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Spatial and Temporal Influences of Nearshore Hydrography on Fish Assemblages Associated with Energy Platforms in the Northern Gulf of Mexico

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Abstract

In 2013–2014, remote video and diver surveys documented fish assemblages around 150 small oil platforms in nearshore federal waters off the entire Louisiana coast (≤ 18 m depth). Results were used to evaluate ecological processes driving differences in fish abundance and assemblages associated with platforms. The nearshore zone was characterized by high spatial and temporal environmental heterogeneity. Surveys documented 55 species of platform-associated fishes. Twenty-nine species were partially or wholly represented by young-of-the-year (YOY) or age 1–2 juveniles, including red, gray, and lane snapper (*Lutjanus campechanus*, *Lutjanus griseus*, and *Lutjanus synagris*), greater amberjack (*Seriola dumerili*), and gag grouper (*Mycteroperca microlepis*). Assemblages were compared among three coastal regions with different hydrography due to interactions between river discharge and bathymetry. Assemblage composition near platforms varied in a region × year interaction associated with inter-annual differences in river discharge and coastal distribution of *Sargassum* drifts. The probability of YOY *L. campechanus* occurrence increased with bottom DO saturation (1.40–124.3%) from 0.15 to 0.72. The probability of YOY *L. synagris* and *M. microlepis* respectively decreased and increased with depth (5.61–16.76 m) from 0.81 to 0.05 and from 0.03 to 0.68. The results show that fish assemblages around platforms in the nearshore zone experienced substantial inter-regional and inter-annual differences that were driven by hydrographic and recruitment variability. Platforms also provided suitable reef habitat for juvenile fishes in areas that experience widespread bottom water hypoxia and large freshwater inflows, highlighting the importance of nearshore platforms as nursery locations for juvenile fishes that represent a variety of early life-history strategies.

Keywords Oil and gas · River-influenced ocean margins · Nursery habitat · Young-of-the-year (YOY) · *Sargassum* · Red snapper (*Lutjanus campechanus*)

Introduction

A distinctive feature of the Louisiana Continental Shelf (LCS) is the unparalleled network of oil and gas platforms (hereafter, platforms) extending from inshore waters to the deep northern Gulf of Mexico (nGOM). Because of the rarity of hard substrate in this region of the Gulf, platforms attract various benthic, demersal, and pelagic fishes (Gallaway et al. 1981; Gallaway and Lewbel 1982), aggregating diverse and high-density assemblages (Reeves et al. 2018a; Munnelly et al. 2019a). Shell ridges are common in the nGOM (Wells and Cowan 2007), while natural rock reefs are rare, occupying just 3.3% of bottom waters 18–91 m deep (Parker et al. 1983). Hard substrate is even rarer in shallow waters (≤ 18 m) of the LCS where sedimentation rates are high. In this environment, platforms might add 0.4–10.4% of hard substrate to this coastal zone (Gallaway et al. 1998; Stanley and Wilson 2003, respectively), making it important to understand the placement and removal of platforms on associated fauna.

Most previous studies of Gulf platforms were focused on the biota, principally the associated fishes. These studies compared species abundances (Gallaway and Lewbel 1982;

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Stanley and Wilson 1998, 2003; Reynolds et al. 2018) and reproductive potential among natural habitats (Glenn et al. 2017; Downey et al. 2018), evaluated potential trophic effects related to secondary productivity (Beaver et al. 2003; Reeves et al. 2018b, 2018c, 2019), or studied overcrowding of aggregated species (Davis et al. 2015; Simonsen et al. 2015; Schwartzkopf et al. 2017; Dance et al. 2018). Other platform studies have assessed the toxicology of produced water discharges and the inevitable leaks and spills associated with the petroleum industry (Gallaway et al. 1980). However, a common thread for all other studies is that they focused on large platforms in deeper waters (20–200 m) and largely ignored small unmanned platforms in shallow coastal waters. Consequently, little information is available regarding the fishes associated with the dominant contingent (BOEM 2019) of small platforms in shallow nearshore waters (≤ 18 m water depth and 3–47 km from shore).

In addition, this unique artificial reef network in the nGOM has been in constant evolution since coastal drilling began in 1942 (BOEM 2019; Fig. 1). During the initial energy development phase (1945–1959), the number of federally managed platforms doubled every 2 years. Since 1960, platform numbers expanded steadily at a mean net rate of 113 ± 6 platforms per year (± 1 standard error). Platform numbers peaked at 4045 in 2001, and between 1992 and 2006, the numbers were relatively stable (mean $= 3960 \pm 13$). Throughout this period, 80% of all platforms in federal waters were small (unmanned and unattended caissons, fixed platforms, and well protectors), 52% were in shallow waters (≤ 18 m water depth), and 46% were both small and in shallow waters. After 2006, platform numbers rapidly diminished as oil exploration moved into deeper waters because of depleted reserves in nearshore waters and enforcement of the Idle Iron policy (BSEE 2019). This trend was accelerated by several natural (hurricanes) and operational disasters (Deepwater Horizon) that motivated companies to remove idle platforms (Kaiser et al. 2009; Kaiser and Yu 2010). From 2007 to 2018, the total platform count declined by 52% from 3898 to 1868 (BOEM 2019). Of these removals, 96% were small platforms, 52% were in shallow waters, and 51% were both small and in shallow waters.

In spite of these removals, a large artificial reef network of platforms remains in the Gulf that are situated in a highly complex and dynamic coastal system known as the “Fertile Fisheries Crescent” (Günter 1963). As implied by the name, this area constitutes a highly productive and economically valuable marine system with the highest fisheries yields in the GOM (Günter 1956; Chesney et al. 2000; NMFS 2019). Many reef-associated and other fishes aggregate at these platforms (Cowan and Rose 2016). Fishing around oil platforms contributes to the highest catch rates of any US recreational fishery (Stanley and Wilson 1990; Chesney et al. 2000; NMFS 2019), and greater than 70% of all nearshore recreational fishing off Louisiana occurs at platforms (Ditton and Auyong 1984; Witzig 1986; Stanley and Wilson 1989).

