life cycles. Density reports for the Gulf of Mexico are more numerous for the former species; thus, this comparison allows us to gauge how this second method fares with varying levels of density data availability.

Mud crabs are omnivorous scavengers and mostly feed on algae; small invertebrates such as amphipods, copepods, polychaetes and bivalves; seagrass detritus; and other dead organic matter. The frequency at which they feed and the quality of what they eat depend on the habitat and their diurnal cycle of activity and foraging (Hegele-Drywa and Normant 2009; Williams 1984). Mud crabs can be found in coastal environments throughout the northern hemisphere, and they are considered global invaders introduced through ballast waters and commercial oyster shipments.

Stone crabs occur on sediment bottoms, oyster reefs, and rock jetties in coastal ecosystems. Adults burrow in mud or sand while juveniles hide among rocks. Stone crabs are high-level predators in waters in the South Atlantic Bight, Caribbean (Western Atlantic stone crab, *M. mercenaria*), and northern and western Gulf of Mexico (Gulf stone crab, *M. adina*) (Williams and Felder 1986). Stone crabs are commercially fished in the southeastern United States and managed as one species (Gerhart and Bert 2008).

Density Data Set

The data used in this paper is part of an extensive data set of nekton abundance in shallow habitats of coastal ecosystems extending from Laguna Madre in southern Texas to the Caloosahatchee River in southern Florida presented in Hollweg et al. (2019). The compilation of the data set, including the databases searched, identity of the variables compiled, criteria applied for data selection, and how the data were extracted or calculated, is explained in detail in Hollweg et al. (2019). This is a companion paper in the Estuaries and Coasts special issue "Quantifying the Benefits of Estuarine Habitat Restoration in the Gulf of Mexico" organized by M. V. Carle and K. Benson. The data set contains mean density values, expressed in number of individuals per square meter of bottom, obtained for specific habitats and time periods as reported by the studies compiled. Here, we used density values compiled for pinfish, black drum, mud crab, and Gulf stone crab. Due to the shallow nature of the habitats included in the compilation and the life histories of these species, density estimates correspond to young of the year (YOY) for pinfish and black drum, and are inclusive of all ages for mud crabs and Gulf stone crabs.

At this point, it is important to emphasize that our protocol, both for the estimation of biomass at recruitment and productivity, can be applied to both temporary and permanent resident fin- and shellfish species in shallow coastal systems. For the estimation of biomass at recruitment, we focus on the first year of life, and thus, the density values used for this estimation must only represent YOY. This should be mostly the case for density data obtained for temporary resident species in shallow coastal systems, since most of the individuals of these species that occur in such shallow systems are YOY (such as the two examples used here, pinfish, and black drum). In contrast, density values obtained for permanent resident species in shallow coastal systems should include more life stages other than YOY. Thus, estimations of YOY density from the wider population density values obtained for permanent resident species in shallow coastal systems must be first carried out before deriving estimates of biomass at recruitment for these species using our protocol. Total population density values must be used in the estimation of productivity with our protocol, since those estimates correspond to the new biomass generated by all different species' life cycle stages as they naturally occur in the system. For permanent resident species in shallow coastal systems, density values should include most life stages and such values can be used in the derivation of productivity estimates using our protocol. This is, however, not the case for density values of temporary resident species in shallow coastal waters, where efforts to estimate the fraction of life stages missing, and thereby produce density estimates that include all life stages within and out of the shallow coastal systems, are needed before deriving productivity estimates using our protocol.

The compiled density data for the four species targeted here (pinfish, black drum, mud crab and Gulf stone crab) included the following habitats: "near" submerged non-vegetated areas (within 5 m from fringing shoreline), "far" submerged non-vegetated areas (farther than 5 m from fringing shoreline), submerged aquatic vegetation (SAV), oyster reefs, and marshes. We divided the non-vegetated sites between "near" and "far" to account for shoreline edge effects (Peterson and Turner 1994, Minello and Rozas 2002). The primary intent of this paper is to demonstrate how our protocol can derive estimates of biomass at recruitment and productivity for fin- and shellfish species in coastal habitats. Additionally, we also suggest potential uses of these estimates such as comparisons across species and habitats with the ultimate goal of informing management decisions. The main purpose of such comparisons is to offer some illustrative examples of uses of our protocol, and thus, we have restricted the comparisons to natural habitats (i.e., habitats that were not ostensibly degraded by human activities and/or that had not been restored by humans) to keep the comparisons simple and consistent. Using our protocol for comparisons between natural and restored coastal systems is definitely a promising venue of work that should be explored in future efforts.

Density Meta-analysis and Corrections

We followed the meta-analytic approach presented in Hollweg et al. (2019). We summarize the steps of this approach and we refer the reader to Hollweg et al. (2019) for further consultation. First, following an imputation method, we estimated the standard error (SE) for the mean density values in the data set where it was not reported or we could not calculate it based on the information available in the paper. Briefly, we used the expected relationship between the sample mean and sample standard deviation (SD) to impute missing SE (Hilbe 2014). Sample SD was regressed against sample mean from the records compiled, and tests were conducted to ensure the regression obtained was robust (Quinn and Keough 2002). SD was estimated from the regression for records with sample mean but not SE provided. If the sample size was not reported, we set it to $n = 1$.

Second, we calculated a weighted average and associated SE for all density entries for the same species corresponding to the same combination of habitat, sampling time, and gear type using a fixed effect model:

$$\text{density weighted average} = \frac{\sum w_i \text{mean}_i}{\sum w_i} \quad (1)$$

$$w_i = \frac{1}{SE_i^2} \quad (2)$$

$$SE_{\text{density weighted average}} = \sqrt{\frac{1}{\sum w_i}} \quad (3)$$

where mean_i is the ith mean of a given combination of habitat, sampling time, and gear type, w_i is the weight of the ith mean, SE_i is the standard error of the ith mean, and $SE_{\text{density weighted average}}$ is the standard error of the density weighted average. In the calculation of w_i, we did not include a random error term encompassing variability due to author bias (i.e., several entries generated by the same authors) or the inclusion of different populations for the same combination of habitat, sampling time, and gear type because we did not have a sufficiently large sample size in the four species targeted to test for such random effects with rigor (Hollweg et al. 2019).

Third, we applied correction factors for gear selectivity, capture efficiency, and recovery efficiency. Gear selectivity corresponds to the range of individual fish sizes that can be collected by the gear given its characteristics. Some gears do not normally capture fish smaller than a minimum or larger than a maximum size threshold (Minello and Rozas 2002, Baker and Minello 2011). Capture efficiency corresponds to the fraction of size-apt fish within the sampled area that are actually enclosed and captured by the gear. Indeed some fish that are within the catchable size range out-swim and escape the gear as it is being operated (Rozas and Minello 1997). Recovery efficiency corresponds to the fraction of captured fish that is actually recovered from the gear and processed. Not all captured fish are necessarily recovered, particularly in gears with a secondary removal method (Rozas and Minello 1997).

Given the individual size ranges included in the data set for the four species considered, and the minimum and maximum size thresholds of the gear types (enclosure, towed and passive) in the data set, selectivity corrections were only deemed necessary for black drum collections with enclosure-type gears. This is further elaborated in the "Results" section as we address each of the four species separately. In contrast, corrections for gear capture and recovery efficiency apply to all four species and gear types considered. Along with gear type, capture and recovery efficiency also depend on the habitat considered. Thus, we developed correction factors for capture and recovery efficiency for all combinations of habitats and gear types compiled in our data set. To do that, we carried out an extensive literature search and, for each combination of habitat and gear type in our data set, we derived a mean conversion factor and SE. We did this separately for capture and recovery efficiency. The procedure is detailed in Hollweg et al. (2019).

We then calculated overall gear efficiency for each combination of habitat and gear type as:

$$G_{hg} = C_{hg} R_{hg} \quad (4)$$

where C_{hg} and R_{hg} are the capture and recovery efficiency for the hth habitat and gth gear type. The variance of G_{hg} was calculated using the equation reported by Goodman (1960) that provides an unbiased estimate of the exact formula of the variance of the product of two independent random variables:

$$\widehat{var}(G_{hg}) = R_{hg}^2 \widehat{var}(C_{hg}) + C_{hg}^2 \widehat{var}(R_{hg}) - \widehat{var}(C_{hg}) \widehat{var}(R_{hg}) \quad (5)$$

The entire populations of the capture and recovery efficiency values for each combination of habitat and gear type are not known in their entirety and without uncertainty. Our efforts, as exhaustive as they may be, can only provide a number of values out of the entire populations of those values. Thus, the mean for capture and recovery efficiency and their variances are based on a limited sample and not on the entire population of values. Because of this, population moments need to be replaced by the corresponding sample moments, and the exact equation of the variance of the product of two independent random variables is converted into its unbiased estimate depicted in Eq. 5 (for further elaboration see Goodman 1960). The inevitably limited sample size in our calculations, as it is the often the case in ecological studies, implies that using the exact equation of the variance of the product of two independent random variables is not as accurate as using its unbiased approximation.

Overall gear efficiency for each combination of habitat and gear type was used to correct the density weighted averages for specific combinations of habitat, sampling time, and gear type:

$$D_{ht}^{G} = \frac{\text{density weighted average}}{G_{hg}} \tag{6}$$

where using the unbiased estimate of the exact formula of the variance of the product of two independent random variables reported by Goodman (1960):

$$\begin{aligned}\widehat{var}\left(D_{ht}^{G}\right) = &\left(\frac{1}{G_{hg}}\right)^{2}\widehat{var}(\text{density weighted average}) \\ &+(\text{density weighted average})^{2}\widehat{var}\left(\frac{1}{G_{hg}}\right) \\ &-\widehat{var}(\text{density weighted average})\widehat{var}\left(\frac{1}{G_{hg}}\right)\end{aligned} \tag{7}$$

and using the Delta method (Casella and Berger 2002):

$$\widehat{var}\left(\frac{1}{G_{hg}}\right) = \left(\frac{1}{G_{hg}}\right)^{4}\widehat{var}\left(G_{hg}\right) \tag{8}$$

Subsequently, we averaged all the density values corrected for overall gear efficiency that corresponded to the same combination of habitat and sampling time (D_{ht}):

$$D_{ht} = \frac{1}{N_{ht}}\sum D_{ht}^{G} \tag{9}$$

and calculated its variance as:

$$\widehat{var}(D_{ht}) = \frac{1}{N_{ht}^{2}}\sum\widehat{var}\left(D_{ht}^{G}\right) \tag{10}$$

where D_{ht}^{G} are the density values corrected for overall gear efficiency corresponding to the specific combination of habitat and sampling time, and N_{ht} is the count (number) of such values. All these steps are common to our calculations of biomass at recruitment and productivity (Fig. 1).

Calculations of Biomass at Recruitment and Productivity

Calculations of Biomass at Recruitment

The next step for these calculations was, using life history tables, to estimate density at recruitment from values of mean density at a given sampling time post-recruitment (Fig. 1). The fraction of YOY present at the beginning of day 1 that remain alive at the end of the day (YOY_1) corresponds to:

$$YOY_1 = e^{-m_1} \tag{11}$$

where m_1 is the mortality rate for day 1 and is expressed in day^{-1}. In turn, the fraction of YOY remaining after t days (YOY_t) corresponds to:

$$YOY_t = \prod_{i=1}^{t} e^{-m_i} = YOY_{t-1}e^{-m_t} \tag{12}$$

where m_i is the mortality rate for day i, m_t is the mortality rate for day t, and YOY_{t-1} is the fraction of YOY present at the beginning of day 1 that remain alive at the end of day t-1. All mortality rates are expressed in day^{-1} and can be obtained as modeled values provided in the life history tables (see Appendix 2 for actual values).

Following this, the density at recruitment (D_R) can be estimated from the density obtained at a sampling time post-recruitment (D_{ht}) as:

$$D_R = D_{ht}\left({}^{1}/_{YOY_t}\right) \tag{13}$$

where t covers the time span elapsed from recruitment to sampling. This procedure allowed us to derive a separate estimate of density at recruitment for each density value in the data set obtained at a later date as specified by the sampling time.

To estimate the variance of D_R, we followed a multi-step process. The first step was to derive variance estimates for the daily mortality rates. To do this, we used the linear regression model provided by Bradford (1992):

$$ln\ (var(m_d)) = 2.231\ ln\ (m_d) - 1.893 \tag{14}$$

where m_d is the mean interannual daily mortality for day d, $var\ (m_d)$ is the variance of the daily mortality values that compose the interannual mean, and ln denotes natural logarithm. The model was generated using a literature survey of mortality rates for egg, juvenile, and adult stages of marine, freshwater, and anadromous fish species. At least two values of daily mortality rates corresponding to different years were obtained for each species. The mean interannual daily mortality was calculated for each species, and after transformation to natural logarithms, the variance of the interannual daily mortality values was regressed against the mean (see Bradford 1992 for further details). Thus, this effort includes temporal variability in the estimates of variance for mortality rates, but it disregards other sources of variance such as spatial variability.

Thus:

$$\widehat{var}(m_d) = \exp(2.231 ln(m_d) - 1.893) \tag{15}$$

Then, the variance of the fraction of YOY present at the beginning of day d remaining at the end of the day (e^{-m_d}) can be derived using the Delta method (Casella and Berger 2002):

$$\widehat{var}(e^{-m_d}) = \widehat{var}(m_d)e^{-2m_d} \tag{16}$$

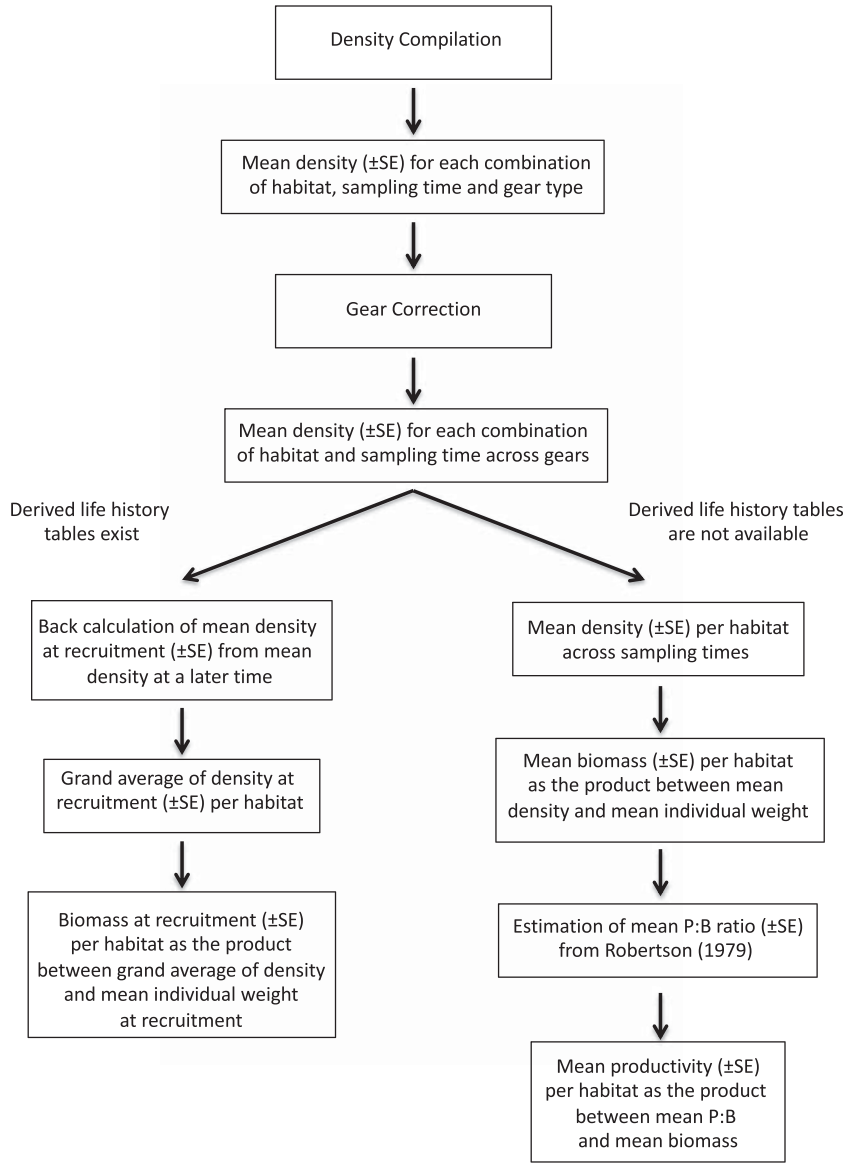

Fig. 1 Steps involved in the calculation of biomass at recruitment for fin- and shellfish species where derived life history tables exist, and productivity for species where derived life history tables are not available

From this, we can calculate the variance of YOY_t following an iterative process. The fraction of recruited YOY that remain alive at the end of day 2 (YOY_2) corresponds to:

$$YOY_2 = e^{-m_1} e^{-m_2} \tag{17}$$

where m_1 and m_2 are the mortality rates on day 1 and 2 respectively. The variance of this product can be estimated using the usual approximate formula for the variance of two dependent variables (Goodman 1960):

$$\widehat{var}(YOY_2) = e^{-2m_2}\widehat{var}(e^{-m_1}) + e^{-2m_1}\widehat{var}(e^{-m_2}) + 2e^{-m_1}e^{-m_2}\widehat{cov}(e^{-m_1}, e^{-m_2}) \tag{18}$$

where

$$\widehat{cov}(e^{-m_1}, e^{-m_2}) = \hat{\rho}\sqrt{\widehat{var}(e^{-m_1})\widehat{var}(e^{-m_2})} \tag{19}$$

and $\hat{\rho}$ is the estimated intra-class correlation for the cumulative remaining fraction of YOY.