Another unique feature of this area is the spatial and temporal heterogeneity created by a combination of the coastal bathymetry and the patterns of river discharge within this highly productive area (Munnelly et al. 2019b; see Fig. 2 for nearshore hydrographic regions). These regional differences have a profound influence on coastal habitats that are expressed in different patterns of productivity, turbidity, salinity, stratification, and sediment types in the nearshore zone. The strongest stratification occurs in the East, because the main branch of the Mississippi River discharges onto a steep continental shelf into the nearshore zone where it is not easily mixed. This allows marine and freshwater conditions to exist within a single water column but very close to shore. In contrast, weak stratification occurs in the nearly homogenous water column (mixoeuhaline) in the West region, where the shelf is broadest and most gently sloped, along with the lowest volume of freshwater discharge into the LCS. Finally, highly variable mixed or stratified polyhaline conditions occur in the Central region. Because the Atchafalaya River discharge occurs within very shallow waters of Atchafalaya Bay, waters are well mixed by tides and local winds as they travel to the LCS.

Further defining this area is the coastal eutrophication and subsequent depletion of bottom water DO (Rabalais et al. 2002a). The seasonally ephemeral hypoxic zone (DO < 2 mg l^{-1}) that forms primarily off coastal Louisiana is among the largest on Earth, and the area and volume of the hypoxic zone are related to nutrient inputs from the rivers (Rabalais et al. 2002a; Obenour et al. 2013). The severity of DO depletion (intensity and thickness) of the lower water column is spatially variable throughout shallow nearshore waters of the hypoxic zone in relation to bathymetry (Renaud 1986; Hetland and DiMarco 2008; Hazen et al. 2009; DiMarco et al. 2010; Munnelly et al. 2019b). Shelf and delta morphology and the distribution of sand shoals can all influence mixing and stratification patterns that in turn affect physical and chemical water quality characteristics (Hetland and DiMarco 2008; DiMarco et al. 2010; Munnelly et al. 2019b). Differences in dominant sediment compositions of sand and mud exert additional biogeochemical effects that can reduce susceptibility to DO depletion over sand shoals relative to the surrounding muddy sediments causing greater environmental heterogeneity (Reeves et al. 2018a; Munnelly et al. 2019b).

The primary objectives of this study were to characterize the platform-associated fish assemblages throughout Louisiana’s shallow nearshore zone, evaluate their relationships with structural complexity, and identify environmental processes that influenced local fish assemblage structure. The hypotheses addressed by the study were as follows: (1) that assemblage composition varies among three coastal regions

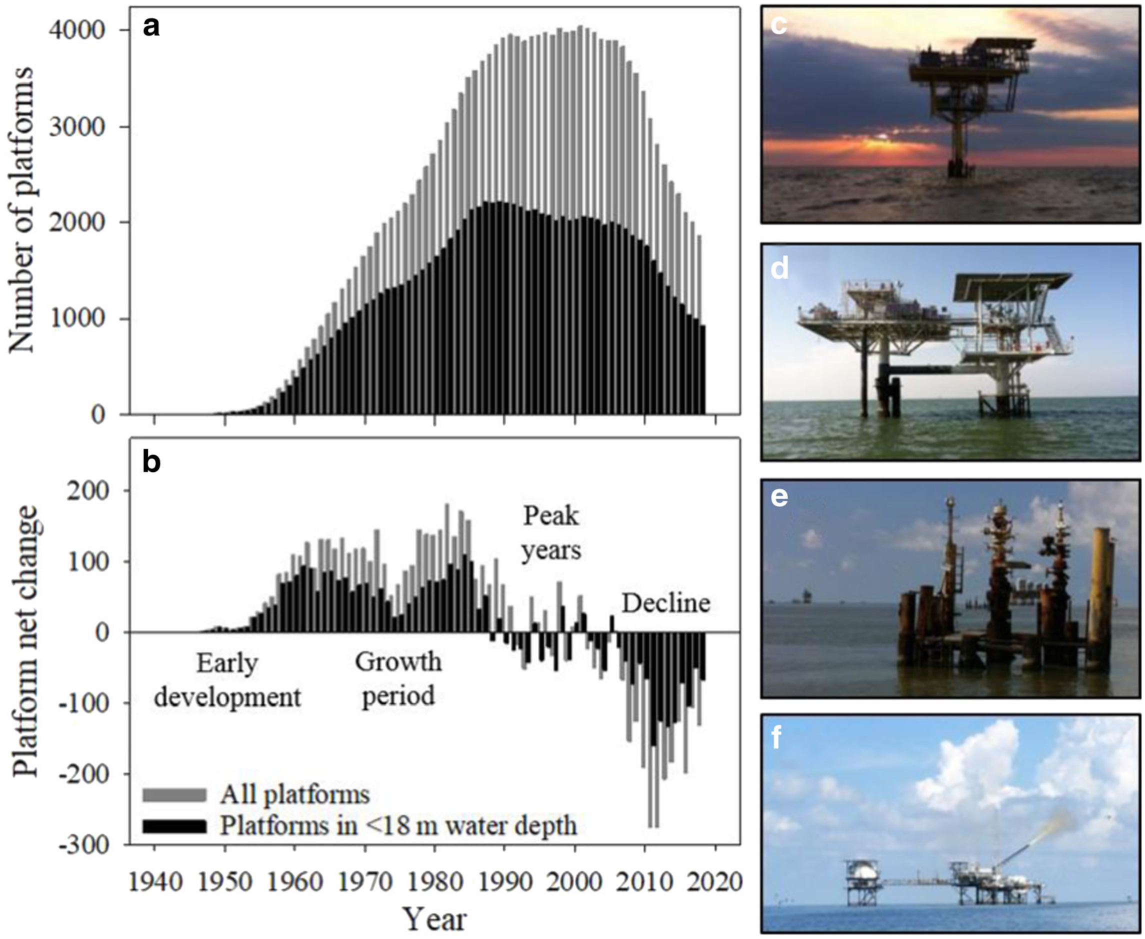

Fig. 1 The rise and decline of the largest "de facto" artificial reef network of the twentieth century. Panels (**a**) and (**b**) show the number of federally managed oil and gas platforms in the northern Gulf of Mexico outer continental shelf and the net annual change in the number of platforms from 1942 to 2018, respectively. The light-colored bars show the total platform count, while the dark bars represent platforms in waters ≤ 18 m depth. 81 structures listed without installation or removal dates were excluded from the analysis. Panels (**c**)–(**f**) show platforms with a range of size and complexity. Relatively small, unmanned, unattended caisson (**c**), fixed (**d**), and well protector (**e**) platforms with 1–10 piling jackets were sampled, while large, highly complex structures, structures discharging produced water, emitting hydrogen sulfide gas, or possessing burn-off flares (**f**) were avoided

described in Munnelly et al. (2019b) because of variable mixing and stratification patterns that coincide with interactions between river discharge and bathymetry; (2) that assemblage composition varies between platforms sited over large sand shoals and those occurring over muddy bottoms; and (3) that assemblage composition varies with differences in platform structural complexity.

Methods

Field

Individual platforms were selected for sampling by a modified-random approach using the Bureau of Ocean Energy Management database in conjunction with United States Geological Survey seabed data. Platforms tend to be clustered into fields (aggregations of platforms) throughout the nGOM reflecting the block-lease contracts that permit drilling operations in federal waters (traditionally > 5 km from shore). Routes were planned to sample within as many fields as possible while prioritizing fields that offered a greater range of habitat conditions. Unmanned and unattended caisson, well protector, and fixed structures in ≤ 18 m water depth were selected across transects intended to span a wide range of salinity, temperature, depth, distance from shore, and dominant sediment types. We also considered platform complexity (the total number of pilings; Fig. 1C–F), the date of deployment, and proximity to other platforms. Large, highly complex structures, structures discharging produced water, emitting hydrogen sulfide gas, or possessing burn-off flares (Fig. 1F) were avoided.

Sampling entailed 28 single-day cruises aboard a 30′ vessel. Sampling dates were spread over 2 years, with 14 days in 2013, and 14 days in 2014, during summer months between

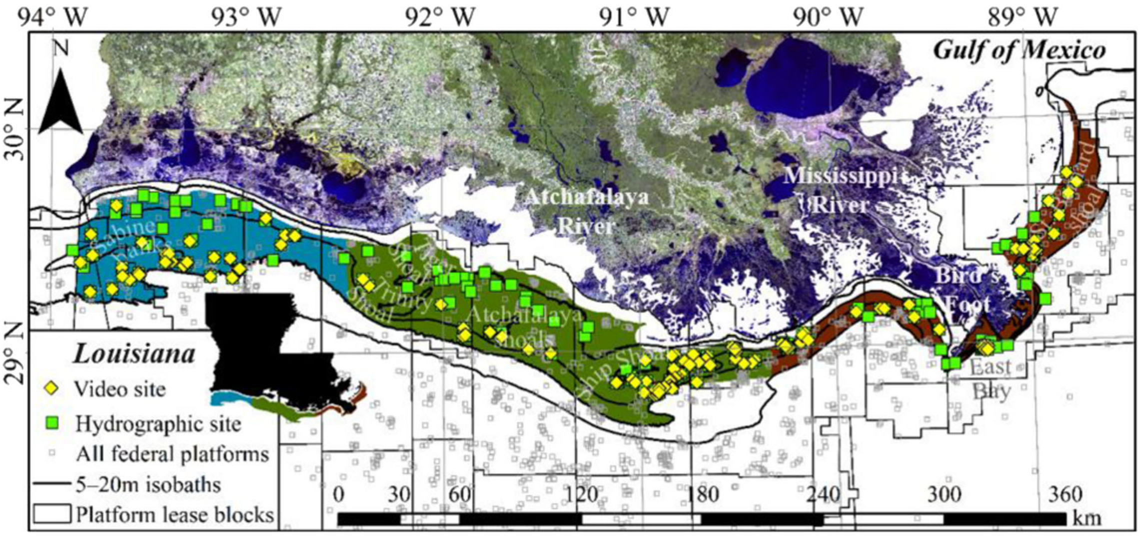

Fig. 2 All sites of hydrographic (green squares; $n = 343$) and video (yellow diamonds; $n = 150$) data used in analyses. Colored areas represent regions of distinctly different hydrography and assemblage composition of reef-associated fishes at longitudinal divides of − 92.5° W separating the West (blue) and Central (green) regions, and − 90.4° W separating the Central and East (brown) regions. Locations of the Mississippi and Atchafalaya rivers and major sand shoals are marked. Hollow gray squares show the distribution of federally managed oil and gas structures. The irregular gridding shows the federal offshore leasing block areas. Contours are shown for the 5–20-m isobaths

July 12 to September 06 of 2013, and July 02 to September 12 of 2014. Routes ran 50–400 km per day and 3–47 km from shore depending on the targeted platforms and sea state.