We have chosen to use the usual approximate formula, and not the exact formula, for the variance of two dependent variables because the additional terms included in the exact formula not present in the approximate formula incur into complex derivatives that, while representing substantial effort, add relatively little to the magnitude of the calculation (see Goodman 1960).

Similarly, the fraction of recruited YOY that remain alive at the end of day 3 (YOY_3) corresponds to:

$$YOY_3 = YOY_2 e^{-m_3} \tag{20}$$

and its variance:

$$\widehat{var}(\mathrm{YOY}_3) = e^{-2m_3}\widehat{var}(\mathrm{YOY}_2) + \mathrm{YOY}_2^2\widehat{var}(e^{-m_3}) + 2\mathrm{YOY}_2 e^{-m_3}\,\widehat{cov}(\mathrm{YOY}_2, e^{-m_3}) \quad (21)$$

Using this approach iteratively to YOY_4, YOY_{t-1} and finally to YOY_t:

$$\widehat{var}(\mathrm{YOY}_t) = e^{-2m_t}\widehat{var}(\mathrm{YOY}_{t-1}) + \mathrm{YOY}_{t-1}^2\widehat{var}(e^{-m_t}) + 2\mathrm{YOY}_{t-1}\, e^{-m_t}\widehat{cov}(\,\mathrm{YOY}_{t-1}, e^{-m_t}) \quad (22)$$

Subsequently, the variance of D_R can be calculated by applying to Eq. 13 the expression reported by Goodman (1960) that provides an unbiased estimate of the exact formula of the variance of the product of two independent random variables:

$$\widehat{var}(D_R) = \left({}^{1}/_{\mathrm{YOY}_t}\right)^2\widehat{var}(D_{ht}) + D_{ht}^2\widehat{var}\left({}^{1}/_{YOY_t}\right) - \widehat{var}(D_{ht})\widehat{var}\left({}^{1}/_{\mathrm{YOY}_t}\right) \quad (23)$$

where using the Delta method (Casella and Berger 2002):

$$\widehat{var}\left({}^{1}/_{\mathrm{YOY}_t}\right) = \left({}^{1}/_{\mathrm{YOY}_t}\right)^4\widehat{var}(\mathrm{YOY}_t) \quad (24)$$

Finally, from the estimates of density at recruitment and their variances, we estimated a grand average of density at recruitment per habitat (D_{RH}) and its variance as:

$$D_{RH} = \frac{1}{N}\sum D_R \quad (25)$$

$$\widehat{var}(D_{RH}) = \frac{1}{N^2}\sum\widehat{var}(D_R) \quad (26)$$

where D_R is each of the estimates of density at recruitment for the given habitat, and N is the count of estimates in the habitat. Density estimates can be converted to biomass from knowledge of the mean individual fish weight at recruitment, which can be obtained from life history tables.

As indicated above, one of the main applications of our protocol is to allow for robust comparisons, or at least as robust as permitted by the size of the data sets available, of fin- and shellfish biomass across diverse shallow coastal habitats (i.e., SAV, oyster reefs, marshes, and non-vegetated bottoms). Such comparisons should be done for the same sampling time in all habitats; otherwise, temporal differences would confound the comparison and attribution of differences to habitat variability. If, rather than back-calculating to the time of recruitment, we had done comparisons across habitats with the same sampling time using the density data (or biomass after conversion from life history tables) directly reported in the data set, we would have been able to carry out only one comparison encompassing all habitats in the case of pinfish (i.e., month of May). All other comparisons for this species would have included three or four habitats, with different combinations of habitats for comparisons with the same number of habitats (for instance the comparison for July would encompass near non-vegetated, SAV, oyster reefs and marshes, and the comparison for October would encompass near non-vegetated, far non-vegetated, SAV and marshes, see Table 1). In the case of black drum, comparisons across habitats for the same sampling time would have involved at most three habitats, with many of them involving only two habitats (see Table 2).

The problems of reducing the number of habitat types that can be compared with the same sampling time when using directly reported density data, and additionally having discrepant combinations of habitat types among comparisons involving the same number of habitat types, apply to most other species included in the Hollweg et al. (2019) density data set. To avert these problems, we have developed the protocol presented above. The protocol allows for the simultaneous inclusion of all sampling times into the cross-habitat comparison by providing back-calculations from any sampling time to a common time point, i.e., the time of recruitment. The protocol provides an integrated and coherent comparison of fin- and shellfish biomass across habitats by bringing together all sampling times in the data set to the same time point. We have chosen time at recruitment because of its ecological and management significance (i.e., appearance of new recruits and onset for their growth in shallow coastal systems). Importantly, we propagate the error involved in our calculations throughout the derivation process, such that the final estimates allow for sound comparisons across habitats where the certainty and robustness of the differences found can be well informed.

Calculations of Productivity

Our protocol for the derivation of productivity values relies on estimation of the P:B ratio (ratio of productivity to biomass) and subsequent multiplication by biomass. Derivation of productivity using the P:B ratio and biomass has been carried out in the literature for macro-invertebrates (Sprung 1993, Cusson and Bourget 2005) and fish (Waters 1977, Randall 2002). Here, we used an empirical model developed by Robertson (1979) for benthic macro-invertebrates that relates the species average P:B to its life span. The model corresponds to a linear regression fit using least-squares to the relationship between the base 10 logs of the two variables for 45 species of benthic macro-invertebrates including polychaetes, gastropods, bivalves, crustaceans, and echinoderms:

$$log_{10}(P:B) = 0.660 - 0.726 log_{10}(\mathrm{Lifespan}) \quad (27)$$

Table 1 Pinfish: Density at sampling and SE; density at recruitment and SE back-calculated from the sampling month; overall density at recruitment per habitat and SE; and biomass at recruitment per habitat and SE. Density is in number of YOY per square meter of habitat, and biomass at recruitment is in gram DW per square meter of habitat. Biomass at recruitment has been derived by multiplying overall density at recruitment times the mean individual weight for YOY at that time (0.00198 g DW per individual) as reported in the life history tables for the species' first year of life (Appendix 2; see text for more details). For these calculations, mean individual weight is considered constant

Habitat	Time	Density at sampling	SE density at sampling	Density at recruitment	SE density at recruitment	Overall density at recruitment per habitat	SE overall density at recruitment per habitat	Biomass at recruitment per habitat	SE biomass at recruitment per habitat
Near non-vegetated	February	0.118	0.398	0.118	0.398	3.590	3.196	0.007	0.006
Near non-vegetated	March	0.005	0.286	0.038	1.959				
Near non-vegetated	April	0.131	0.345	1.642	4.263				
Near non-vegetated	May	0.185	0.049	3.736	1.221				
Near non-vegetated	June	0.102	0.113	3.104	3.344				
Near non-vegetated	July	0.188	0.104	7.923	4.573				
Near non-vegetated	August	0.044	0.416	2.485	22.866				
Near non-vegetated	October	0.113	0.100	9.672	8.676				
Far non-vegetated	February	8.751	5.847	8.751	5.847	5.766	6.892	0.011	0.014
Far non-vegetated	May	0.436	0.101	8.808	2.650				
Far non-vegetated	September	0.078	0.078	5.507	5.507				
Far non-vegetated	October	0.000	0.312	0.000	26.237				
Near and far nonvegetated	February	0.111	0.030	0.111	0.030	14.183	7.136	0.028	0.014
Near and far nonvegetated	March	5.303	3.453	37.074	24.303				
Near and far nonvegetated	April	3.860	1.771	48.538	23.005				
Near and far nonvegetated	May	0.156	0.038	3.155	0.965				
Near and far nonvegetated	June	0.408	0.946	12.400	27.709				
Near and far nonvegetated	July	0.609	0.595	25.719	24.651				
Near and far nonvegetated	August	0.000	0.011	0.000	0.598				
Near and far nonvegetated	September	0.007	0.395	0.504	26.921				
Near and far nonvegetated	October	0.002	0.372	0.148	30.057				
SAV	February	0.453	0.820	0.453	0.820	20.603	8.918	0.041	0.018
SAV	March	1.276	0.946	8.925	6.467				
SAV	April	1.849	1.048	23.244	12.691				
SAV	May	1.267	0.736	25.592	13.967				
SAV	June	0.488	0.919	14.810	26.398				
SAV	July	0.790	0.728	33.364	26.619				
SAV	August	0.338	0.726	18.971	38.460				
SAV	September	0.333	0.578	23.663	37.959				
SAV	October	0.424	0.502	36.404	39.355				
Oyster reefs	May	7.806	2.591	157.618	59.912	93.205	30.417	0.185	0.060

Table 1 (continued)

Habitat	Time	Density at sampling	SE density at sampling	Density at recruitment	SE density at recruitment	Overall density at recruitment per habitat	SE overall density at recruitment per habitat	Biomass at recruitment per habitat	SE biomass at recruitment per habitat
Oyster reefs	July	0.682	0.215	28.793	10.550				
Marshes	February	0.460	0.158	0.460	0.158	21.306	3.693	0.042	0.007
Marshes	March	2.083	0.378	14.561	3.830				
Marshes	April	1.540	0.325	19.363	5.507				
Marshes	May	4.449	1.324	89.840	31.151				
Marshes	June	0.740	0.133	22.477	5.939				
Marshes	July	0.460	0.060	19.412	4.575				
Marshes	August	0.117	0.047	6.555	2.877				
Marshes	September	0.269	0.044	19.088	4.875				
Marshes	October	0.000	0.012	0.000	0.975				

In this equation, life span is expressed in years and ranges from 1.6 to 25.1 years. The P:B ratio is expressed in year^{-1} and ranges from 0.5 to 6.3 year^{-1}. It is important to stress that P:B corresponds to the mean ratio for the species, that is a ratio that includes all individual age classes and represents the mean P:B that would be measured at a population level including simultaneously all the different species' life cycle stages as they naturally occur in the system.

We can use the Robertson (1979) model to predict P:B from lifespan values for species of interest. Those predictions can be multiplied by mean biomass to derive estimates of productivity (Fig. 1). Thus, the uncertainty in these productivity estimates comes from the uncertainty in the predicted P:B values and the uncertainty in the mean biomass. To derive the predicted P:B value, we inputted the lifespan for the species of interest in the equation above and solved for P:B. The entry corresponds to a species not included in the initial regression in Robertson (1979), and thus, the predicted P:B value for the entered lifespan is determined by the overall functional association between life span, body size and turnover rate across species (Brown et al. 2004), on the one hand, and idiosyncratic, species-specific variability in such functional association on the other. Therefore, we estimated the uncertainty of this prediction as the variance associated with a predicted single value of the dependent variable from a given value of the independent variable in the linear regression model (and not as the predicted mean value of the dependent variable for a given value of the independent variable, Neter et al. 1996). This variance $\left(\widehat{var}_{\hat{Y}\ \text{single}}\right)$ corresponds to:

$$\widehat{var}_{\hat{Y}\ \text{single}} = MSE\left(1 + \frac{1}{n} + \frac{\left(x^{*} - \bar{x}\right)^{2}}{S_{xx}}\right) \tag{28}$$

where MSE is the mean squared error from the model fit, n is the number of paired observations in the regression, $x^{*}$is the specific value of the independent variable for which we seek the predicted value of the dependent variable, $\bar{x}$ is the mean for all the values of the independent variable used to obtain the regression fit, and S_{xx} is the sum of squares of the independent variable. Since we used a regression model with base 10 log variables, the variance derived in this way corresponded to $\widehat{var}\log_{10}(P:B)$. We used the Delta method (Casella and Berger 2002) to calculate $\widehat{var}\ P:B$:

$$\widehat{var}\ P:B = \widehat{var}log_{10}(P:B)\ (P:B\ ln10)^{2} \tag{29}$$

where $ln10$ denotes the natural logarithm of 10, and P:B is the back transformed value of the predicted $\log_{10}(P:B)$:

$$P:B = 10^{\log_{10}(P:B)} \tag{30}$$

Table 2 Black drum: Density at sampling and SE; density at recruitment and SE back-calculated from the sampling period; overall density at recruitment per habitat and SE; and biomass at recruitment per habitat and SE. Density is in number of YOY per square meter of habitat, and biomass at recruitment is in gram DW per square meter of habitat. Biomass at recruitment has been derived by multiplying overall density at recruitment times the mean individual weight for YOY at that time (0.000726 g DW per individual) as reported in the life history tables for the species' first year of life (Appendix 2; see text for more details). For these calculations, mean individual weight is considered constant

Habitat	Time	Density at sampling	SE density at sampling	Density at recruitment	SE density at recruitment	Overall density at recruitment per habitat	SE overall density at recruitment per habitat	Biomass at recruitment per habitat	SE biomass at recruitment per habitat
Near non-vegetated	March, April, and May	0.302	0.125	0.302	0.125	15.735	11.439	0.011	0.008
Near non-vegetated	April	0.000	0.088	0.000	0.088				
Near non-vegetated	May	0.000	0.088	0.000	5.173				
Near non-vegetated	June	0.000	0.058	0.000	6.412				
Near non-vegetated	June, July, and August	0.666	0.403	125.577	82.440				
Near non-vegetated	July	0.000	0.088	0.000	15.716				
Near non-vegetated	August	0.000	0.088	0.000	22.924				
Near non-vegetated	September, October, and November	0.000	0.063	0.000	27.169				
Far non-vegetated	March, April, and May	0.000	0.183	0.000	0.183	0.000	19.998	0.000	0.015
Far non-vegetated	June, July, and August	0.000	0.224	0.000	39.995				
SAV	March, April, and May	0.067	0.139	0.067	0.139	0.034	13.027	2.45×10^{-5}	0.009
SAV	June, July, and August	0.000	0.146	0.000	26.055				
Marshes	April	0.000	0.094	0.000	0.094	3.870	6.630	0.003	0.005
Marshes	May	0.000	0.094	0.000	5.505				
Marshes	June	0.000	0.094	0.000	10.407				
Marshes	July	0.000	0.094	0.000	16.725				
Marshes	August	0.070	0.097	19.348	26.085				

To derive mean biomass and its variance by habitat, we first estimated the mean density and its variance in the specific habitat (Fig. 1). Estimates of mean density came from a two-step process. First, we pooled all density values corrected for overall gear efficiency corresponding to the same combination of habitat and sampling time, i.e., we derived D_{ht} from D_{ht}^G, and $\widehat{var}(D_{ht})$ from $\widehat{var}\left(D_{ht}^G\right)$ as explained in Eqs. 9 and 10. Second, we estimated the grand average density (D_H) and its variance ($\widehat{var}(D_H)$) per habitat by pooling all the sampling times within the specific habitat:

$$\mathrm{D}_H = \frac{1}{N_t}\sum D_{ht} \tag{31}$$

$$\widehat{var}(\mathrm{D}_H) = \frac{1}{N_t^2}\sum \widehat{var}(D_{ht}) \tag{32}$$

where N_t is the number of sampling times in the habitat. The purpose was to obtain a mean biomass value for the population that includes all individual age classes, or at least as many as possible, as they naturally occur. Thus, by first averaging all density values corrected for overall gear efficiency corresponding to the same combination of habitat and sampling time, this approach helps to reduce overweighting our final estimates with specific sampling times that could under- or over-represent certain age classes.

We then derived estimates of mean biomass per habitat (B_H) as the product between D_H and mean individual weight (IW), with the latter also encompassing all size classes. Values of $IW$and its variance were obtained from the literature. We calculated the variance of B_H using the equation reported by Goodman (1960) that provides an unbiased estimate of the exact formula of the variance of the product of two independent random variables:

$$\widehat{var}(B_H) = IW^2\widehat{var}(D_H) + D_H^2\widehat{var}(IW) - \widehat{var}(D_H)\widehat{var}(IW) \tag{33}$$

where values and variance of D_H and B_H are specific to the habitat, and the value and variance of IW are applied uniformly to all habitats. Finally, we derived estimates of mean productivity per habitat (P_H) as the product between B_H and P:B, and its variance as (Goodman 1960):

$$\widehat{var}\,(P_H) = (P:B)^2\,\widehat{var}\,(B_H) + B_H^2\widehat{var}\,(P:B) - \widehat{var}\,(B_H)\,\widehat{var}\,(P:B) \tag{34}$$

where the value and variance of the predicted P:B is applied uniformly to all habitats.

Results

Species with Derived Life History Tables: Estimation of Biomass at Recruitment

Pinfish

The data set used for pinfish in this paper comprised 278 density records from 26 papers (Appendix 3). Records per paper ranged from 2 (Reese et al. 2008, Cebrian et al. 2009) to 48 (Zimmerman et al. 1990). Density data spanned six habitats (marsh, oyster reefs, SAV, near non-vegetated bottom, far non-vegetated bottom, and near and far non-vegetated bottom combined together). Pinfish density data also spanned all twelve months and eight different gear types. Since the pinfish density data set compiled in Hollweg et al. (2019) was well populated with entries reported by month, we decided not to include entries reported by season (i.e., mean density values for a single or several seasons) in this paper to avoid the uncertainty associated with those entries when back-calculating density at recruitment. In total, the pinfish data set used here had 100 unique combinations of habitat, month, and gear type, with 51 of those combinations having one entry (Appendix 3). The number of entries per habitat/month/gear type combination ranged from 1 to 32 (marsh/May/drop sampler).