While maneuvering within a mean distance of 3.0 m ± 0.2 (95% CI) of 322 platform sites during the study period, an array of four GoPro Hero 3 cameras was lowered from the bow of the boat at a rate of 0.23 ± 0.02 m s^{-1}. The array was left on the seafloor for 90 s to allow disturbed sediment to clear before retrieval. The video array consisted of three cameras with 62° horizontal and 36° vertical fields of view that were mounted to the underside of the top panel of a triangular-prism frame at 120° from one another to provide a non-overlapping, circular sampling volume. The fourth camera was centrally mounted among the other three and faced down to record fishes swimming under the array, to reference a depth gauge, and to provide benthic substrate images. A pair of lasers spaced 10 cm apart were mounted to the top side of the top panel with the forward-facing camera centered between them to provide a scale reference. The cameras were synchronized to the same frame number using a wireless remote control to simultaneously start and stop all four cameras. See Online Supplement 1 for an example of a remote video deployment.

Following sampling with the remote video array, a pair of divers sampled a randomly selected subset of the platforms to meet the objectives of concurrent studies, as well as to assess the performance of the video array. Divers noted the presence of small or cryptic species potentially not detected by the video array. Presence and absence for YOY red and lane snapper (*Lutjanus campechanus* and *Lutjanus synagris*) and gag grouper (*Mycteroperca microlepis*) were recorded throughout the study period and classed by ordinal abundance estimates of 0, 1–9, 10–99, or ≥ 100 snapper, and 0, 1, or 2–3 grouper. See Online Supplement 2 for an example of a diver survey.

Hydrographic data were collected at 343 sites, including all platforms sampled throughout the coastal zone immediately after video sampling at each platform, as well as at 21 additional sites without platforms (Fig. 2). A YSI model 6820 V2 sonde was used to profile salinity, temperature (°C), depth (m), atmospheric pressure (mm Hg), pressure at depth (psia), DO (mg l^{-1} and % saturation), pH, and turbidity (NTU). One reading was made every 2 s on descent, between ~ 0.2 m below the surface and ~ 0.2 m above the bottom, and the sonde was lowered at a rate of 0.04 ± 0.004 m s^{-1}. A Secchi disk was used to estimate water clarity (m). Of the 343 hydrographic profiles, 181 profiles were sampled in 2013, and 162 were sampled in 2014. For further details pertaining to the hydrographic data, see Munnelly et al. (2019a). See Online Supplement 3 for a monthly timeline showing the number of sites sampled hydrographically, by remote video array, and by diver survey, within each region.

Video Processing

Visibility in nearshore waters is highly variable due to dense phytoplankton blooms and sediment inputs from the rivers (Scarborough-Bull and Kendall 1994). Consequently, remote video recordings of platform fish assemblages were selected for analysis based on initial visibility criteria that required the submerged structure of a platform (the jacket) be visible in recordings. The deployment distance from the platform jacket

(3.0 m ± 0.2; 95% CI) meant that a nominal 3.0-m threshold of visibility was required. This threshold was adequate for this study due to the strong association of the fishes with the platforms and the small structural footprint of the platforms targeted (Reeves et al. 2018a; Munnelly et al. 2019b). The effect was a concentrated fish assemblage that was more amenable to video-based sampling than prior studies of larger structures had reported (Scarborough-Bull and Kendall 1994). Visibility was adequate in 177 of 322 remote videos recorded at platforms during the study period, or about 55% of all recordings. Of these, 150 videos were recorded at unique platforms representing independent samples that were included in analyses. Thirty-two videos were obtained from the West region, 70 were obtained from the Central region, and 48 were obtained from the East region (Fig. 2). Of those, 65 videos were from 2013 and 85 from 2014. Also, 68 videos were recorded over sand-dominated sediments (> 63 μm) and 82 were recorded over mud-dominated sediments (≤ 63 μm).

Relative abundances were estimated using a method that did not risk double counting (Ellis and DeMartini 1995). The peak abundance of each species observed on remote video (hereafter, MAXNO) was located for the synchronized set of frames for the three outward-facing cameras. This represented the minimum and conservative estimate for that species' abundance at each individual site (Priede et al. 1994; Ellis and DeMartini 1995; Willis and Babcock 2000; Wells and Cowan 2007). The downward-facing camera views were reviewed and used in place of the outward-facing cameras for a given species if the counts resulted in a greater abundance estimate. Although length data was not quantitatively processed from the video due to the effort and subjectivity required to extract this information using the single pair of lasers mounted to the remote video array, course ontological classifications for the species observed were noted. Classifications for YOY juveniles, age 1–2 juveniles, and adults were based on known approximate size classes and distinct differences in body shape or pigmentation and used in the interest of reporting the presence of juvenile species at shallow-water nearshore platforms.

Statistical Analyses

The sampling adequacy for our fish data was evaluated for within-comparison groups using rarefaction curves for species richness in EstimateS (Colwell 1997), where individual platforms were replicates. Species richness reached an asymptote within our sample number across the different groups, indicating that sampling was adequate to characterize the fish assemblages associated with each comparison (to the potential of our methods). Assumptions of all parametric and non-parametric statistical tests were met or accounted for as specified. Significance was reported as an alpha (α) of 0.05, and error was reported as one standard error from the mean unless noted otherwise. For further details, see Munnelly et al. (2019a), which uses the same dataset, and Reeves et al. (2018a), which uses the same methods for data collected within the same study region in 2016.