The density data compiled in Hollweg et al. (2019) for pinfish corresponds to YOY. Corrections for gear selectivity were not necessary since most YOY pinfish do not grow beyond 10 cm in length before they leave the shallow parts of coastal ecosystems to which they recruit (Nelson 1998, McDonald et al. 2016) and, thus, generally remain below the maximum size threshold captured by the gear types included in the data set (Rozas and Minello 1997, 1998; see Hollweg et al. 2019 for further detail). Pinfish usually recruit to shallow areas through a few pulses over the winter and most YOY leave these areas towards deeper waters the next fall (Hansen 1969, Nelson 1998, Cebrian et al. 2009, McDonald et al. 2016). Thus, to ensure that our calculations represent most of the recruited YOY, we assigned February 15th as the recruitment time for the back-calculations of density at recruitment from density values obtained at a later month, which we equated to the 15th day of the given month. In other words, day 1 was February 15th and day t was the 15th of the month at sampling for the estimation of density at recruitment from density values at a later date (Eqs. 12 and 13). Muncy (1984) reports that pinfish are about 20 days old when they recruit to shallow areas. Thus, the mortality rate assigned for February 15th was the mortality rate for 20-day-old fish, for February 16th it was the mortality rate for 21-day-old fish, and so forth consecutively through day 15th of the sampling

month (Appendix 2). We only did these calculations for February through October, and not for November, December, and January since most YOY leave the shallow areas in the fall.

Pinfish biomass at recruitment (±SE) ranged from 0.007 ± 0.006 g DW per square meter in near non-vegetated habitat to 0.185 ± 0.060 g DW per square meter in oyster beds (Table 1, Fig. 2). In general, pinfish biomass at recruitment showed higher values in structured habitats, such as SAV beds, oyster beds, and marshes, than on bare sediment habitats, although recruitment values varied considerably within habitat types.

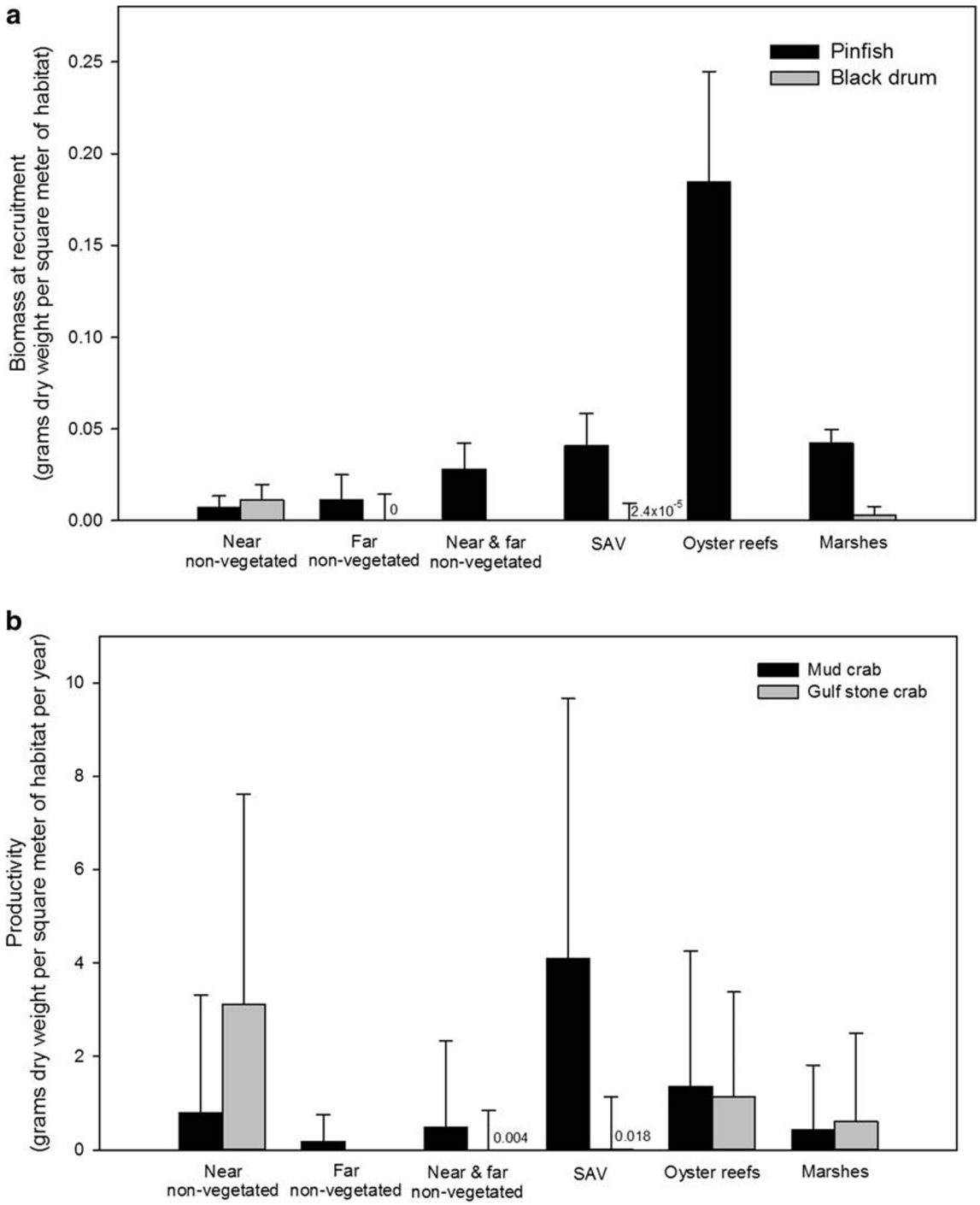

Fig. 2 **a** Estimates of mean (and SE) biomass at recruitment for pinfish and black drum in the various habitats examined; **b** Estimates of mean (and SE) productivity for mud crab and Gulf stone crab in the various habitats examined. Bars represent means and lines SE. For both panels, number insets represent mean values too small to see (black drum, far non-vegetated: 0; black drum, SAV: 2.4×10^{-5}; Gulf stone crab, near and far non-vegetated: 0.004; Gulf stone crab, SAV: 0.018)

Black Drum

Density data availability for black drum in shallow coastal systems contrasted sharply with that for pinfish. Despite our extensive search (Hollweg et al. 2019), we could only find 37 records of black drum density from 4 papers (Appendix 3). The number of records per paper ranged from 3 (Gordon 2010) to 22 (Zimmerman and Minello 1984). The data set encompassed four habitat types (marsh, SAV, near non-vegetated bottom, and far non-vegetated bottom) and three gear types (drop sampler, throw trap, and seine). Due to the limited density data available for this species, we decided to use all the density data we could obtain and, unlike pinfish, we considered entries reported by month or season. Entries reported by season entail additional uncertainty in the back-calculation of density at recruitment. In total, there were 29 unique combinations of habitat, sampling time (month or season), and gear type, with only seven of them having more than one entry (Appendix 3). The number of entries per habitat/sampling time/gear type combination ranged from 1 to 3 (near non-vegetated bottom, June, throw trap).

The density data compiled in Hollweg et al. (2019) for black drum corresponds to YOY. Corrections of this data for gear selectivity were necessary for enclosure-type gears (drop sampler and throw trap). This is because YOY black drum become larger than 10 cm before they leave the shallow areas in the fall (Sutter et al. 1986, Leard et al. 1993) and, thus, generally surpass the maximum size threshold for enclosure-type gears (Rozas and Minello 1997, 1998). Correction factors for selectivity can be derived from monthly individual size histograms of YOY fish. In this particular case, we can derive correction factors for specific months or seasons as the fraction of fish < 10 cm in the YOY population in the specific month or season. Despite our efforts, we could only find one report with such histograms for YOY black drum (Peters and McMichael 1990). The histograms are recreated in Fig. 3, and they show how YOY black drum grow quickly in shallow areas to reach a size over 10 cm by September. We calculated monthly correction factors as the average value of the two months in the two consecutive years in the study (1982 and 1983), and seasonal correction factors as the average for all months in the season pooling both years together (see legend of Fig. 3 for exact values). Since we derive these corrections factors based on a single report, we have chosen to not assign any variability to these factors (e.g., SE of the mean) but rather consider them as fixed constants for our calculations. The main purpose of this gear selectivity correction exercise is illustrative. Accurate derivation of selectivity correction factors will necessitate multiple reports of monthly individual size histograms.

Black drum YOY start recruiting to shallow areas in late winter and most recruitment has normally occurred by mid spring. The YOY stay in the shallow areas through the fall, at which time they move to deeper waters (Sutter et al. 1986, Peters and McMichael 1990, Leard et al. 1993). Based on this, for our calculations, we assigned April 15th as the recruitment time and included the months of April, May, June, July, August, September, and October, and the spring, summer, and fall seasons (with exceptions for enclosure-type gears, see Fig. 3). We excluded the months of November, December, January, February, and March, and the winter season. Day 1 was set at April 15th and day t corresponded to the 15th day of the month of sampling, or to the central point of the season of sampling (April 15th for spring; July 15th for summer; and October 15th for fall) for the estimation of density at recruitment from density values at a later date (Eqs. 12 and 13). According to Sutter et al. (1986), YOY black drum are around 15 days old when they arrive in shallow areas. Thus, the mortality rate at day 1 corresponded to the mortality rate for 15-day-old fish, at day 2, it corresponded to the mortality rate for 16-day-old fish, and so forth consecutively through day t (Appendix 2).

Biomass at recruitment was much lower for black drum than for pinfish in the habitats studied (Table 2, Fig. 2). Values (± SE) ranged from a rounded-up value of 0 by the authors (± 0.015) in far non-vegetated, to $2.4 \times 10^{-5} \pm 0.009$ in SAV beds, to 0.003 ± 0.005 in marshes, and to 0.011 ± 0.008 g DW per square meter in near non-vegetated habitat.

Species Without Derived Life History Tables: Estimation of Productivity

Mud Crab

The density data set compiled by Hollweg et al. (2019) for this species contained 162 records from 19 papers (Appendix 3). The number of records per paper ranged from 1 (Zeug et al. 2007, Roth and Baltz 2009) to 46 (Zimmerman et al. 1990). Density data spanned all six habitats and three gear types. Data for mud crab were reported by single month, by combinations of two months within a season, by single seasons, or even by combination of seasons. We included all these sampling times in our calculations since the intent for this species is to generate density estimates that integrate all individual age classes as they naturally occur in the habitats studied. In total, there were 49 unique combinations of habitat, sampling time, and gear type, with 17 of those combinations having one entry (Appendix 3). The number of entries per habitat/sampling time/gear type ranged from 1 to 20 (marsh/May/drop sampler).

Corrections for gear selectivity were not necessary since mud crabs do not normally exceed 10 cm in length (Williams 1984). Most of the sampling times averaged within each habitat to calculate the grand average density in the habitat corresponded to spring, summer, fall, or combinations of those, with little sampling done in winter. Hence, since winter

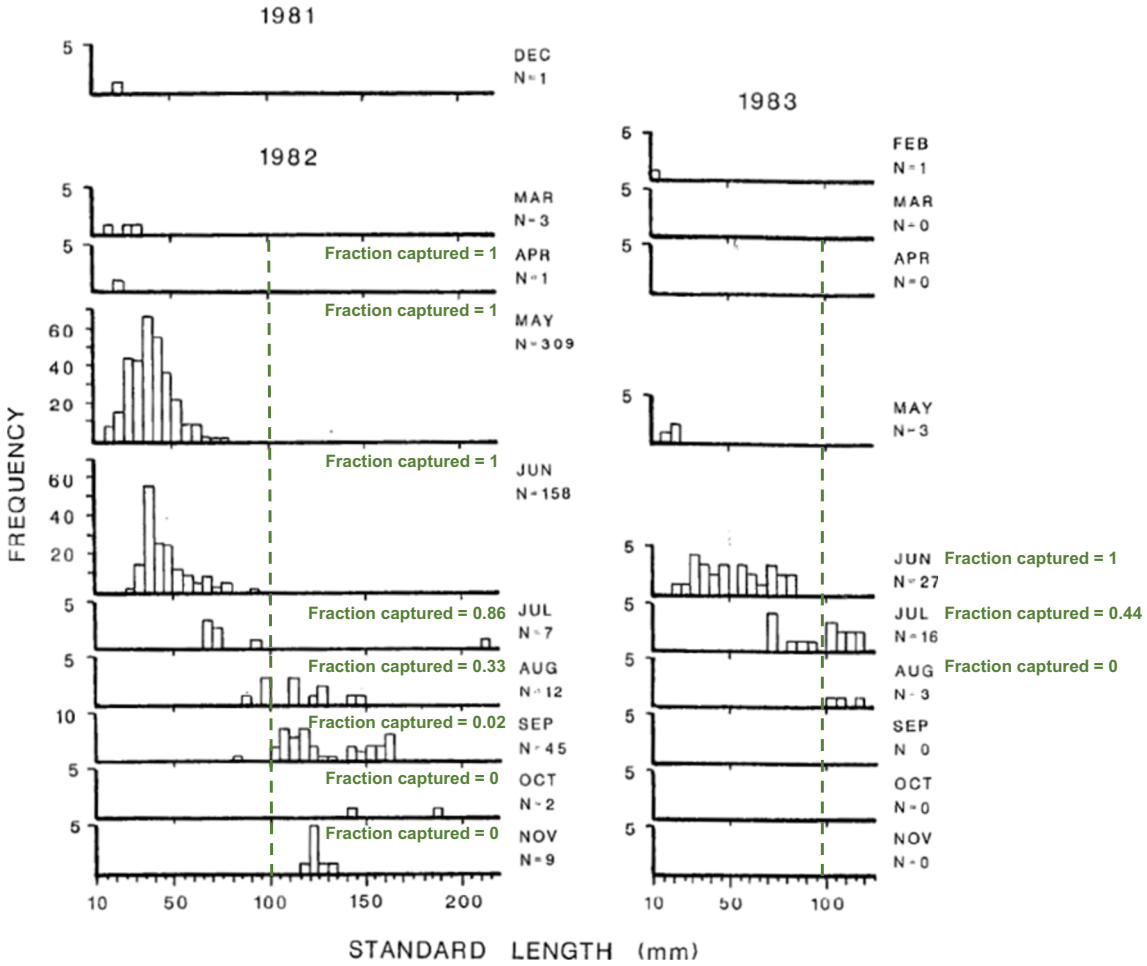

Fig. 3 Fish size histograms of YOY black drum (adapted from Peters and McMichael 1990). The dashed green light shows the fraction of fish caught with enclosure-type gears (drop sampler and throw trap) assuming a maximum size threshold of 10 cm (Rozas and Minello 1997, 1998). These fractions have been applied for gear selectivity corrections, and correspond to 0.65 for July, 0.165 for August, and 0.605 for summer (see text for more details). Records for September, October, and the fall obtained with enclosure-type gears are excluded in our calculations since very few YOY would be captured with these gears at those sampling times according to the histograms

is poorly reported, our final estimates of grand average density per habitat may have some bias in relation to well-balanced estimates that encompass all of the species age classes as they occur in nature. However, data were reported in a similar frequency for spring, summer and fall within each of the habitats. In other words, for each habitat, approximately 1/3 of the data corresponded to spring, 1/3 to summer, and 1/3 to fall. Therefore, despite potentially having some implicit bias, our estimates should still provide sound comparisons across habitats because spring, summer and fall are sampled to a similar extent (1/3 of the total data for the habitat) within each of the habitats.

Mud crab productivity (±SE) in the habitats studied ranged from 0.180 ± 0.569 (far non-vegetated) to 0.793 ± 2.516 (near non-vegetated) in non-structured habitats, and from 0.425 ± 1.388 (marsh) to 4.098 ± 5.567 g DW per square meter per year (SAV beds) in structured habitats (Table 3, Fig. 2). In general, productivity values were higher in structured than in non-structured habitats. However, large variability in mud crab productivity was observed within each of the habitats studied.

Gulf Stone Crab

Data availability was much more limited for Gulf stone crab in relation to mud crab. Despite our extensive search (Hollweg et al. 2019), we only obtained 34 density records from 6 papers for Gulf stone crab (Appendix 3). The number of records per paper ranged from 1 (Roth and Baltz 2009) to 18 (Peterson and Stricklin 2008). Density data spanned five habitats and four gear types. Data for Gulf stone crab was reported by single months, combinations of months, seasons, and combinations of seasons. Similarly to mud crab, we included all these sampling times in our calculations since we intended to generate density estimates that encompass all individual age classes as they naturally occur in the habitats studied. In total, there were 20 unique combinations of habitat, sampling time, and gear type, with 13 of those combinations having one

Table 3 Mud crab: Density at sampling and SE; overall density at sampling per habitat and SE; and productivity and SE. Density is in number of individuals per square meter of habitat, and productivity is in gram DW per square meter of habitat per year. Productivity has been derived by multiplying overall density times the mean individual dry weight ± SE (0.563 ± 0.014 g per individual) and production to biomass ratio ± SE (1.841 ± 0.128 per year) encompassing all age classes. In turn, the mean production to biomass ratio is calculated from the species life span of 3 years using Robertson (1979). Sources are Turoboyski (1973) for mean individual weight, and Williams (1984) for lifespan

Habitat	Time	Density at sampling	SE density at sampling	Overall density at sampling per habitat	SE overall density at sampling per habitat	Productivity	SE productivity
Near non-vegetated	March and April	0.672	1.263	0.765	2.434	0.793	2.516
Near non-vegetated	March, April, and May	0.000	0.305				
Near non-vegetated	April	0.087	0.245				
Near non-vegetated	May	0.059	0.337				
Near non-vegetated	June	0.161	0.230				
Near non-vegetated	July	0.074	0.349				
Near non-vegetated	July and August	7.101	8.177				
Near non-vegetated	September	0.827	1.378				
Near non-vegetated	October	0.000	0.305				
Near non-vegetated	October and November	0.000	0.305				
Near non-vegetated	November	0.030	0.286				
Near non-vegetated	Spring, Summer, Fall, and Winter	0.171	0.156				
Far non-vegetated	May	0.006	0.472	0.174	0.550	0.180	0.569
Far non-vegetated	September	0.226	0.606				
Far non-vegetated	October	0.443	0.787				
Far non-vegetated	Spring, Summer, Fall, and Winter	0.019	0.031				
Near and far non-vegetated	April and May	2.253	4.270	0.466	1.793	0.483	1.854
Near and far non-vegetated	May	0.117	0.431				
Near and far non-vegetated	September	0.122	0.603				
Near and far non-vegetated	Spring and Summer	0.000	0.688				
Near and far non-vegetated	Spring and Fall	0.277	2.144				
Near and far non-vegetated	Spring, Summer, and Fall	0.789	1.152				
Near and far non-vegetated	Spring, Summer, and Winter	0.000	0.688				
Near and far non-vegetated	Spring, Summer, Fall, and Winter	0.172	0.283				
SAV	March and April	6.310	7.206	3.955	5.379	4.098	5.567
SAV	May	1.489	1.978				
SAV	July and August	9.188	10.311				
SAV	September	0.896	2.802				
SAV	October	5.036	4.997				
SAV	Month not specified	0.080	0.351				
SAV	Spring and Fall	8.057	5.908				
SAV	Spring, Summer, Fall, and Winter	0.579	1.201				

Table 3 (continued)

Habitat	Time	Density at sampling	SE density at sampling	Overall density at sampling per habitat	SE overall density at sampling per habitat	Productivity	SE productivity
Oyster reefs	March and April	0.000	0.817	1.305	2.811	1.353	2.907
Oyster reefs	July and August	0.525	1.374				
Oyster reefs	Spring, Summer, and Fall	4.696	5.382				
Oyster reefs	Spring, Summer, Fall, and Winter	0.000	0.310				
Marshes	April	0.126	0.389	0.410	1.343	0.425	1.388
Marshes	April and May	0.000	0.324				
Marshes	May	0.140	0.484				
Marshes	June	0.048	0.432				
Marshes	July	0.155	0.313				
Marshes	September	0.055	0.558				
Marshes	October	0.077	0.450				
Marshes	October and November	0.077	0.371				
Marshes	November	0.157	0.366				
Marshes	Spring and Fall	2.321	3.709				
Marshes	Spring, Summer, and Fall	1.736	2.510				
Marshes	Spring, Summer, Fall, and Winter	0.028	0.134				

Table 4 Gulf stone crab: Density at sampling and SE; overall density at sampling per habitat and SE; and productivity and SE. Density is in number of individuals per square meter of habitat, and productivity is in gram DW per square meter of habitat per year. Productivity has been derived by multiplying overall density times the mean individual dry weight ± SE (3.768 ± 0.636 g per individual) and production to biomass ratio ± SE (1.059 ± 0.074 per year) encompassing all age classes. In turn, the mean production to biomass ratio is calculated from the species life span of 7.5 years using Robertson (1979). Sources are Caudill (2005) and Ricciardi and Bourget (1998) for mean individual weight, and Gerhart and Bert (2008) for lifespan

Habitat	Time	Density at sampling	SE density at sampling	Overall density at sampling per habitat	SE overall density at sampling per habitat	Productivity	SE productivity
Near non-vegetated	March, April, and May	0.779	1.141	0.779	1.141	3.108	4.510
Near and far nonvegetated	Spring, Summer, and Fall	0.000	0.305	0.001	0.216	0.004	0.846
Near and far nonvegetated	Spring, Summer, Fall, and Winter	0.002	0.010				
SAV	November	0.000	0.401	0.004	0.285	0.018	1.117
SAV	Spring, Summer, Fall, and Winter	0.009	0.031				
Oyster reefs	February	0.000	0.377	0.286	0.568	1.141	2.238
Oyster reefs	March	0.000	0.377				
Oyster reefs	May	0.000	0.377				
Oyster reefs	August	0.000	0.377				
Oyster reefs	November	0.120	0.632				
Oyster reefs	December	0.000	0.377				
Oyster reefs	Spring, Summer, and Fall	0.079	0.395				
Oyster reefs	Spring, Summer, Fall, and Winter	2.089	1.148				
Marshes	August, September, and October	0.332	0.682	0.155	0.479	0.617	1.882
Marshes	November	0.000	0.403				
Marshes	Spring and Summer	0.221	0.270				
Marshes	Spring, Summer, and Fall	0.217	0.668				
Marshes	Spring, Summer, Fall, and Winter	0.003	0.011				

entry (Appendix 3). The number of entries per habitat/sampling time/gear type combination ranged from 1 to 3 (several combinations had 3 entries, see Appendix 3).

Since Gulf stone crabs do not normally exceed 10 cm (Gerhart and Bert 2008), corrections for gear selectivity were not necessary. Except for near non-vegetated bottom, sampling times were similarly distributed throughout the year within the habitats examined, with similar relative sampling frequencies reported for spring, summer, fall, and winter within each habitat. This suggests our density estimates for Gulf stone crab should encompass all individual age classes as they naturally occur in the habitats examined, except in near non-vegetated bottom.

Values (± SE) of Gulf stone crab productivity showed large variability within and across habitats, ranging from 0.004 ± 0.846 in near and far non-vegetated, 0.018 ± 1.117 in SAV beds, 0.617 ± 1.882 in marshes, 1.141 ± 2.238 in oyster beds, and 3.108 ± 4.510 g DW per square meter per year in near non-vegetated habitats (Table 4, Fig. 2).

Discussion

In this paper, we combine a number of established methods to develop procedures that generate estimates of biomass at recruitment for species of fin- and shellfish with derived life history tables, and estimates of productivity for species where sufficient information does not exist to derive life history tables. Our results contribute to a growing battery of tools for the calculation of fish biomass and productivity in coastal ecosystems (e.g., Wong et al. 2011, Minello et al. 2012, French McCay et al. 2003a,b, Nelson et al. 2013, French McCay et al. 2015). The calculations presented here are straightforward and can be implemented in guidelines and policies for environmental management. For instance, our protocol can help managers estimate the biomass and productivity of species targeted for commercial, conservation, or restoration purposes. It also provides the base to estimate fisheries productivity under various scenarios of conservation and/or restoration of coastal habitats such as SAV beds, marshes, and oyster reefs. Importantly, the protocol further quantifies the uncertainty around all such estimates, thereby helping managers make well-informed decisions.

Our calculations indicate that pinfish biomass at recruitment is higher in structured (SAV beds, oyster reefs and marshes) than in non-structured habitats (bare sediment bottoms). These results are consistent with the preference that recruiting juvenile pinfish typically show for structured vs. non-structured habitats. Indeed, other studies have also shown higher levels of recruitment, abundance, and growth of juvenile pinfish in structured vs. non-structured habitats (Stoner 1983, Jordan et al. 1996, Tolan et al. 1997, Cebrian et al. 2009, McDonald et al. 2016). Black drum biomass at recruitment is generally much lower than for pinfish in the habitats studied. In addition, our results suggest that recruiting juvenile black drum does not show the preference for structured habitat that is apparent with juvenile pinfish, which is consistent with past reports on the life cycle, biology, and habitat distribution for black drum (Osburn and Matlock 1984, Cody et al. 1985, Sutter et al. 1986). At any rate, density data for juvenile black drum are very scarce for the habitats studied; thus, the results must be regarded with caution. Because of the low sample size, it is likely that the estimates of biomass at recruitment for this species are inaccurate (i.e., rather far from the true value) and imprecise (i.e., high SE in relation to the mean value). Thus, while it seems possible that biomass at recruitment is generally lower for black drum than for pinfish in the habitats studied, our calculations cannot resolve with accuracy how much lower it is and also the true differences (or lack of) in black drum biomass at recruitment across the habitats studied. New measurements and resulting larger data sets of YOY density for this species are needed to analyze these differences with rigor.

Our estimates of mud crab productivity are generally larger in structured than in non-structured habitats. However, there exists large variability in these estimates within any given habitat. Indeed, the ratio of SE to the mean value of productivity in the habitat varies from 1.4 in SAV beds to 2.1 in oyster beds to around 3.5 for the rest of the habitats. This high variability emerges, at least in part, from the high variability also observed in the primary density data gathered for our calculations. For instance, when comparing the means versus their SE's of density values corrected for overall gear efficiency corresponding to the same combination of habitat, sampling time, and gear type (D_{ht}^{G}), we find a lower value for the mean than for its SE in 46 out of the 49 combinations (higher mean than its SE in 3 of the combinations). In contrast for pinfish, we find a lower value for the mean than for its SE in 52 out of the 100 combinations (higher mean than its SE in 43 combinations, and equal mean and SE in 5 combinations). This higher variance in mud crab in relation to pinfish density is not related to the number of records averaged in specific combinations of habitat, sampling time, and gear type when there are multiple records for the combination, since overall those numbers were similar in the two species (see Appendix 3). The differences in density variability between mud crab and pinfish pervade as averages are calculated across gears for specific combinations of habitat and sampling time (D_{ht}), although somewhat muffled. In addition, the high variability in density values for mud crab in relation to pinfish seems irrespective of the length covered by the sampling time, since mud crab density values show similarly large variability when comparing sampling times including one month, several months, and several seasons. Thus, when comparing mud crab and pinfish, the two relatively well documented species

examined here, it appears that mud crab density is intrinsically highly variable in relation to pinfish density (see also Boyle et al. 2010, Gagnon and Boström 2016, McDonald et al. 2016). This substantial variability in the compiled density values cascades through the final productivity estimates, and it hinders strong inferences regarding differences in mud crab productivity across the habitats studied. Larger data sets for this species in shallow coastal systems may alleviate these caveats by decreasing the variability around the estimates; however, our search has been exhaustive and only, if any, little additional data should exist at present.

Our results for Gulf stone crab show high variability in its productivity within and across the habitats studied. The calculations are based on a poorly reported data set, and thus, these results must be viewed with caution. As a matter of fact, the estimate for near non-vegetated habitat comes from only one mean density value for a sole sampling time, and all other estimates also suffer from highly limited sample size. Because of this, it is likely that our estimates of Gulf stone crab productivity are inaccurate (i.e., they probably are considerably off from the true value), and also imprecise (as seen in the magnitude of the SE in relation to the mean value). Thus, our calculations may offer a general idea of Gulf stone crab productivity in coastal habitats, but they bear little value for strong inferences regarding the accurate assessment of this productivity and its differences across the habitats studied. Because our compilation is exhaustive, it seems this is the best information our calculations can provide until more density data are obtained for this species in shallow coastal systems.

Despite our efforts to estimate the variability around the derived values of biomass at recruitment and productivity, there are sources of variability not included in our calculations. For instance, we do not include the variability across different populations corresponding to the same combination of habitat, sampling time, and gear type, nor do we include the variability due to author bias that can be generated when several density values for the same combination come from the same authors or paper. Additionally, our estimates of fraction of recruited YOY remaining at a given sampling time do not include the spatial variability of the daily YOY mortality rates derived in life history tables (we only include temporal variability using Bradford (1992)). We made an exhaustive search but, unfortunately, we did not find any reports that would have allowed us to derive robust estimates of such variability and include it in our calculations. The best information we found was measurements of YOY mortality rates obtained from the decrease in YOY abundance over a month's time in spring reported by Nelson (1998) in Choctawhatchee Bay, Tampa Bay, and Charlotte Harbor. Given the closeness of the values obtained (0.022, 0.021, and 0.023 day^{-1}, respectively) and locations studied, we did not judge these values as appropriate to derive robust estimates of spatial variability in YOY mortality rates.

Our calculations also include not well-constrained sources of uncertainty. Based on similarities between gear types and habitats, we assigned surrogate correction factors for gear type and habitat combinations where the literature lacked specific correction values, which may generate bias in our estimates of biomass at recruitment and productivity (see detailed explanation in Hollweg et al. 2019). The inclusion of seasons along with months as sampling times in the calculations of density at recruitment for black drum may generate further bias. Including seasons along with months increases the sample size; however, this also generates an additional source of uncertainty in that the sample collection date is assigned to the central point of the season (April 15th in spring; July 15th in summer, October 15th in fall), but the real collection could in reality have happened any time during the season and be substantially off from the assigned collection date. Ultimately, the choice of including seasons as sampling times in the calculations should be dictated by whether, despite the uncertainty brought about by assigning the collection date to the central seasonal point, the derived estimates are more robust than if seasons are not included. There are quantitative tools to help inform such decision, such as error propagation techniques and sensitivity analysis (Lehrter and Cebrian 2010). Here, we have not carried out analyses to justify inclusion of seasons along with months as sampling times in our calculations. We decided to include seasons based on the fact that about 40% of the mean density values corrected for overall gear efficiency used to back-calculate density at recruitment from density obtained at a later date (D_{ht}) were reported by season, so discarding those values would have further crippled an already highly limited data set. However, had we elected to exclude them, we would have reached similar results: black drum recruitment seems lower than for pinfish and not associated with structured habitats, but a larger data set is needed to substantiate these suggestions.

Therefore, large density data sets simultaneously available for YOY pinfish and black drum, and for total populations of mud crab and Gulf stone crab, along with more complete gear efficiency data sets in shallow coastal systems would much help produce accurate (close to the true value), precise (with relatively low SE in relation to the mean value), and inclusive (including as many sources of variability as possible) estimates of biomass at recruitment for pinfish and black drum and productivity for mud crab and Gulf stone crab. Such large data sets would allow for robust comparisons and inferences of differences among species and habitats. Our work also highlights the importance of documenting data sets thoroughly. When reporting information, an effort should be made to provide the most complete documentation possible regarding means, sample sizes, effect sizes, and variability (SD and SE), thereby allowing for rigorous further analysis of the data. For instance, when using our imputation method to estimate missing SE's, incomplete data reporting (e.g., no sample size

reported) generates bias and higher variability for the density weighted average derived for specific combinations of habitat, sampling time, and gear type (Hollweg et al. 2019). Large data sets that are well documented can do much in advancing our understanding of fin and shellfish biomass and productivity in coastal ecosystems as well as our capacity to manage these ecosystems.

The results for pinfish and mud crab point to differences across the habitats examined in biomass at recruitment for the former species and productivity for the latter, suggesting higher values in structured vs. non-structured habitats. However, when attempting to assign statistical significance to these visually apparent differences, our efforts prove challenging. This is an important endeavor since the extent of within-habitat variability found for the two species sheds doubt on whether statistically significant differences do occur among habitats, particularly for mud crab productivity. In our calculations, the density values corrected for overall gear efficiency corresponding to the same combination of habitat, sampling time, and gear type (D_{ht}^{G}) have a non-normal distribution. When pooling these values into the calculation of D_{ht} and D_H for mud crab, these summatory variables are based on too few summands to, based on the Central Limit Theorem, reasonably assume they have a normal distribution. Non-normality pervades through the final calculations of B_H and P_H. For pinfish, the calculated values of density at recruitment (D_R) have a non-normal distribution, and similarly the summatory variable D_{RH} derived from D_R is based on too few summands to assume normality. Biomass at recruitment per habitat should also have a non-normal distribution, since it is derived as the product between D_{RH} and a constant. Thus, we could not simply compare estimates of biomass at recruitment for pinfish, or productivity for mud crab, among habitats using a z-statistic. In the same vein, because we cannot assume normality for many of the variables derived throughout our calculations, it is highly questionable to use the Welch-Satterthwaite formula (Ku 1966, Lehrter and Cebrian 2010) to meticulously propagate degrees of freedom with the intent of deriving confidence intervals for the final estimates of biomass at recruitment or productivity per habitat based on the t-statistic.

The possibility of using bootstrapping methods to build confidence intervals for final estimates of biomass at recruitment and productivity per habitat is also questionable within our calculation framework, since we end up with a rather limited number of estimates of density at recruitment for pinfish (D_R, from 2 estimates in oyster reefs to 9 in various other habitats) or density at sampling for mud crab within habitats (D_{ht}, from 4 in far non-vegetated and oyster reefs to 12 in near non-vegetated and marshes) and the confidence limits derived in this way would not be very robust. In the case of pinfish, perhaps bootstrapping techniques could be applied more powerfully if estimates of density at recruitment were derived from each primary single record, that is for every single record pooled into density weighted averages for specific combinations of habitat, sampling time, and gear type when several records exist for the specific combination, and not from pooled averages for the same sampling time (D_{ht}). This, however, necessitates further analysis since the approach would be significantly different from the one used here. Regarding mud crab, density values need to be averaged by sampling time to prevent over-representation of a given sampling time when deriving productivity estimates, so the use of bootstrapping seems inherently limited when using the P:B method. We suggest the use of Bayesian methods to test for inferences regarding differences in our estimates of biomass at recruitment and productivity among species and habitats. Given reasonably large density data sets, as well as sufficient detail for other complementary information such as thorough gear efficiency correction factors, Bayesian methods should prove adequate to derive sound conclusions regarding differences in biomass at recruitment and productivity between species and habitats as calculated with our approach, and we suggest this as a promising avenue of research for a more complete utilization and application of our approach.

Our approach can be extended to derive productivity estimates for fin- and shellfish species with derived life history tables. For instance, we can adapt our calculations to estimate productivity of pinfish and black drum from hatching to a later time in their juvenile life stage before migration to deeper waters. To do this, we would first calculate the density values corrected for overall gear efficiency for each of the sampling times considered (D_{ht}), be months or seasons, and from this we would calculate the density at the time of interest. If the time of interest is earlier than the sampling time for D_{ht}, we would then back-calculate density at the time of interest from D_{ht}. These back-calculations would be tantamount to the calculations done here (Eq. 13), only that the time of interest would not be time at recruitment. If the time of interest is later than the sampling time for D_{ht}, we would fore-calculate density at the time of interest from D_{ht}. Fore-calculations would follow the same rationale as back-calculations, only that we would be moving forward in time, rather than backwards. In this regard, Eq. 13 can be modified to calculate density at a later time from density at a former time. Once we have all estimates of density at the time of interest (i.e., one independent estimate of density at the time of interest from each D_{ht}), we would calculate their grand average and multiply times the mean individual fish weight at that time, which can be obtained from the derived life history tables. These final estimates would correspond to fish productivity from hatching to the time of interest, and it would be expressed in g DW per square meter per the time period elapsed from hatching to the time of interest. The variability (SE) for these productivity estimates would also be obtained following the procedure presented

here, conveniently adapted to the particular amendments made. Similarly, we could estimate juvenile biomass export by equating the time of migration to deeper waters to the time of interest in the calculations. As a matter of fact, our approach could be used to estimate fish productivity from hatching to any life-cycle stage (age class), assuming that there are good age-class-specific density data for the species.