Species richness and Shannon-Weiner diversity indices were used to compare fish assemblage structure, and a Bray-Curtis similarity matrix was used to compare fish assemblage compositions. Species richness reflected the raw total number of species, while Shannon-Weiner diversity (H') additionally accounted for species evenness and was expressed as the effective number of species (ENS) for a more meaningful interpretation (Hill 1973; Jost 2006): $\mathrm{ENS} = \exp(H') = \exp\left(-\sum_i p_i \ln p_i\right)$, where p_i was the total proportion of the ith species (Shannon 1948). Three-way analyses of covariance (ANCOVAs) were used to compare species richness and Shannon-Weiner diversity by regions (West, Central, and East) established based on substantial differences among hydrographic regimes (Fig. 1 of Munnelly et al. 2019b), year (2013 and 2014), and dominant sediment type (sand or mud) effects and included covariates for platform complexity, and visibility based on midwater turbidity (SAS 9.4, GLIMMIX procedure). Assumptions of normality and homogeneity were met. Species richness was treated as a negative binomial distribution using the log link, and Shannon-Weiner diversity was treated as a normal distribution. Pairwise differences between least-squares means under multiple comparisons were determined using Tukey-Kramer post hoc adjustments.

A three-factor permutational multivariate analysis of variance (PERMANOVA) was used to compare patterns in the fish assemblage Bray-Curtis similarity matrix by region, year, and dominant sediment type effects and included covariates for platform complexity and effort (PRIMER 6 and PERMANOVA+). Species with < 10 observations in the dataset were excluded due to sensitivity of the test to exceptionally rare species (Clarke and Gorley 2006). MAXNOs were fourth-root transformed to down-weigh contributions from exceptionally abundant species (Anderson 2001; Anderson et al. 2008). Dispersion was not influential for the PERMANOVA, and pairwise comparisons were made for significant effects detected in the main test. Pairwise tests were used to guide interpretations of regional, annual, and dominant sediment type effects based on a Bonferroni-adjusted alpha (α) of 0.0083. Pairwise comparisons were presented as canonical analyses of principal coordinates (CAP) and similarity percentage analysis (SIMPER). The CAP analyses provided visual representations and a measure of fit for the site groupings. The SIMPER analyses were used to compare individual species contributions (expressed as MAXNO relative abundances) that influence similarities or differences among groupings.

Ordered multinomial logistic regressions were used to predict the probability of occurrence of YOY *L. campechanus*, *L. synagris*, and *M. microlepis* at platforms based on the diver ordinal abundance data for the 0, 1–9, 10–99, or ≥ 100 snapper, and 0, 1, or 2–3 grouper categories (SAS 9.4, Logistic procedure). Forward, backward, and stepwise selection were used to select the environmental variable most correlated with the ordinal abundance observations based on p value after removing non-significant variables. Environmental variables considered included surface, midwater, and bottom water salinity, temperature, DO, Secchi depth, water depth, distance from shore, sediment type, platform complexity, year, and day of the year. The proportional odds assumption was met for each of the ordinal groupings among all species comparisons, and so response curves were plotted using the proportional odds model (Agresti 2007).

Results

Fishes Observed Around Small Platforms

During this study, 55 fish species representing 28 families were observed in association with small oil and gas platforms throughout the Louisiana nearshore coastal zone (Online Supplement 4). However, occurrence and abundance of all species associated with small platforms were not all well-represented on remote video recordings. Forty fish species belonging to 21 families were identified on remote video. Of these 40 species, 21 were present partially or wholly as either YOY or age 1–2 juveniles (Online Supplement 4). For the majority of those species, YOY individuals were underestimated in counts due to their small size, cryptic appearance, or evasive behavior. Consequently, most YOY were omitted from relative abundance estimates. There were another 15 species from seven families that were observed by divers, but not on remote video. Diver observation confirmed these species as a regular and substantial component of the fish assemblage. No effort was made to quantify or analyze the distribution of most of these species during this study; however, blenny distributions were quantified in a related study (Reeves et al. 2018b). Cryptic fishes that were not quantified included adult cardinalfish (*Apogon* spp.), adult hardhead catfish (*Ariopsis felis*), YOY spotfin butterflyfish (*Chaetodon ocellatus*), adult and YOY featherduster blenny (*Hypleurochilus multifilis*), zebratail blenny (*H. caudovittatus*), seaweed blenny (*Parablennius marmoreus*), and molly miller (*Scrtella cristata*), YOY *Mycteroperca microlepis*, adult flounder (*Paralicthys* spp.), adult and YOY cubbyu (*Pareques umbrosus*), adult whitespotted soapfish (*Rypticus maculatus*), adult and YOY belted sandfish (*Serranus subligarius*), adult Caribbean sharpnose puffer (*Canthigaster rostrata*), and adult and YOY cocoa damsel (*Stegastes variabilis*). Age 1–2 juvenile horse-eye jack (*Caranx latus*) were also observed by divers, but not recorded by the remote video array. While not cryptic, this species was very rare around nearshore platforms during 2013 and 2014.

Unexpected findings were the presence of the Atlantic goliath grouper (*Epinephelus itajara*) and scarcity of the invasive lionfish (*Pterois* spp.) around nearshore platforms. Three *E. itajara* were observed in East Bay during this study. Two *E. itajara* were encountered during a dive survey in September of 2013, while a third was videoed in July of 2014. A potential fourth *E. itajara* was recorded by the remote video array during July of 2013, although the image was of low quality. Interestingly, the only observations of *Pterois* spp. at nearshore platforms also occurred in East Bay.

Factors Influencing Nearshore Fish Distributions

Species richness and Shannon-Weiner diversity varied across the study area or between the summers of 2013 and 2014. Species richness varied by region ($F_{2,136} = 3.75$, $p = 0.0260$) and year ($F_{1,136} = 6.70$, $p = 0.0107$). Pairwise comparison of species richness showed an increase in richness from east to west (Fig. 3A). Species richness was higher in 2014 than 2013 for all regions (Fig. 3B). Shannon-Weiner diversity varied by the number of pilings only ($F_{1,135} = 6.71$, $p = 0.0106$), which showed an increase in the ENS with increasing number of pilings (Fig. 3C). The mean ENS among regions and between years and dominant sediment types was 3.79 ± 0.24 species (95% CI), where H' was 1.26 ± 0.07.