Conclusion

Building from existing methods, here we developed a protocol that allows for calculations of biomass at recruitment for species of fin- and shellfish with derived life history tables, and for calculations of productivity for species where derived life history tables do not exist. Our procedure propagates the uncertainty of variables included in the calculations, and thus generates brackets of variability for the final estimates. For species with better reported density data sets, reasonable inferences regarding differences among species or habitats can be suggested. For species with poorly reported density data, only a general idea of biomass at recruitment or productivity can be gleaned. However, larger data sets of fin- and shellfish density in shallow coastal systems, and other complementary information such as thorough gear efficiency correction factors, are needed to generate estimates of biomass at recruitment and productivity that are more accurate, precise, and inclusive of variability sources. In combination with larger data sets and Bayesian statistics, our protocol offers promise for a better understanding of fisheries productivity in coastal systems and enhanced management of these systems.

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Appendix 1

Equations used for the derivation of individual fish mass and mortality rates. The equations are run on daily steps for the first year of life (see Appendix 2). Species-specific values for initialization and validation of the equations have been obtained from Nelson (2002) for pinfish and Murphy and Muller (1995) for black drum. Water temperature was set at 26 °C, which is a representative mean value during the larval stage period for these two species in the region studied (Boyer et al. 2011). For details, see pages 11–13 in French McCay et al. (2015)

Larval stage:

Duration of the larval stage (Houde 1989)

$$D_l = 952.5T^{-1.0752} \tag{35}$$

where D_l is the duration of the larval stage (days) and T is water temperature (C)

Growth/Length (Pepin 1991)

$$G_l = 0.031e^{0.073T}L^{0.54} \tag{36}$$

where G_l corresponds to the daily growth increment of the larval individual (mm/day), T is water temperature (C), and L is larval length (mm)

Mortality (Pepin 1991)

$$M_l = 0.25e^{0.067T}L^{-0.68} \tag{37}$$

where M_l is the larval mortality rate (day^{-1}), T is water temperature (C), and L is larval length (mm)

Juvenile stage:

Duration of the juvenile stage (first year of life) (French McCay et al. 2015)

$$D_j = 365 - D_l - D_e \tag{38}$$

where D_j is the duration of the juvenile stage (days), D_l is the duration of the larval stage (days), and D_e is the duration of the egg stage (days) (see French McCay et al. 2015 for derivation of the latter term)

Growth/Length (first year of life) (French McCay et al. 2015)

$$G_j = \frac{\mathrm{In}\left(\frac{W_1}{W_l}\right)}{D_j} \tag{39}$$

$$W_\tau = W_l e^{\left(G_j(\tau - D_l)\right)} \tag{40}$$

where G_j is the juvenile growth rate (day^{-1}) from the end of the larval stage to age 1 year, W_1 is the individual wet weight at age 1 year (grams), W_l is the individual wet weight at the end of the larval stage (grams), D_j is the duration of the juvenile stage up to age 1 year (days), W_τ is the individual wet

weight at age τ (grams), and D_l is the duration of the larval stage (days).

Mortality (first year of life) (Lorenzen 1996)

$$M_j = \frac{3.69W^{-0.305}}{365} \tag{41}$$

where M_j is the juvenile mortality rate (day^{-1}), and W is the individual wet weight (grams)

Length-weight conversion equations

Length to wet weight (Wiebe and Davis 1985)

$$W_{wet} = 0.0069L^{2.886} \tag{42}$$

Wet weight to dry weight (Nixon and Oviatt 1973)

$$W_{dry} = 0.22W_{wet} \tag{43}$$

where W_{wet} is wet weight (grams), L is length (mm), and W_{dry} is dry weight (grams)

Appendix 2

Estimates of mortality rates and individual fresh weight for daily intervals during the first year of life for pinfish larvae and juveniles. For calculation details, see Appendix 1. Estimates of mortality rates and individual fresh weight for daily intervals during the first year of life for black drum larvae and juveniles. For calculation details, see Appendix 1 (Tables 5 and 6)

Table 5 Estimates of mortality rates and individual fresh weight for daily intervals during the first year of life for pinfish larvae and juveniles. For calculation details, see Appendix 1

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
1.467006485	0.890800801	5.1006E-05
2.467006485	0.809859163	7.64197E-05
3.467006485	0.740384809	0.000111821
4.467006485	0.680239149	0.00016021
5.467006485	0.627767965	0.000225242
6.467006485	0.581674272	0.000311323
7.467006485	0.540928696	0.000423711
8.467006485	0.504705182	0.000568627
9.467006485	0.472334144	0.000753371
10.46700648	0.443267818	0.000986449
11.46700648	0.417054311	0.001277709
12.46700648	0.39331792	0.001638475
13.46700648	0.371744045	0.002081707
14.46700648	0.352067496	0.00262215
15.46700648	0.334063359	0.003276506
16.46700648	0.317539777	0.004063609
17.46700648	0.302332216	0.005004605
18.46700648	0.288298869	0.006123148
19.46700648	0.275316937	0.007445598
20.46700648	0.263279613	0.009001234
21.46700648	0.252093618	0.010822473
22.46700648	0.241677163	0.012945095
23.46700648	0.231958269	0.015408481
24.46700648	0.222873373	0.018255863
25.46700648	0.214366153	0.021534576
26.46700648	0.206386551	0.025296323
27.46700648	0.19888994	0.029597453
28.46700648	0.191836423	0.034499239
29.46700648	0.185190237	0.04006818
30.46700648	0.026797848	0.040917904
31.46700648	0.026626877	0.041785648
32.46700648	0.026456996	0.042671794
33.46700648	0.026288199	0.043576733
34.46700648	0.026120479	0.044500862
35.46700648	0.025953829	0.04544459
36.46700648	0.025788242	0.046408332
37.46700648	0.025623712	0.047392511
38.46700648	0.025460231	0.048397562
39.46700648	0.025297793	0.049423926
40.46700648	0.025136392	0.050472057
41.46700648	0.024976021	0.051542416
42.46700648	0.024816672	0.052635474
43.46700648	0.024658341	0.053751712
44.46700648	0.024501019	0.054891622
45.46700648	0.024344702	0.056055706
46.46700648	0.024189381	0.057244476
47.46700648	0.024035052	0.058458457
48.46700648	0.023881707	0.059698183
49.46700648	0.02372934	0.0609642
50.46700648	0.023577946	0.062257065
51.46700648	0.023427517	0.063577347
52.46700648	0.023278049	0.064925629
53.46700648	0.023129533	0.066302504
54.46700648	0.022981966	0.067708578
55.46700648	0.02283534	0.069144471
56.46700648	0.022689649	0.070610814

Table 5 (continued)

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
57.46700648	0.022544888	0.072108255
58.46700648	0.02240105	0.073637451
59.46700648	0.022258131	0.075199077
60.46700648	0.022116123	0.07679382
61.46700648	0.021975021	0.078422383
62.46700648	0.021834819	0.080085483
63.46700648	0.021695512	0.081783852
64.46700648	0.021557093	0.083518239
65.46700648	0.021419558	0.085289406
66.46700648	0.0212829	0.087098135
67.46700648	0.021147114	0.088945221
68.46700648	0.021012194	0.090831478
69.46700648	0.020878135	0.092757737
70.46700648	0.020744932	0.094724846
71.46700648	0.020612578	0.096733671
72.46700648	0.020481069	0.098785098
73.46700648	0.020350398	0.100880028
74.46700648	0.020220562	0.103019387
75.46700648	0.020091554	0.105204114
76.46700648	0.019963369	0.107435173
77.46700648	0.019836001	0.109713545
78.46700648	0.019709446	0.112040235
79.46700648	0.019583699	0.114416267
80.46700648	0.019334606	0.116842688
81.46700648	0.019211251	0.119320565
82.46700648	0.019088682	0.121850991
83.46700648	0.018966895	0.124435079
84.46700648	0.018845885	0.127073968
85.46700648	0.018725648	0.12976882
86.46700648	0.018606177	0.132520821
87.46700648	0.018487469	0.135331184
88.46700648	0.018369518	0.138201146
89.46700648	0.018252319	0.141131972
90.46700648	0.018135868	0.144124951
91.46700648	0.018020161	0.147181402
92.46700648	0.017905191	0.150302671
93.46700648	0.017790955	0.153490133
94.46700648	0.017677448	0.156745191
95.46700648	0.017564665	0.160069279
96.46700648	0.017452601	0.163463861
97.46700648	0.017341253	0.166930431
98.46700648	0.017230615	0.170470517
99.46700648	0.017120683	0.174085677
100.4670065	0.017011452	0.177777504
101.4670065	0.016902918	0.181547623
102.4670065	0.016795076	0.185397695
103.4670065	0.016687923	0.189329416
104.4670065	0.016581453	0.193344516
105.4670065	0.016475663	0.197444764
106.4670065	0.016370547	0.201631966
107.4670065	0.016266102	0.205907966
108.4670065	0.016162324	0.210274646
109.4670065	0.016059207	0.214733931
110.4670065	0.015956749	0.219287783
111.4670065	0.015854944	0.223938209
112.4670065	0.015753788	0.228687256
113.4670065	0.015653278	0.233537016
114.4670065	0.01555341	0.238489625
115.4670065	0.015454178	0.243547263
116.4670065	0.01535558	0.248712159
117.4670065	0.01525761	0.253986586
118.4670065	0.015160266	0.259372868
119.4670065	0.015063543	0.264873376
120.4670065	0.014967436	0.270490534
121.4670065	0.014871943	0.276226814
122.4670065	0.019334606	0.282084743
123.4670065	0.01477706	0.288066901
124.4670065	0.014682781	0.294175922
125.4670065	0.014589104	0.300414497
126.4670065	0.014496025	0.306785374
127.4670065	0.01440354	0.313291357
128.4670065	0.014311644	0.319935312
129.4670065	0.014220335	0.326720165
130.4670065	0.014129609	0.333648905
131.4670065	0.014039461	0.340724581
132.4670065	0.013949889	0.347950312
133.4670065	0.013860888	0.355329278
134.4670065	0.013772455	0.362864729
135.4670065	0.013684586	0.370559985
136.4670065	0.013597277	0.378418433
137.4670065	0.013510526	0.386443535
138.4670065	0.013424328	0.394638825
139.4670065	0.01333868	0.403007912
140.4670065	0.013253579	0.411554483
141.4670065	0.01316902	0.420282299
142.4670065	0.013085001	0.429195206
143.4670065	0.013001518	0.438297129
144.4670065	0.012918568	0.447592076
145.4670065	0.012836147	0.45708414
146.4670065	0.012754252	0.466777502
147.4670065	0.012672879	0.476676431
148.4670065	0.012592025	0.486785286

Table 5 (continued)

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
149.4670065	0.012511687	0.497108519
150.4670065	0.012431862	0.507650676
151.4670065	0.012352546	0.518416401
152.4670065	0.012273736	0.529410433
153.4670065	0.012195429	0.540637615
154.4670065	0.012117622	0.552102892
155.4670065	0.012040311	0.563811313
156.4670065	0.011963493	0.575768033
157.4670065	0.011887165	0.587978319
158.4670065	0.011811325	0.600447548
159.4670065	0.011735968	0.613181211
160.4670065	0.011661092	0.626184916
161.4670065	0.011586693	0.639464391
162.4670065	0.01151277	0.653025482
163.4670065	0.011439318	0.666874163
164.4670065	0.011366334	0.681016532
165.4670065	0.011293816	0.695458818
166.4670065	0.011221761	0.710207381
167.4670065	0.011150166	0.725268716
168.4670065	0.011079027	0.740649456
169.4670065	0.011008342	0.756356375
170.4670065	0.010938109	0.772396389
171.4670065	0.010868323	0.788776563
172.4670065	0.010798982	0.805504111
173.4670065	0.010730084	0.822586399
174.4670065	0.010661626	0.840030951
175.4670065	0.010593604	0.857845448
176.4670065	0.010526016	0.876037737
177.4670065	0.01045886	0.894615828
178.4670065	0.010392132	0.913587904
179.4670065	0.01032583	0.932962321
180.4670065	0.01025995	0.952747609
181.4670065	0.010194491	0.972952483
182.4670065	0.01012945	0.993585841
183.4670065	0.010064823	1.01465677
184.4670065	0.010000609	1.036174549
185.4670065	0.009936805	1.058148654
186.4670065	0.009873408	1.080588764
187.4670065	0.009810415	1.103504759
188.4670065	0.009747824	1.126906733
189.4670065	0.009685632	1.150804992
190.4670065	0.009623837	1.17521006
191.4670065	0.009562437	1.200132685
192.4670065	0.009501428	1.225583843
193.4670065	0.009440808	1.251574743
194.4670065	0.009380575	1.27811683
195.4670065	0.009320727	1.305221794
196.4670065	0.00926126	1.332901572
197.4670065	0.009202173	1.361168354
198.4670065	0.009143463	1.390034588
199.4670065	0.009085127	1.419512986
200.4670065	0.009027163	1.449616532
201.4670065	0.008969569	1.480358483
202.4670065	0.008912343	1.511752376
203.4670065	0.008855482	1.543812038
204.4670065	0.008798984	1.576551588
205.4670065	0.008742846	1.609985445
206.4670065	0.008687066	1.644128331
207.4670065	0.008631642	1.678995284
208.4670065	0.008576572	1.714601659
209.4670065	0.008521853	1.750963136
210.4670065	0.008467483	1.78809573
211.4670065	0.00841346	1.826015793
212.4670065	0.008359781	1.864740025
213.4670065	0.008306446	1.90428548
214.4670065	0.00825345	1.944669574
215.4670065	0.008200793	1.985910091
216.4670065	0.008148471	2.028025194
217.4670065	0.008096483	2.07103343
218.4670065	0.008044827	2.114953739
219.4670065	0.007993501	2.159805465
220.4670065	0.007942502	2.205608359
221.4670065	0.007891829	2.252382593
222.4670065	0.007841478	2.300148765
223.4670065	0.007791449	2.348927913
224.4670065	0.007741739	2.398741518
225.4670065	0.007692347	2.449611518
226.4670065	0.007643269	2.501560315
227.4670065	0.007594505	2.554610789
228.4670065	0.007546051	2.608786301
229.4670065	0.007497907	2.66411071
230.4670065	0.00745007	2.720608382
231.4670065	0.007402538	2.778304198
232.4670065	0.00735531	2.837223566
233.4670065	0.007308382	2.897392434
234.4670065	0.007261755	2.9588373
235.4670065	0.007215424	3.021585225
236.4670065	0.007169389	3.085663842
237.4670065	0.007123648	3.151101372
238.4670065	0.007078199	3.217926632
239.4670065	0.00703304	3.286169052
240.4670065	0.006988169	3.355858687

Table 5 (continued)

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
241.4670065	0.006943584	3.427026226
242.4670065	0.006899283	3.499703011
243.4670065	0.006855266	3.57392105
244.4670065	0.006811529	3.649713028
245.4670065	0.006768071	3.727112322
246.4670065	0.00672489	3.80615302
247.4670065	0.006681985	3.88686993
248.4670065	0.006639354	3.969298599
249.4670065	0.006596994	4.05347533
250.4670065	0.006554905	4.139437193
251.4670065	0.006513084	4.227222045
252.4670065	0.006471531	4.316868546
253.4670065	0.006430242	4.408416176
254.4670065	0.006389217	4.501905253
255.4670065	0.006348453	4.597376948
256.4670065	0.00630795	4.694873307
257.4670065	0.006267705	4.794437267
258.4670065	0.006227716	4.896112675
259.4670065	0.006187983	4.999944309
260.4670065	0.006148504	5.105977895
261.4670065	0.006109276	5.214260131
262.4670065	0.006070298	5.324838703
263.4670065	0.006031569	5.437762309
264.4670065	0.005993088	5.553080682
265.4670065	0.005954852	5.670844605
266.4670065	0.005916859	5.791105943
267.4670065	0.005879109	5.913917657
268.4670065	0.0058416	6.039333834
269.4670065	0.005804331	6.167409705
270.4670065	0.005767299	6.298201676
271.4670065	0.005730503	6.431767346
272.4670065	0.005693942	6.568165537
273.4670065	0.005657615	6.707456318
274.4670065	0.005621519	6.849701032
275.4670065	0.005585653	6.994962323
276.4670065	0.005550016	7.143304163
277.4670065	0.005514607	7.294791882
278.4670065	0.005479423	7.449492194
279.4670065	0.005444464	7.607473229
280.4670065	0.005409729	7.768804559
281.4670065	0.005375214	7.933557236
282.4670065	0.00534092	8.101803815
283.4670065	0.005306845	8.273618392
284.4670065	0.005272987	8.449076632
285.4670065	0.005239345	8.628255807
286.4670065	0.005205918	8.811234827
287.4670065	0.005172704	8.998094274
288.4670065	0.005139701	9.18891644
289.4670065	0.00510691	9.383785364
290.4670065	0.005074328	9.582786863
291.4670065	0.005041953	9.786008578
292.4670065	0.005009785	9.993540007
293.4670065	0.004977822	10.20547254
294.4670065	0.004946064	10.42189953
295.4670065	0.004914508	10.64291626
296.4670065	0.004883153	10.86862009
297.4670065	0.004851998	11.09911042
298.4670065	0.004821042	11.33448873
299.4670065	0.004790283	11.57485871
300.4670065	0.004759721	11.8203262
301.4670065	0.004729354	12.07099931
302.4670065	0.00469918	12.32698843
303.4670065	0.004669199	12.5884063
304.4670065	0.00463941	12.85536804
305.4670065	0.00460981	13.12799124
306.4670065	0.004580399	13.40639593
307.4670065	0.004551176	13.69070475
308.4670065	0.004522139	13.98104289
309.4670065	0.004493288	14.27753821
310.4670065	0.00446462	14.5803213
311.4670065	0.004436136	14.8895255
312.4670065	0.004407833	15.20528697
313.4670065	0.004379711	15.52774479
314.4670065	0.004351768	15.85704095
315.4670065	0.004324004	16.19332048
316.4670065	0.004296416	16.53673147
317.4670065	0.004269005	16.88742517
318.4670065	0.004241768	17.245556
319.4670065	0.004214706	17.61128171
320.4670065	0.004187816	17.98476334
321.4670065	0.004161097	18.36616538
322.4670065	0.004134549	18.75565579
323.4670065	0.004108171	19.15340611
324.4670065	0.00408196	19.55959151
325.4670065	0.004055917	19.97439085
326.4670065	0.00403004	20.39798683
327.4670065	0.004004328	20.83056599
328.4670065	0.00397878	21.27231883
329.4670065	0.003953396	21.72343991
330.4670065	0.003928173	22.18412789
331.4670065	0.003903111	22.65458565
332.4670065	0.003878209	23.1350204