The PERMANOVA detected inter-regional and inter-annual differences in the assemblage compositions. The global test (Table 1) indicated that fish assemblages varied by region × year (pseudo-$F_{2,136} = 3.9148$, p (perm) < 0.001) and region × dominant sediment type interactions (pseudo-$F_{2,136} = 2.9534$, p (perm) = 0.002), as well as the visibility (pseudo-$F_{1,136} = 12.246$, p (perm) < 0.001) and number of piling covariates (pseudo-$F_{1,136} = 13.731$, p (perm) < 0.001). Pairwise comparisons of the region × year and region × dominant sediment type main effects were made against a Bonferroni-adjusted alpha value of $\alpha = 0.00833$. Pairwise comparisons of the region × year interaction (Table 2) indicated intra-regional differences in fish assemblages between sampling years for the West and Central regions, but not in the East region (pseudo-$t_{(1,42)} = 1.1996$, p (perm) = 0.237). There were inter-regional differences among the fish assemblages within all three regions in 2014, but in 2013, the assemblage composition did not differ between the Central and East regions (pseudo-$t_{(1,47)} = 1.9234$, p (perm) = 0.01). Pairwise comparisons of the region × dominant sediment type interaction (Table 2) indicated intra-regional differences in fish assemblages between dominant sediment types of sand and mud for the Central and East regions, but not the West region (pseudo-$t_{(1,26)} = 1.4226$, p (perm) = 0.054).

Groupings compared in the CAP and SIMPER analyses were based upon the pairwise PERMANOVA tests. The

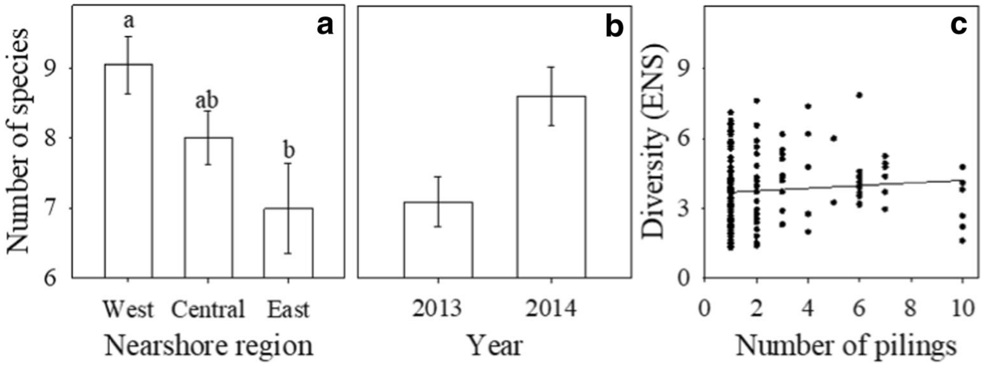

Fig. 3 Pairwise comparison of species richness by region (West, Central, and East; **a**) and year (2013 and 2014; **b**), and the effective number of species (ENS) based on Shannon-Weiner entropy (H') by the total number of pilings (1–10; **c**). The mean ENS among regions and between years and dominant sediment types (sand or mud) was 3.79 species and H' was 1.26. Refer to Fig. 2 for region locations. Refer to Fig. 1 for images of small platforms of varying complexity

CAP analysis for the region × year interactive effect reported 107 of 150 sites correctly classified for a score of > 71% (Fig. 4A and B). The CAP analysis for the region × dominant sediment type interactive effect reported 92 of 150 sites correctly classified for a score of > 61% (Fig. 4C and D). Separation of these groupings in the multivariate space in Fig. 4A and D provided a visual representation of these differences, and plots of vectors for the 13 most influential species or life-history stages showed the primary species that drove the separation (Fig. 4B and C).

The 13 species or life-history stages driving consistent differences in assemblage structure were identified by their contribution to the ratio of percent dissimilarity to the standard deviation as part of the SIMPER analysis (Clarke and Warwick 2001). Of the 28 species and life-history stages included in the analyses, 13 consistently contributed to dissimilarity of one or more comparisons and together accounted for > 97% of all fishes observed (Online Supplement 4). These numerically dominant nearshore platform species included the following: Atlantic bumper (*Chloroscombrus chrysurus*; ~ 56%), Atlantic spadefish (*Chaetodipterus faber*; ~ 18%), blue runner (*Caranx crysos*; ~ 9%), bluefish (*Pomatomus saltatrix*; ~ 4%), sheepshead (*Archosargus probatocephalus*; ~ 3%), gray snapper (*Lutjanus griseus* (~ 2%), sergeant major (*Abudefduf saxatilis*; ~ 1%), Bermuda chub (*Kyphosus sectatrix*; < 1%), YOY greater amberjack (*Seriola dumerili*; < 1%), gray triggerfish (*Balistes capriscus*; < 1%), adult *L. campechanus*; < 1%), age 1–2 *L. campechanus*, and cobia (*Rachycentron canadum*; < 1%). *C. faber* was the most widely distributed species, occurring at 149 of the platforms included in these analyses. Mean abundances and standard errors of the 28 species and life-history stages were plotted by groupings based on the pairwise PERMANOVA tests (Fig. 5) for the region × year and region × dominant sediment type interactions.

Table 1 Output from the permutational multivariate analysis of variance (PERMANOVA) comparison of assemblage composition across region (West, Central, and East), year (2013 and 2014), dominant sediment type (sand or mud) effects, interactions, and the number of pilings and visibility covariates. Pairwise comparisons (Table 2) were made for effects were *p* (perm) that was < 0.05. Refer to Fig. 2 for regional and sand shoal locations. Refer to Fig. 1 for images of small platforms of varying complexity

Environmental variable	df	SS	MS	Pseudo-*F*	*p* (perm)	Unique
Region	2	7545.6	3772.8	9.1813	0.001	999
Year	1	3615.9	3615.9	8.7996	0.001	999
Sediment	1	2693.7	2693.7	6.5553	0.001	997
Region × year	2	3217.3	1608.7	3.9148	0.001	999
Region × sediment	2	2427.2	1213.6	2.9534	0.002	998
Year × sediment	1	480.77	480.77	1.17	0.33	999
Region × year × sediment	2	1060.9	530.43	1.2908	0.235	999
Pilings	1	5642.4	5642.4	13.731	0.001	999
Visibility	1	5032.2	5032.2	12.246	0.001	999
Res	136	55,885	410.92			
Total	149	87,601				

Table 2 Pairwise comparisons of the region × year and region × dominant sediment type interactions for regions West (W.), Central (C.), and East (E.) in years 2013 and 2014 and dominant sand or mud sediment types. Effects in the "*p* (perm)" column were interpreted with a Bonferroni-adjusted alpha (α) of 0.0083. Refer to Table 1 for the results of the main test. Refer to Fig. 2 for regional and sand shoal locations

Pairwise test	Level 1	Level 2	df	*t*	*p* (perm)	Unique
Region × year	Region: E.	Year: 2013, 2014	42	1.1996	0.237	998
	Region: C.	Year: 2013, 2014	64	2.7571	0.001	999
	Region: W.	Year: 2013, 2014	26	2.2533	0.001	999
	Year: 2013	Region: E., C.	47	1.9234	0.01	999
	"	Region: E., W.	39	1.8511	0.001	999
	"	Region: C., W.	26	1.8913	0.001	999
	Year: 2014	Region: E., C.	59	2.1457	0.001	999
	"	Region: E., W.	29	3.2667	0.001	999
	"	Region: C., W.	64	2.5948	0.001	999
Region × sediment	Region: E.	Sediment: sand, mud	42	1.866	0.005	999
	Region: C.	Sediment: sand, mud	64	2.6647	0.001	999
	Region: W.	Sediment: sand, mud	26	1.4226	0.054	999
	Sediment: sand	Region: E., C.	45	1.7178	0.007	999
	"	Region: E., W.	17	2.0519	0.003	998
	"	Region: C., W.	56	2.8351	0.001	998
	Sediment: mud	Region: E., C.	61	2.695	0.001	999
	"	Region: E., W.	51	2.8572	0.001	998
	"	Region: C., W.	34	1.9533	0.002	999

In 2014, higher mean abundances for most species were observed with the exceptions of age 1–2 and adult *L. campechanus*, *L. griseus*, and *L. synagris*, which were all more abundant in 2013 (Fig. 5A). During 2013, the platform-associated fish assemblage composition of the Central region was similar to that of the East region, but in 2014, the assemblage composition of the Central region was unique, and more closely resembled the assemblage in the West region. Species that greatly contributed to the dissimilarity driving differences between the East and the Central regions in 2014 were higher numbers of *L. griseus* and *L. campechanus* in the East region, and higher numbers of *C. chrysurus*, *C. crysos*, *C. faber*, *K. sectatrix*, *A. saxatilis*, *A. probatocephalus*, and *B. capriscus* in the Central region. Species that greatly contributed to the dissimilarity driving differences between the Central and West regions in 2014 were higher abundances of *P. saltatrix*, YOY *S. dumerili*, *A. saxatilis*, *K. sectatrix*, *R. canadum*, *C. faber*, and *B. capriscus* in the West region and higher abundances of *C. chrysurus*, *C. crysos*, *L. griseus*, and *A. probatocephalus* in the Central region. Species that greatly contributed to the dissimilarity driving differences between the East and West regions for both years included higher numbers of *L. griseus*, *L. campechanus*, and *A. probatocephalus* in the East region and higher numbers of *C. crysos*, *C. faber*, YOY *S. dumerili*, and *R. canadum* in the West region (Figs. 4A and 5A–D).

Sediment composition influenced fish assemblage composition in the East and Central regions but did not in the West region. Intra-regional differences between sand and mud-dominated sediment types among the three regions (Figs. 4B and 5E–I) indicated that in the East region, sandy sediments were associated with higher numbers of *C. chrysurus*, *C. crysos*, adult *L. campechanus*, and age 1–2 *L. campechanus*, while muddy sediments were associated with higher numbers of *L. griseus* and *A. probatocephalus*. In the Central region, *C. chrysurus*, *A. saxatilis*, *L. griseus*, *B. capriscus*, and *C. faber* were more abundant over sandy sediments while *C. crysos* and *K. sectatrix* were more abundant over muddy sediments. The West region was associated with overall higher abundances of *P. saltatrix*, YOY *S. dumerili*, and *R. canadum* than found within the East or Central regions, regardless of dominant sediment type.

Diver observations corroborated general patterns shown by the remote video analyses, namely the regional differences in assemblage composition and the greater abundances and diversity of fishes in 2014 relative to 2013. The locations of the 49 dive sites are shown in Fig. 6A–C. Additionally, divers detected YOY *L. campechanus* and *L. synagris* at ~29% and ~33% of platforms selected for diving in 2013, respectively, and ~48% of platforms