Table 5 (continued)

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
333.4670065	0.003853466	23.6256437
334.4670065	0.00382888	24.12667163
335.4670065	0.003804452	24.63832483
336.4670065	0.003780179	25.16082864
337.4670065	0.003756062	25.69441316
338.4670065	0.003732098	26.23931338
339.4670065	0.003708287	26.79576928
340.4670065	0.003684628	27.36402591
341.4670065	0.00366112	27.94433354
342.4670065	0.003637761	28.53694772
343.4670065	0.003614552	29.14212944
344.4670065	0.003591491	29.76014523
345.4670065	0.003568577	30.39126724
346.4670065	0.00354581	31.03577343
347.4670065	0.003523187	31.69394763
348.4670065	0.003500709	32.36607971
349.4670065	0.003478374	33.05246565
350.4670065	0.003456182	33.75340775
351.4670065	0.003434132	34.4692147
352.4670065	0.003412222	35.20020173
353.4670065	0.003390451	35.94669077
354.4670065	0.00336882	36.70901057
355.4670065	0.003347327	37.48749685
356.4670065	0.003325971	38.28249245
357.4670065	0.003304751	39.09434749
358.4670065	0.003283667	39.9234195
359.4670065	0.003262717	40.7700736
360.4670065	0.0032419	41.63468265
361.4670065	0.003221217	42.51762743
362.4670065	0.003200665	43.41929678
363.4670065	0.003180245	44.34008778
364.4670065	0.003159955	45.28040596
365.4670065	0.003139794	46.24066542
366.4670065	0.003119762	47.22128906
367.4670065	0.003099858	48.22270874

Table 6 Estimates of mortality rates and individual fresh weight for daily intervals during the first year of life for black drum larvae and juveniles. For calculation details, see Appendix 1

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
1.467006485	0.890800801	5.1006E-05
2.467006485	0.809859163	7.64197E-05
3.467006485	0.740384809	0.000111821
4.467006485	0.680239149	0.00016021
5.467006485	0.627767965	0.000225242
6.467006485	0.581674272	0.000311323
7.467006485	0.540928696	0.000423711
8.467006485	0.504705182	0.000568627
9.467006485	0.472334144	0.000753371
10.46700648	0.443267818	0.000986449
11.46700648	0.417054311	0.001277709
12.46700648	0.39331792	0.001638475
13.46700648	0.371744045	0.002081707
14.46700648	0.352067496	0.00262215
15.46700648	0.334063359	0.003276506
16.46700648	0.317539777	0.004063609
17.46700648	0.302332216	0.005004605
18.46700648	0.288298869	0.006123148
19.46700648	0.275316937	0.007445598
20.46700648	0.263279613	0.009001234
21.46700648	0.252093618	0.010822473
22.46700648	0.241677163	0.012945095
23.46700648	0.231958269	0.015408481
24.46700648	0.222873373	0.018255863
25.46700648	0.214366153	0.021534576
26.46700648	0.206386551	0.025296323
27.46700648	0.19888994	0.029597453
28.46700648	0.191836423	0.034499239
29.46700648	0.185190237	0.04006818
30.46700648	0.026739553	0.041211109
31.46700648	0.026511156	0.042386639
32.46700648	0.02628471	0.043595701
33.46700648	0.026060198	0.044839252
34.46700648	0.025837603	0.046118274
35.46700648	0.02561691	0.047433779
36.46700648	0.025398102	0.048786809
37.46700648	0.025181163	0.050178434
38.46700648	0.024966077	0.051609754
39.46700648	0.024752828	0.053081902
40.46700648	0.024541401	0.054596042
41.46700648	0.024331779	0.056153373
42.46700648	0.024123948	0.057755126
43.46700648	0.023917893	0.059402568
44.46700648	0.023713597	0.061097003
45.46700648	0.023511046	0.062839771

Table 6 (continued)

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
46.46700648	0.023310225	0.06463225
47.46700648	0.02311112	0.06647586
48.46700648	0.022913715	0.068372057
49.46700648	0.022717997	0.070322344
50.46700648	0.02252395	0.072328261
51.46700648	0.022331561	0.074391396
52.46700648	0.022140815	0.076513381
53.46700648	0.021951698	0.078695895
54.46700648	0.021764196	0.080940665
55.46700648	0.021578297	0.083249465
56.46700648	0.021393985	0.085624123
57.46700648	0.021211247	0.088066518
58.46700648	0.02103007	0.090578581
59.46700648	0.020850441	0.093162299
60.46700648	0.020672346	0.095819717
61.46700648	0.020495772	0.098552937
62.46700648	0.020320707	0.10136412
63.46700648	0.020147136	0.104255492
64.46700648	0.019975049	0.107229339
65.46700648	0.019804431	0.110288013
66.46700648	0.01963527	0.113433936
67.46700648	0.019467555	0.116669594
68.46700648	0.019301272	0.119997548
69.46700648	0.019136409	0.123420431
70.46700648	0.018972955	0.12694095
71.46700648	0.018810896	0.130561891
72.46700648	0.018650222	0.134286117
73.46700648	0.018490921	0.138116576
74.46700648	0.018332979	0.142056297
75.46700648	0.018176388	0.146108397
76.46700648	0.018021133	0.150276081
77.46700648	0.017867205	0.154562648
78.46700648	0.017714591	0.158971486
79.46700648	0.017563281	0.163506085
80.46700648	0.017413264	0.168170032
81.46700648	0.017264528	0.172967016
82.46700648	0.017117062	0.177900832
83.46700648	0.016970856	0.182975383
84.46700648	0.016825898	0.188194684
85.46700648	0.016682179	0.193562863
86.46700648	0.016539688	0.199084168
87.46700648	0.016398413	0.204762965
88.46700648	0.016258345	0.210603748
89.46700648	0.016119474	0.216611137
90.46700648	0.015981789	0.222789885
91.46700648	0.01584528	0.229144878

Table 6 (continued)

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
92.46700648	0.015709936	0.235681146
93.46700648	0.015575749	0.242403858
94.46700648	0.015442708	0.249318332
95.46700648	0.015310804	0.25643004
96.46700648	0.015180026	0.263744606
97.46700648	0.015050365	0.271267817
98.46700648	0.014921812	0.279005624
99.46700648	0.014794356	0.28696415
100.4670065	0.01466799	0.295149689
101.4670065	0.014542702	0.303568718
102.4670065	0.014418485	0.312227896
103.4670065	0.014295329	0.321134074
104.4670065	0.014173225	0.330294297
105.4670065	0.014052164	0.339715812
106.4670065	0.013932136	0.349406072
107.4670065	0.013813134	0.359372742
108.4670065	0.013695149	0.369623708
109.4670065	0.013578171	0.380167079
110.4670065	0.013462193	0.391011195
111.4670065	0.013347205	0.402164636
112.4670065	0.013233199	0.413636224
113.4670065	0.013120167	0.425435034
114.4670065	0.0130081	0.437570401
115.4670065	0.012896991	0.450051924
116.4670065	0.012786831	0.462889478
117.4670065	0.012677612	0.476093218
118.4670065	0.012569325	0.48967359
119.4670065	0.012461964	0.503641336
120.4670065	0.012355519	0.518007507
121.4670065	0.012249984	0.532783467
122.4670065	0.01214535	0.547980906
123.4670065	0.01204161	0.563611846
124.4670065	0.011938756	0.579688652
125.4670065	0.011836781	0.596224042
126.4670065	0.011735677	0.613231098
127.4670065	0.011635436	0.630723274
128.4670065	0.011536051	0.648714407
129.4670065	0.011437515	0.66721873
130.4670065	0.011339821	0.686250882
131.4670065	0.011242962	0.705825918
132.4670065	0.011146929	0.725959325
133.4670065	0.011051717	0.746667029
134.4670065	0.010957319	0.767965412
135.4670065	0.010863726	0.789871323
136.4670065	0.010770933	0.812402091
137.4670065	0.010678933	0.835575541

Table 6 (continued)

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
138.4670065	0.010587718	0.859410004
139.4670065	0.010497283	0.883924336
140.4670065	0.01040762	0.90913793
141.4670065	0.010318723	0.935070732
142.4670065	0.010230585	0.961743256
143.4670065	0.0101432	0.989176604
144.4670065	0.010056561	1.017392477
145.4670065	0.009970663	1.046413197
146.4670065	0.009885498	1.076261722
147.4670065	0.00980106	1.106961663
148.4670065	0.009717344	1.138537309
149.4670065	0.009634343	1.171013638
150.4670065	0.009552051	1.204416341
151.4670065	0.009470462	1.238771843
152.4670065	0.009389569	1.274107322
153.4670065	0.009309368	1.310450732
154.4670065	0.009229851	1.347830823
155.4670065	0.009151014	1.386277166
156.4670065	0.00907285	1.425820177
157.4670065	0.008995354	1.466491136
158.4670065	0.00891852	1.508322218
159.4670065	0.008842342	1.551346516
160.4670065	0.008766815	1.595598065
161.4670065	0.008691933	1.641111871
162.4670065	0.00861769	1.687923941
163.4670065	0.008544082	1.736071307
164.4670065	0.008471102	1.785592058
165.4670065	0.008398746	1.836525368
166.4670065	0.008327008	1.888911532
167.4670065	0.008255882	1.942791989
168.4670065	0.008185364	1.998209366
169.4670065	0.008115448	2.055207502
170.4670065	0.00804613	2.113831487
171.4670065	0.007977404	2.174127698
172.4670065	0.007909264	2.236143834
173.4670065	0.007841707	2.299928957
174.4670065	0.007774727	2.365533525
175.4670065	0.007708318	2.433009437
176.4670065	0.007642477	2.502410074
177.4670065	0.007577199	2.573790336
178.4670065	0.007512478	2.647206692
179.4670065	0.00744831	2.722717221
180.4670065	0.00738469	2.800381658
181.4670065	0.007321613	2.880261442
182.4670065	0.007259075	2.962419766
183.4670065	0.007197071	3.046921623
184.4670065	0.007135597	3.133833863
185.4670065	0.007074648	3.223225241
186.4670065	0.00701422	3.315166472
187.4670065	0.006954308	3.40973029
188.4670065	0.006894907	3.506991504
189.4670065	0.006836014	3.607027056
190.4670065	0.006777624	3.709916083
191.4670065	0.006719732	3.815739979
192.4670065	0.006662335	3.92458246
193.4670065	0.006605429	4.036529629
194.4670065	0.006549008	4.151670048
195.4670065	0.00649307	4.270094802
196.4670065	0.006437609	4.391897575
197.4670065	0.006382622	4.517174724
198.4670065	0.006328104	4.646025355
199.4670065	0.006274052	4.778551399
200.4670065	0.006220462	4.914857697
201.4670065	0.00616733	5.055052078
202.4670065	0.006114651	5.199245448
203.4670065	0.006062423	5.347551878
204.4670065	0.00601064	5.50008869
205.4670065	0.0059593	5.656976555
206.4670065	0.005908399	5.818339584
207.4670065	0.005857932	5.98430543
208.4670065	0.005807896	6.155005387
209.4670065	0.005758288	6.330574492
210.4670065	0.005709103	6.511151637
211.4670065	0.005660338	6.696879675
212.4670065	0.00561199	6.887905531
213.4670065	0.005564055	7.084380325
214.4670065	0.00551653	7.286459485
215.4670065	0.00546941	7.494302873
216.4670065	0.005422693	7.708074912
217.4670065	0.005376375	7.927944714
218.4670065	0.005330452	8.154086216
219.4670065	0.005284922	8.386678316
220.4670065	0.00523978	8.625905013
221.4670065	0.005195024	8.871955558
222.4670065	0.005150651	9.125024597
223.4670065	0.005106656	9.385312332
224.4670065	0.005063038	9.653024671
225.4670065	0.005019792	9.9283734
226.4670065	0.004976915	10.21157634
227.4670065	0.004934404	10.50285754
228.4670065	0.004892257	10.80244741
229.4670065	0.004850469	11.11058297

Table 6 (continued)

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
230.4670065	0.004809039	11.42750798
231.4670065	0.004767962	11.75347315
232.4670065	0.004727236	12.08873634
233.4670065	0.004686859	12.43356279
234.4670065	0.004646826	12.78822527
235.4670065	0.004607134	13.15300436
236.4670065	0.004567782	13.52818863
237.4670065	0.004528766	13.91407489
238.4670065	0.004490084	14.3109684
239.4670065	0.004451732	14.71918314
240.4670065	0.004413707	15.13904204
241.4670065	0.004376007	15.57087725
242.4670065	0.004338629	16.0150304
243.4670065	0.004301571	16.47185284
244.4670065	0.004264829	16.94170595
245.4670065	0.0042284	17.42496145
246.4670065	0.004192283	17.92200161
247.4670065	0.004156475	18.43321965
248.4670065	0.004120972	18.95901999
249.4670065	0.004085772	19.49981857
250.4670065	0.004050874	20.05604322
251.4670065	0.004016273	20.62813395
252.4670065	0.003981968	21.21654335
253.4670065	0.003947956	21.8217369
254.4670065	0.003914234	22.44419336
255.4670065	0.0038808	23.08440514
256.4670065	0.003847652	23.7428787
257.4670065	0.003814787	24.42013497
258.4670065	0.003782203	25.11670971
259.4670065	0.003749897	25.83315397
260.4670065	0.003717867	26.57003451
261.4670065	0.003686111	27.32793429
262.4670065	0.003654626	28.10745285
263.4670065	0.00362341	28.90920688
264.4670065	0.00359246	29.73383063
265.4670065	0.003561775	30.58197644
266.4670065	0.003531352	31.45431528
267.4670065	0.003501189	32.35153724
268.4670065	0.003471283	33.2743521
269.4670065	0.003441633	34.2234899
270.4670065	0.003412236	35.19970148
271.4670065	0.003383091	36.2037591
272.4670065	0.003354194	37.23645708
273.4670065	0.003325544	38.29861236
274.4670065	0.003297139	39.3910652
275.4670065	0.003268976	40.51467983
276.4670065	0.003241054	41.67034512
277.4670065	0.00321337	42.85897531
278.4670065	0.003185923	44.08151071
279.4670065	0.00315871	45.33891845
280.4670065	0.00313173	46.63219325
281.4670065	0.00310498	47.9623582
282.4670065	0.003078459	49.33046559
283.4670065	0.003052164	50.7375977
284.4670065	0.003026094	52.1848677
285.4670065	0.003000246	53.67342051
286.4670065	0.00297462	55.2044337
287.4670065	0.002949212	56.77911844
288.4670065	0.002924021	58.39872044
289.4670065	0.002899045	60.06452095
290.4670065	0.002874283	61.77783776
291.4670065	0.002849732	63.54002626
292.4670065	0.002825391	65.3524805
293.4670065	0.002801258	67.21663428
294.4670065	0.002777331	69.13396231
295.4670065	0.002753608	71.10598137
296.4670065	0.002730088	73.13425149
297.4670065	0.002706769	75.22037723
298.4670065	0.002683649	77.36600888
299.4670065	0.002660726	79.57284382
300.4670065	0.002638	81.84262787
301.4670065	0.002615467	84.17715661
302.4670065	0.002593127	86.57827686
303.4670065	0.002570978	89.04788813
304.4670065	0.002549017	91.58794408
305.4670065	0.002527245	94.20045413
306.4670065	0.002505658	96.887485
307.4670065	0.002484256	99.65116237
308.4670065	0.002463037	102.4936725
309.4670065	0.002441999	105.4172642
310.4670065	0.00242114	108.4242502
311.4670065	0.00240046	111.5170092
312.4670065	0.002379956	114.697988
313.4670065	0.002359628	117.969703
314.4670065	0.002339473	121.3347423
315.4670065	0.00231949	124.7957681
316.4670065	0.002299678	128.3555182
317.4670065	0.002280035	132.0168088
318.4670065	0.00226056	135.7825363
319.4670065	0.002241252	139.6556797
320.4670065	0.002222108	143.639303
321.4670065	0.002203128	147.7365576

Table 6 (continued)

Age (days)	Mortality rate (day^{-1})	Fresh weight per individual (grams; dry to fresh weight conversion: 0.22 g DW to 1 g FW)
322.4670065	0.00218431	151.9506847
323.4670065	0.002165652	156.2850182
324.4670065	0.002147154	160.7429868
325.4670065	0.002128814	165.3281172
326.4670065	0.002110631	170.0440367
327.4670065	0.002092603	174.8944759
328.4670065	0.002074729	179.883272
329.4670065	0.002057007	185.0143715
330.4670065	0.002039437	190.2918336
331.4670065	0.002022017	195.7198332
332.4670065	0.002004746	201.3026644
333.4670065	0.001987623	207.0447437
334.4670065	0.001970645	212.9506135
335.4670065	0.001953813	219.0249459
336.4670065	0.001937124	225.2725463
337.4670065	0.001920578	231.698357
338.4670065	0.001904174	238.3074614
339.4670065	0.001887909	245.1050879
340.4670065	0.001871783	252.0966141
341.4670065	0.001855795	259.2875707
342.4670065	0.001839944	266.6836466
343.4670065	0.001824228	274.2906927
344.4670065	0.001808646	282.1147267
345.4670065	0.001793198	290.1619382
346.4670065	0.001777881	298.4386933
347.4670065	0.001762695	306.9515395
348.4670065	0.001747639	315.7072113
349.4670065	0.001732711	324.7126352
350.4670065	0.001717911	333.9749353
351.4670065	0.001703238	343.5014389
352.4670065	0.00168869	353.2996822
353.4670065	0.001674266	363.3774166
354.4670065	0.001659965	373.7426143
355.4670065	0.001645786	384.4034752
356.4670065	0.001631728	395.3684331
357.4670065	0.001617791	406.646162
358.4670065	0.001603973	418.2455836
359.4670065	0.001590272	430.1758743
360.4670065	0.001576689	442.4464717
361.4670065	0.001563221	455.0670832
362.4670065	0.001549869	468.0476926
363.4670065	0.001536631	481.3985687
364.4670065	0.001523506	495.1302734
365.4670065	0.001510493	509.2536695
366.4670065	0.001497591	523.77993
367.4670065	0.001484799	538.7205463

Table 7 Number of density records arranged by source (paper); habitat; sampling time; and gear type for the four species studied here. For full reference of sources, see Hollweg, T.A., M.C. Christman, J. Cebrian, B.P. Wallace, S.L. Friedman, H.R. Ballestero, M.T. Huisenga, and K.G. Benson. 2019. Meta-analysis of nekton utilization of coastal habitats in the northern Gulf of Mexico. Estuaries and Coasts (in press)

Pinfish (*Lagodon rhomboides*)		
Arranged by source		
Source	Frequency	Cumulative frequency
Anton et al. (2009)[a]	10	10
Burfeind and Stunz (2006)[a]	12	22
Cebrian et al. (2009)[a]	2	24
Gain (2009)[a]	6	30
Gordon (2010)[a]	3	33
Hoese and Jones (1963)[a]	12	45
King and Sheridan (2006)[a]	12	57
Merino et al. (2010)[a]	8	65
Minello and Webb (1997)[a]	3	68
Minello et al. (1991)[a]	12	80
Reese et al. (2008)[a]	2	82
Rozas and Minello (1998)[a]	6	88
Rozas and Minello (2007)[a]	9	97
Rozas et al. (2005)[a]	3	100
Rozas et al. (2007)[a]	24	124
Rozas et al. (2012)[a]	7	131
Rozas et al. (2013)[a]	3	134
Sheridan (2004)[a]	3	137
Sheridan and Minello (2003)[a]	3	140
Stoner (1983)	33	173
Stunz et al. (2010)[a]	6	179
Subrahmanyam and Drake (1975)[a]	3	182
Zimmerman and Minello (1984)	22	204
Zimmerman et al. (1989)[a]	6	210
Zimmerman et al. (1990a)[a]	20	230
Zimmerman et al. (1990b)[a]	48	278
Arranged by habitat		
Habitat	Frequency	Cumulative frequency
Near non-vegetated	50	50
Far non-vegetated	17	67
Near & far non-vegetated	32	99
SAV	92	191
Oyster reefs	4	195
Marshes	83	278
Arranged by sampling time		
Time	Frequency	Cumulative frequency
January	10	10
February	12	22
March	16	38
April	21	59
May	87	146
June	22	168
July	27	195
August	10	205
September	20	225
October	29	254
November	12	266

Table 7 (continued)

December	12	278
Arranged by gear type		
Gear	Frequency	Cumulative frequency
Beam trawl	10	10
Drop net	12	22
Drop sampler	177	199
Epibenthic sled	14	213
Otter trawl	33	246
Seine	5	251
Throw trap	24	275
Trawl	3	278
Black drum (*Pogonias cromis*)		
Arranged by source		
Source	Frequency	Cumulative frequency
Gordon (2010)	3	3
La Peyre and Birdsong (2008)[a]	4	7
Scott (1998)[a]	8	15
Zimmerman and Minello (1984)[a]	22	37
Arranged by habitat		
Habitat	Frequency	Cumulative frequency
Near non-vegetated	20	20
Far non-vegetated	2	22
SAV	4	26
Marshes	11	37
Arranged by sampling time		
Time	Frequency	Cumulative frequency
February	2	2
March	4	6
March, April, and May	6	12
April	2	14
May	2	16
June	5	21
June, July, and August	4	25
July	2	27
August	2	29
September, October, and November	2	31
October	2	33
November	2	35
December	2	37
Arranged by gear type		
Gear	Frequency	Cumulative frequency
Drop sampler	22	22
Seine	4	26
Throw trap	11	37
Mud crab (*Rhithropanopeus harrisii*)		
Arranged by source		
Source	Frequency	Cumulative frequency
Duque (2004)[a]	2	2
Glancy et al. (2003)[a]	6	8
La Peyre et al. (2013a)[a]	9	17
Minello (1999)[a]	6	23
Minello et al. (1991)[a]	6	29
Peterson et al. (2000)[a]	3	32
Reed et al. (2007)[a]	10	42
Roth and Baltz (2009)	1	43
Rozas and Minello (1998)	6	49
Rozas and Minello (1999)[a]	2	51
Rozas and Minello (2006)[a]	12	63
Rozas and Zimmerman (2000)[a]	7	70
Rozas et al. (2005)[a]	3	73
Rozas et al. (2013)[a]	9	82
Shervette and Gelwick (2008)[a]	3	85
Stunz et al. (2010)[a]	3	88
Zeug et al. (2007)	1	89
Zimmerman et al. (1990a)[a]	27	116
Zimmerman et al. (1990b)[a]	46	162
Arranged by habitat		
Habitat	Frequency	Cumulative frequency
Near non-vegetated	45	45
Far non-vegetated	9	54
Near & far non-vegetated	21	75
SAV	22	97
Oyster reefs	4	101
Marshes	61	162
Arranged by sampling time		
Time	Frequency	Cumulative frequency
March and April	3	3
March, April, and May	1	4
April	4	8
April and May	5	13
May	45	58
June	8	66
July	4	70
July and August	3	73
September	21	94
October	14	108
October and November	4	112
November	16	128
Month not specified	7	135
Spring and Summer	5	140
Spring and Fall	5	145
Spring, Summer, and Fall	4	149
Spring, Summer, and Winter	2	151
Spring, Summer, Fall, and Winter	11	162
Arranged by gear type		
Gear	Frequency	Cumulative frequency
Drop sampler	144	144
Drop sampler / throw trap	3	147
Seine	9	156
Throw trap	6	162
Gulf stone crab (*Menippe adina*)		
Arranged by source		
Source	Frequency	Cumulative frequency
Caudill (2005)	3	3
Gain (2009)[a]	3	6
Minello (1999)[a]	6	12
Peterson and Stricklin (2008)	18	30
Roth and Baltz (2009)	1	31
Shervette and Gelwick (2008)[a]	3	34
Arranged by habitat		
Habitat	Frequency	Cumulative frequency
Near non-vegetated	1	1
Near & far non-vegetated	2	3

Table 7 (continued)

SAV	2	5
Oyster reefs	21	26
Marshes	8	34
Arranged by sampling time		
Time	Frequency	Cumulative frequency
February	3	3
March	3	6
March, April, and May	1	7
May	3	10
August	3	13
August, September, and October	1	14
November	6	20
December	3	23
Spring and Summer	1	24
Spring, Summer, and Fall	4	28
Spring, Summer, Fall, and Winter	6	34
Arranged by gear type		
Gear	Frequency	Cumulative frequency
Drop sampler	10	10
Lift net	3	13
Substrate tray	18	31
Throw trap	3	34

[a] see Table S6

Appendix 3

Number of density records arranged by source (paper); habitat; sampling time; and gear type for the four species studied here. For full reference of sources, see Hollweg, T.A., M.C. Christman, J. Cebrian, B.P. Wallace, S.L. Friedman, H.R. Ballestero, M.T. Huisenga, and K.G. Benson. 2019. Meta-analysis of nekton utilization of coastal habitats in the northern Gulf of Mexico. Estuaries and Coasts (in press). Unique combinations of habitat, sampling time, and gear type for the four species studied here. The number of records for the combinations is also provided (Tables 7 and 8)

Table 8 Unique combinations of habitat, sampling time, and gear type for the four species studied here. The number of records for the combinations is also provided

Habitat	Time	Gear	Frequency	Cumulative Frequency
Pinfish (*Lagodon rhomboides*)				
Near non-vegetated	February	Drop sampler	2	2
Near non-vegetated	March	Drop sampler	2	4
Near non-vegetated	April	Drop sampler	3	7
Near non-vegetated	May	Drop sampler	20	27
Near non-vegetated	June	Drop sampler	5	32
Near non-vegetated	June	Throw trap	3	35
Near non-vegetated	July	Drop sampler	7	42
Near non-vegetated	August	Drop sampler	1	43
Near non-vegetated	October	Drop sampler	5	48
Near non-vegetated	November	Drop sampler	1	49
Near non-vegetated	December	Drop sampler	1	50
Far non-vegetated	February	Drop sampler	1	51
Far non-vegetated	May	Drop sampler	14	65
Far non-vegetated	September	Drop sampler	1	66
Far non-vegetated	October	Drop sampler	1	67
Near & far non-vegetated	January	Drop sampler	1	68
Near & far non-vegetated	February	Drop sampler	1	69
Near & far non-vegetated	March	Drop sampler	1	70
Near & far non-vegetated	March	Seine	1	71
Near & far non-vegetated	April	Drop sampler	1	72
Near & far non-vegetated	April	Seine	1	73
Near & far non-vegetated	April	Throw trap	1	74
Near & far non-vegetated	May	Drop sampler	5	79
Near & far non-vegetated	May	Trawl	3	82
Near & far non-vegetated	June	Drop sampler	1	83
Near & far non-vegetated	June	Seine	1	84

Table 8 (continued)

Habitat	Time	Gear	Frequency	Cumulative Frequency
Near & far non-vegetated	July	Drop sampler	2	86
Near & far non-vegetated	July	Throw trap	1	87
Near & far non-vegetated	August	Drop sampler	1	88
Near & far non-vegetated	September	Drop sampler	3	91
Near & far non-vegetated	September	Seine	1	92
Near & far non-vegetated	October	Drop sampler	1	93
Near & far non-vegetated	October	Seine	1	94
Near & far non-vegetated	October	Throw trap	1	95
Near & far non-vegetated	November	Drop sampler	1	96
Near & far non-vegetated	December	Drop sampler	2	98
Near & far non-vegetated	December	Throw trap	1	99
SAV	January	Drop net	1	100
SAV	January	Epibenthic sled	4	104
SAV	January	Otter trawl	3	107
SAV	February	Drop net	1	108
SAV	February	Epibenthic sled	1	109
SAV	February	Otter trawl	3	112
SAV	March	Drop net	1	113
SAV	March	Epibenthic sled	4	117
SAV	March	Otter trawl	3	120
SAV	April	Beam trawl	1	121
SAV	April	Drop net	1	122
SAV	April	Drop sampler	3	125
SAV	April	Otter trawl	3	128
SAV	April	Throw trap	3	131
SAV	May	Beam trawl	1	132
SAV	May	Drop net	1	133
SAV	May	Drop sampler	3	136
SAV	May	Epibenthic sled	1	137
SAV	May	Otter trawl	3	140
SAV	May	Throw trap	2	142
SAV	June	Beam trawl	1	143
SAV	June	Drop net	1	144
SAV	June	Otter trawl	3	147
SAV	July	Drop net	1	148
SAV	July	Otter trawl	3	151
SAV	July	Throw trap	3	154
SAV	August	Beam trawl	2	156
SAV	August	Drop net	1	157
SAV	August	Otter trawl	3	160
SAV	September	Beam trawl	1	161
SAV	September	Drop net	1	162
SAV	September	Drop sampler	4	166
SAV	September	Otter trawl	3	169
SAV	October	Beam trawl	2	171
SAV	October	Drop net	1	172
SAV	October	Epibenthic sled	4	176
SAV	October	Otter trawl	3	179
SAV	October	Throw trap	2	181

Table 8 (continued)

Habitat	Time	Gear	Frequency	Cumulative Frequency
SAV	November	Beam trawl	1	182
SAV	November	Drop net	1	183
SAV	November	Otter trawl	3	186
SAV	November	Throw trap	1	187
SAV	December	Beam trawl	1	188
SAV	December	Drop net	1	189
SAV	December	Throw trap	2	191
Oyster reefs	May	Throw trap	1	192
Oyster reefs	July	Drop sampler	1	193
Oyster reefs	November	Throw trap	1	194
Oyster reefs	December	Drop sampler	1	195
Marshes	January	Drop sampler	1	196
Marshes	February	Drop sampler	3	199
Marshes	March	Drop sampler	4	203
Marshes	April	Drop sampler	4	207
Marshes	May	Drop sampler	32	239
Marshes	May	Throw trap	1	240
Marshes	June	Drop sampler	7	247
Marshes	July	Drop sampler	9	256
Marshes	August	Drop sampler	2	258
Marshes	September	Drop sampler	6	264
Marshes	October	Drop sampler	8	272
Marshes	November	Drop sampler	2	274
Marshes	November	Throw trap	1	275
Marshes	December	Drop sampler	3	278
Black drum (*Pogonias cromis*)				
Near non-vegetated	February	Drop sampler	1	1
Near non-vegetated	March	Drop sampler	2	3
Near non-vegetated	March, April, and May	Seine	2	5
Near non-vegetated	March, April, and May	Throw trap	1	6
Near non-vegetated	April	Drop sampler	1	7
Near non-vegetated	May	Drop sampler	1	8
Near non-vegetated	June	Drop sampler	1	9
Near non-vegetated	June	Throw trap	3	12
Near non-vegetated	June, July, and August	Throw trap	1	13
Near non-vegetated	July	Drop sampler	1	14
Near non-vegetated	August	Drop sampler	1	15
Near non-vegetated	September, October, and November	Seine	2	17
Near non-vegetated	October	Drop sampler	1	18
Near non-vegetated	November	Drop sampler	1	19
Near non-vegetated	December	Drop sampler	1	20
Far non-vegetated	March, April, and May	Throw trap	1	21
Far non-vegetated	June, July, and August	Throw trap	1	22
SAV	March, April, and May	Throw trap	2	24
SAV	June, July, and August	Throw trap	2	26
Marshes	February	Drop sampler	1	27
Marshes	March	Drop sampler	2	29
Marshes	April	Drop sampler	1	30
Marshes	May	Drop sampler	1	31

Table 8 (continued)

Habitat	Time	Gear	Frequency	Cumulative Frequency
Marshes	June	Drop sampler	1	32
Marshes	July	Drop sampler	1	33
Marshes	August	Drop sampler	1	34
Marshes	October	Drop sampler	1	35
Marshes	November	Drop sampler	1	36
Marshes	December	Drop sampler	1	37
Mud crab (*Rhithropanopeus harrisii*)				
Near non-vegetated	March and April	Throw trap	1	1
Near non-vegetated	March, April, and May	Drop sampler	1	2
Near non-vegetated	April	Drop sampler	2	4
Near non-vegetated	May	Drop sampler	13	17
Near non-vegetated	June	Drop sampler	4	21
Near non-vegetated	July	Drop sampler	2	23
Near non-vegetated	July and August	Throw trap	1	24
Near non-vegetated	September	Drop sampler	2	26
Near non-vegetated	October	Drop sampler	4	30
Near non-vegetated	October	Drop sampler / throw trap*	3	33
Near non-vegetated	October and November	Drop sampler	2	35
Near non-vegetated	November	Drop sampler	8	43
Near non-vegetated	Spring, Summer, Fall, and Winter	Drop sampler	2	45
Far non-vegetated	May	Drop sampler	2	47
Far non-vegetated	September	Drop sampler	4	51
Far non-vegetated	October	Drop sampler	1	52
Far non-vegetated	Spring, Summer, Fall, and Winter	Drop sampler	2	54
Near & far non-vegetated	April and May	Drop sampler	2	56
Near & far non-vegetated	May	Drop sampler	4	60
Near & far non-vegetated	September	Drop sampler	3	63
Near & far non-vegetated	Spring and Summer	Seine	5	68
Near & far non-vegetated	Spring and Fall	Drop sampler	1	69
Near & far non-vegetated	Spring and Fall	Seine	2	71
Near & far non-vegetated	Spring, Summer, and Fall	Drop sampler	1	72
Near & far non-vegetated	Spring, Summer, and Winter	Seine	2	74
Near & far non-vegetated	Spring, Summer, Fall, and Winter	Drop sampler	1	75
SAV	March and April	Throw trap	1	76
SAV	May	Drop sampler	6	82
SAV	July and August	Throw trap	1	83
SAV	September	Drop sampler	4	87
SAV	October	Drop sampler	1	88
SAV	Month not specified	Drop sampler	7	95
SAV	Spring and Fall	Drop sampler	1	96
SAV	Spring, Summer, Fall, and Winter	Drop sampler	1	97
Oyster reefs	March and April	Throw trap	1	98
Oyster reefs	July and August	Throw trap	1	99
Oyster reefs	Spring, Summer, and Fall	Drop sampler	1	100
Oyster reefs	Spring, Summer, Fall, and Winter	Drop sampler	1	101
Marshes	April	Drop sampler	2	103
Marshes	April and May	Drop sampler	3	106

Table 8 (continued)

Habitat	Time	Gear	Frequency	Cumulative Frequency
Marshes	May	Drop sampler	20	126
Marshes	June	Drop sampler	4	130
Marshes	July	Drop sampler	2	132
Marshes	September	Drop sampler	8	140
Marshes	October	Drop sampler	5	145
Marshes	October and November	Drop sampler	2	147
Marshes	November	Drop sampler	8	155
Marshes	Spring and Fall	Drop sampler	1	156
Marshes	Spring, Summer, and Fall	Drop sampler	2	158
Marshes	Spring, Summer, Fall, and Winter	Drop sampler	4	162
Gulf Stone crab (*Menippe adina*)				
Near non-vegetated	March, April, and May	Drop sampler	1	1
Near & far non-vegetated	Spring, Summer, and Fall	Drop sampler	1	2
Near & far non-vegetated	Spring, Summer, Fall, and Winter	Drop sampler	1	3
SAV	November	Throw trap	1	4
SAV	Spring, Summer, Fall, and Winter	Drop sampler	1	5
Oyster reefs	February	Substrate tray	3	8
Oyster reefs	March	Substrate tray	3	11
Oyster reefs	May	Substrate tray	3	14
Oyster reefs	August	Substrate tray	3	17
Oyster reefs	November	Substrate tray	3	20
Oyster reefs	November	Throw trap	1	21
Oyster reefs	December	Substrate tray	3	24
Oyster reefs	Spring, Summer, and Fall	Drop sampler	1	25
Oyster reefs	Spring, Summer, Fall, and Winter	Drop sampler	1	26
Marshes	August, September, and October	Lift net	1	27
Marshes	November	Throw trap	1	28
Marshes	Spring and Summer	Lift net	1	29
Marshes	Spring, Summer, and Fall	Drop sampler	1	30
Marshes	Spring, Summer, and Fall	Lift net	1	31
Marshes	Spring, Summer, Fall, and Winter	Drop sampler	3	34

* This entry is not considered any further in the calculations to avoid mixing gear correction types

References

Aven, A.M., R.H. Carmichael, M.J. Ajemian, and S.P. Powers. 2015. Addition of passive acoustic telemetry mitigates lost data from satellite-tracked manatees. *Marine and Freshwater Research* 66 (4): 371–374.

Baker, R., and T.J. Minello. 2011. Trade-offs between gear selectivity and logistics when sampling nekton from shallow open water habitats: A gear comparison study. *Gulf and Caribbean Research* 23 (1): 37–48.

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, H.S. Lenihan, M.W. Luckenbach, C.L. Toropova, G. Zhangand, and X. Guo. 2011. Oyster reefs at risk and recommendations for conservation, restoration, and management. *BioScience* 61: 107–116.

Boyer, T.P., M. Biddle, M. Hamilton, A.V. Mishonov, C.R. Paver, D. Seidov, and M. Zweng. 2011. Gulf of Mexico Regional Climatology. *NOAA/NODC, dataset*. https://doi.org/10.7289/V5C53HSW.

Boyle, T., D. Keith, and R. Pfau. 2010. Occurrence, reproduction, and population genetics of the estuarine mud crab, *Rhithropanopeus harrisii* (Gould) (Decapoda, Panopidae) in Texas freshwater reservoirs. *Crustaceana* 83: 493–505.

Bradford, M.J. 1992. Precision of recruitment predictions from early life stages of marine fishes. *Fishery Bulletin* 90: 439–453.

Brown, J.H., J.F. Gillooly, A.P. Allen, V.M. Savage, and G.B. West. 2004. Toward a metabolical theory of ecology. *Ecology* 85: 1771–1789.

Casella, G., and R.L. Berger. 2002. *Statistical inference*. 2nd ed. Pacific Grove: Duxbury.

Caudill, M.C. 2005. *Nekton utilization of black mangrove (Avicennia germinans) and smooth cordgrass (Spartina alterniflora) sites in southwestern Caminada Bay*. Louisiana. M. S. Thesis: Louisiana State University, Baton Rouge, LA.

Cebrian, J., G.A. Miller, J.P. Stutes, A.L. Stutes, M. Miller, and K. 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: 57–61.

Cody, T. J., K. W. Rice and C. E. Bryan. 1985. Distribution and gonadal development of black drum in Texas gulf waters. Tex. Pks. Wildl. Dep., Coast Fish. Branch, Manage. Data Ser. No. 72. 16pp.

Cusson, M., and E. Bourget. 2005. Global patterns of macroinvertebrate production in marine benthic habitats. *Marine Ecology Progress Series* 297: 1–14.

Duarte, C.M., J.J. Middelburg, and N. Caraco. 2005. Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences* 2: 1–8.

Fourqurean, J.W., C.M. Duarte, H. Kennedy, N. Marbà, M. Holmer, M.A. Mateo, E.T. Apostolaki, G.A. Kendrick, D. Krause-Jensen, K.J. McGlathery, and O. Serrano. 2012. Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience* 5: 505–509.

French McCay, D.P., M. Gibson, and J.S. Cobb. 2003a. Scaling restoration of American lobsters: Combined demographic and discounting model for an exploited species. *Marine Ecology Progress Series* 264: 177–196.

French McCay, D.P., C.H. Peterson, J.T. DeAlteris, and J. Catena. 2003b. Restoration that targets function as opposed to structure: Replacing lost bivalve production and filtration. *Marine Ecology Progress Series* 264: 197–212.

French McCay, D. P, R. Balouskus, M. C. McManus, M. Schroeder, J. J. Rowe and E. Bohaboy. 2015. Technical Reports for Deepwater Horizon Water Column Injury Assessment: WC_TR.12: Evaluation of Production Foregone as the Result of Direct Kill of Fish and Invertebrate Individuals. Project Number: 2011–144. RPS ASA 55 Village Square Drive, South Kingstown, RI 02879, September 2015.

Gagnon, K., and C. Boström. 2016. Habitat expansion of the Harris mud crab *Rhithropanopeus harrisii* (Gould, 1841) in the northern Baltic Sea: Potential consequences for the eelgrass food web. *BioInvasions Records* 5 (2): 101–106.

Gerhart, S.D., and T.M. Bert. 2008. Life-history aspects of stone crabs (genus *Menippe*): Size at maturity, growth, and age. *Journal of Crustacean Biology* 28 (2): 252–261.

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

Gordon, J.A. 2010. *Impacts of marsh loss and fragmentation on microhabitat use by estuarine nekton in Southwest Louisiana*. MS Thesis: Louisiana State University.

Handley, L., D. Altsman and R. DeMay (Eds.). 2007. Seagrass Status and Trends in the Northern Gulf of Mexico: 1940–2002. Scientific Investigations Report 2006–5287. U.S. Environmental Protection Agency 855-R-04-003.

Hansen, D.J. 1969. Food, growth, migration, reproduction, and abundance of pinfish, Lagodon rhomboides, and Atlantic croaker, Micropogon undulatus, near Pensacola, Florida, 1963–65. *Fishery Bulletin* 68 (1): 135–146.

Hegele-Drywa, J., and M. Normant. 2009. Feeding ecology of the American crab *Rhithropanopeus harrisii* (Crustacea, Decapoda) in the coastal waters of the Baltic Sea. *Oceanologia* 51: 361–375.

Hilbe, J.M. 2014. *Modeling count data*. New York: Cambridge University Press.

Hollweg, T.A., M.C. Christman, J. Cebrian, B.P. Wallace, S.L. Friedman, H.R. Ballestero, M.T. Huisenga, and K.G. Benson. 2019. Meta-analysis of nekton utilization of coastal habitats in the northern Gulf of Mexico. *Estuaries and Coasts* (In Press).

Hoss, D.E. 1974. Energy requirement of a population of pinfish *Lagodon rhomboides* (Linneaus). *Ecology* 55: 848–855.

Houde, E.D. 1989. Comparative growth, mortality, and energetics of marine fish larvae: temperature and implied latitudinal effects. *Fishery Bulletin* 87: 471–495.

Jensen, A.L., R.H. Reider, and W.P. Kovalak. 1988. Estimation of production forgone. *North American Journal of Fisheries Management* 8: 191–198.

Jordan, F., M. Bartolini, C. Nelson, P.E. Patterson, and H.L. Soulen. 1996. Risk of predation affects habitat selection by the pinfish, *Lagodon rhomboides* (Linnaeus). *Journal of Experimental Marine Biology and Ecology* 208: 45–56.

Kennish, M.J. 1999. *Estuary restoration and maintenance: The National Estuary Program*. Boca Raton: CRC Press.

Ku, H. 1966. Notes on the use of propagation of error formulas. Journal of Research of the National Bureau of standards C. Engineering and Instrumentation 70 (C): 263–273.

Leard, R., R. Matheson, K. Meador, W. Keithly, C. Luquet, M. Van Hoose, C. Dyer, S. Gordon, J. Robertson, D. Horn, and R. Scheffler. 1993. The black drum fishery of the Gulf of Mexico, United States: A regional management plan. Gulf States Marine Fisheries Commission, Number 28, May 1993.

Lehrter, J.C., and J. Cebrian. 2010. Uncertainty propagation in an ecosystem nutrient budget. *Ecological Applications* 20: 508–524.

Lellis-Dibble, K. A., K. E. McGlynn and T. E. Bigford. 2008. Estuarine fish and shellfish species in US commercial and recreational fisheries: Economic value as an incentive to protect and restore estuarine habitat. National Oceanic and Atmospheric Administration. NOAA Technical Memorandum no. NMFS-F/SPO-90.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. *Journal of Fishery Biology* 49: 627–647.

Lotze, H.K., H.S. Lenihan, B.J. Bourque, R.H. Bradbury, R.G. Cooke, M.C. Kay, S.M. Kidwel, M.X. Kirby, C.H. Peterson, and J.B.C. Jackson. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* 312 (5781): 1806–1809.

Manis, J.E., S.K. Garvis, S.M. Jachec, and L.J. Walters. 2015. Wave attenuation experiments over living shorelines over time: A wave tank study to assess recreational boating pressures. *Journal of Coastal Conservation* 19: 1–11.

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.

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., L.P. Rozas, P.A. Caldwell, and C. Liese. 2012. A comparison of salt marsh construction costs with the value of exported shrimp production. *Wetlands* 32 (5): 791–799. https://doi.org/10.1007/s13157-011-0237-9.

Muncy, R. J. 1984. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)—Pinfish. U.S. Fish Wildl. Serv. FWS/OBS-82/11.26. U.S. Army Corps of Engineers, TR EL-82-4 18 pp.

Murphy, M.D., and R.G. Muller. 1995. A stock assessment of black drum Pogonias cromis in Florida. Department of Environmental Protection, Florida Marine Research institute, St. Petersburg, FL. IHR 1995-005.

Nelson, G.A. 1998. Abundance, growth, and mortality of young-of-the-year pinfish, *Lagodon rhomboides* , in three estuaries along the gulf coast of Florida. *Fishery Bulletin* 96: 315–328.

Nelson, G.A. 2002. Age, growth, mortality, and distribution of pinfish (Lagodon rhomboides) in Tampa Bay and adjacent Gulf of Mexico waters. *Fishery Bulletin* 100: 582–592.

Nelson, J.A., C.D. Stallings, W.M. Landing, and J. Chanton. 2013. Biomass transfer subsidizes nitrogen to offshore food webs. *Ecosystems* 16: 1130–1138.

Neter, J., M.H. Kutner, C.J. Nachtsheim, and W. Wasserman. 1996. *Applied linear statistical models*. McGraw-Hill.

Nixon, S.W., and C.A. Oviatt. 1973. Ecology of a New England salt marsh. *Ecological Monograph* 43: 463–498.

Osburn, H.R., and G.C. Matlock. 1984. Black drum movement in Texas bays. *N. Am. J. Fish. Manage.* 4: 523–530.

Pepin, P. 1991. Effect of temperature and size on development, mortality and survival rates of the pelagic early life history stages of marine fish. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 503–518.

Peters, K.M., and R.H. McMichael. 1990. Early life history of the black drum Pogonias cromis (Pisces: Sciaenidae) in Tampa Bay, Florida. *Northeast Gulf Science* 11 (1): 39–58.

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. In *Fisheries ecology laboratory*. The Nature Conservancy, Alabama Coastal Program, Mobile, AL: University of Southern Mississippi. Prepared for.

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.

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.

Quinn, G.P., and M.J. Keough. 2002. *Experimental design and data analysis for biologists*. Cambridge: Cambridge University Press.

Randall, R.G. 2002. Using allometry with fish size to estimate production to biomass (P/B) ratios of salmonid populations. *Ecology of Freshwater Fish* 11: 196–202.

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.

Ricciardi, A., and E. Bourget. 1998. Weight-to-weight conversion factors for marine macroinvertebrates. *Marine Ecology Progress Series* 163: 245–251.

Robertson, A.I. 1979. The relationship between annual production: Biomass ratios and lifespans for marine macrobenthos. *Oecologia* 38 (2): 193–202.

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.

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: 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., 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 (2): 572–586.

Sharma, S., J. Goff, R. Moody, A. McDonald, D. Byron, K.L. Heck, S.P. Powers, C. Ferraro, and J. Cebrian. 2016. Effects of shoreline dynamics on saltmarsh vegetation. *PLoS One*. https://doi.org/10.1371/journal.pone.0159814.

Sheaves, M., R. Baker, I. Nagelkerken, and R.M. Connolly. 2015. True value of estuarine and coastal nurseries for fish: Incorporating complexity and dynamics. *Estuaries and Coasts* 38: 401–414.

Sparks, E.L., J. Cebrian, P.D. Biber, K.L. Sheehan, and C.R. Tobias. 2013. Cost-effectiveness of two small-scale salt marsh restoration designs. *Ecological Engineering* 53: 250–256.

Sparks, E.L., J. Cebrian, C.R. Tobias, and C.A. May. 2015. Groundwater nitrogen processing in Northern Gulf of Mexico restored marshes. *Journal of Environmental Management* 150: 206–215.

Sprung, M. 1993. Estimating macrobenthic secondary production from body weight and biomass: A field test in a non-boreal intertidal habitat. *Marine Ecology Progress Series* 100: 103–109.

Stoner, A.W. 1982. The influence of benthic macrophytes on the foraging behavior of the pinfish, *Lagodon rhomboides* (L.). *Journal of Experimental Marine Biology and Ecology* 58: 271–284.

Stoner, A.W. 1983. Distribution of fishes in seagrass meadows: Role of macrophyte biomass and species composition. *Fishery Bulletin* 81: 837–846.

Sutter, F. C., R. S. Waller, and T. D. McIlwain. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)-black drum. U.S. Fish Wildl.. Serv. Biol. Rep. 82 (11.51). U.S. Army Corps of Engineers, TR EL-82-4. 10 pp.

Tobias, C., S. Macko, I. Anderson, E. Canuel, and J. Harvey. 2001. Tracking the fate of a high concentration nitrate plume through a fringing marsh: A combined groundwater tracer and in-situ isotope enrichment study. *Limnology and Oceanography* 46: 1977–1989.

Tolan, J.M., S.A. Holt, and C.P. Onuf. 1997. Distribution and community structure of ichthyoplankton in Laguna Madre seagrass meadows: Potential impact of seagrass species change. *Estuaries* 20: 450–464.

Turoboyski, K. 1973. Biology and ecology of the crab Rhithropanopeus harrisii ssp. tridentatus. *Marine Biology* 23: 303–313.

Valiela, I. 2006. *Global coastal change*, 376 pp. Hoboken, New Jersey: Wiley-Blackwell.

Waters, T.F. 1977. Secondary production in inland waters. *Adv. Ecol. Research.* 10: 91–164.

Waycott, M., C.M. Duarte, T.J.B. Carruthers, R.J. Orth, W.D. Dennison, S. Olyarnik, A. Calladine, J.W. Fourqurean, K.L. Heck Jr., A. Randall Hughes, G.A. Kendrick, W.J. Kenworthy, F.T. Short, and S.L. Williams. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the USA Natural Academy of Sciences* 106: 12377–12381.

Wiebe, P.H., and C.S. Davis. 1985. Macrozooplankton biomass in a warm-core Gulf Stream ring: Time series changes in size structure, taxonomic composition, and vertical distribution. *Journal of Geophysical Research* 90 (C5): 8871–8884.

Williams, A.B. 1984. *Shrimps, lobsters, and crabs of the Atlantic coast of the Eastern United States, Maine to Florida*. Washington DC: Smithsonian Institution Press.

Williams, A.B., and D.L. Felder. 1986. Analysis of stone crabs: *Menippe mercenaria* (Say), restricted, and a previously unrecognized species described (Decapoda: Xanthidae). *Proceedings of the Biological Society of Washington* 99: 517–543.

Wong, M.C., C.H. Peterson, and M.F. Piehler. 2011. Evaluating estuarine habitats using secondary production as a proxy for food web support. *Marine Ecology Progress Series* 440: 11–25.

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. 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.

Zimmerman, R.J., T.J. Minello, D.L. Smith, and J. Kostera. 1990. 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.

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, W. Rodney, J.L. Ruesink, S.P. Powers, and R. Brumbaugh. 2012. Historical ecology with real numbers: Past and present extent and biomass of an imperiled estuarine habitat. *Proceedings of the Biological Sciences* 279: 3393–3400.