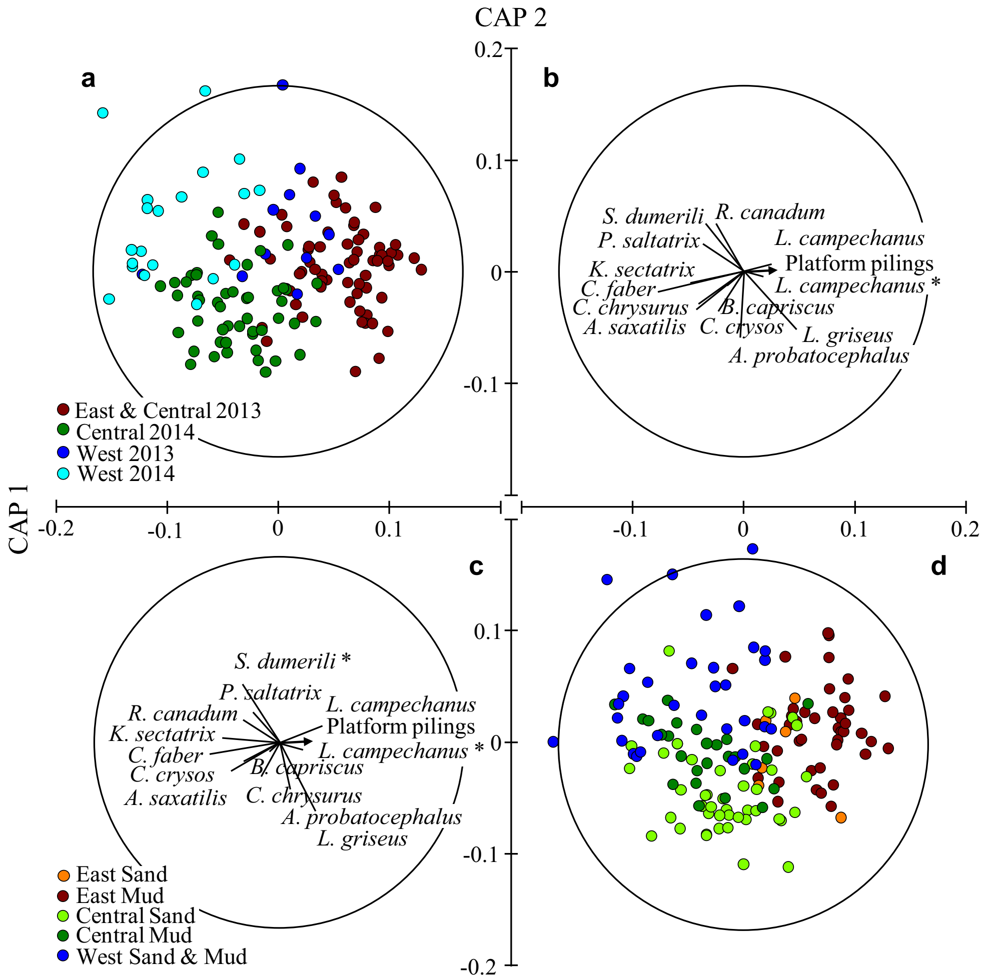

Fig. 4 Canonical analyses of principal coordinates (CAP) displaying assemblage composition of the region × year (**a** and **b**) and region × dominant sediment type (**c** and **d**) effects in the PERMANOVA model. Vectors are plotted for the thirteen most abundant species that were responsible for driving differences in assemblage composition based on similarity percentage analysis (SIMPER) and together account for > 97% of fishes observed. The vector related to the number of platform pilings is plotted as an arrow. Refer to Fig. 2 for regional and sand shoal locations

selected for diving in 2014 for both species. Where present, numbers of *L. campechanus* and *L. synagris* observed varied from one YOY to > 1000 YOY. Divers detected YOY *M. microlepis* at 33% of platforms selected for diving in 2013 and 12% of platforms selected for diving in 2014. Where present, *M. microlepis* occurred in abundances of one to three YOY per platform.

Diver ordinal abundance estimates of YOY *L. campechanus*, *L. synagris*, and *M. microlepis* were correlated with the probability of occurrence of one or more environmental variables. Forward, backward, and stepwise selection procedures for the variable most highly correlated with the presence of YOY *L. campechanus* identified bottom DO ($p = 0.0180$). The score test validated the proportional odds assumption ($p = 0.5397$), and so a common odds ratio of 1.0219 ± 1.0092 per unit DO saturation was accepted for each of three intercepts ($b = 0.1726$, 0.0797, and 0.0204 for 0–9, 10–99, and ≥ 100 YOY per platform density categories, respectively). The probability of YOY *L. campechanus* occurrence increased with bottom DO saturation (1.40–124.3%) from 0.15 to 0.72 for 0–9 YOY per platform, from 0.08 to 0.54 for 10–99 YOY per platform, and from 0.02 to 0.23 for ≥ 100 YOY per platform (Fig. 6D). Similarly, selection procedures for the variable most highly correlated with the presence of YOY *L. synagris* identified depth ($p = 0.0033$). The score test validated the proportional odds assumption ($p = 0.1431$), and so a common odds ratio of − 0.6711 ± 1.1451 m^{-1} depth was accepted for each of three intercepts ($b = 41.2974$, 33.6832, and 4.1227 for 0–9, 10–99, and ≥ 100 YOY per platform density categories, respectively). The probability of YOY *L. synagris* decreased as depth increased (5.61–16.76 m) from 0.81 to 0.05 for 0–9 YOY per platform, from 0.78 to 0.04 for 10–99 YOY per platform, and from 0.30 to < 0.01 for ≥ 100 YOY per platform (Fig. 6E). Selection procedures for the variable most correlated with the presence of YOY *M. microlepis* were depth ($p = 0.0086$). The score test validated the proportional odds assumption ($p = 0.8955$), and so a common odds ratio of 1.4765 ± 1.1598 m^{-1} depth was accepted for each of two intercepts ($b = 0.0031$ and 0.0009 for 1 and 2–3 YOY per platform density categories, respectively). The probability of YOY *M. microlepis* increased as depth increased from 0.03 to 0.68 for 1 YOY per platform and from < 0.01 to 0.39 for 2–3 YOY per platform (Fig. 6F).

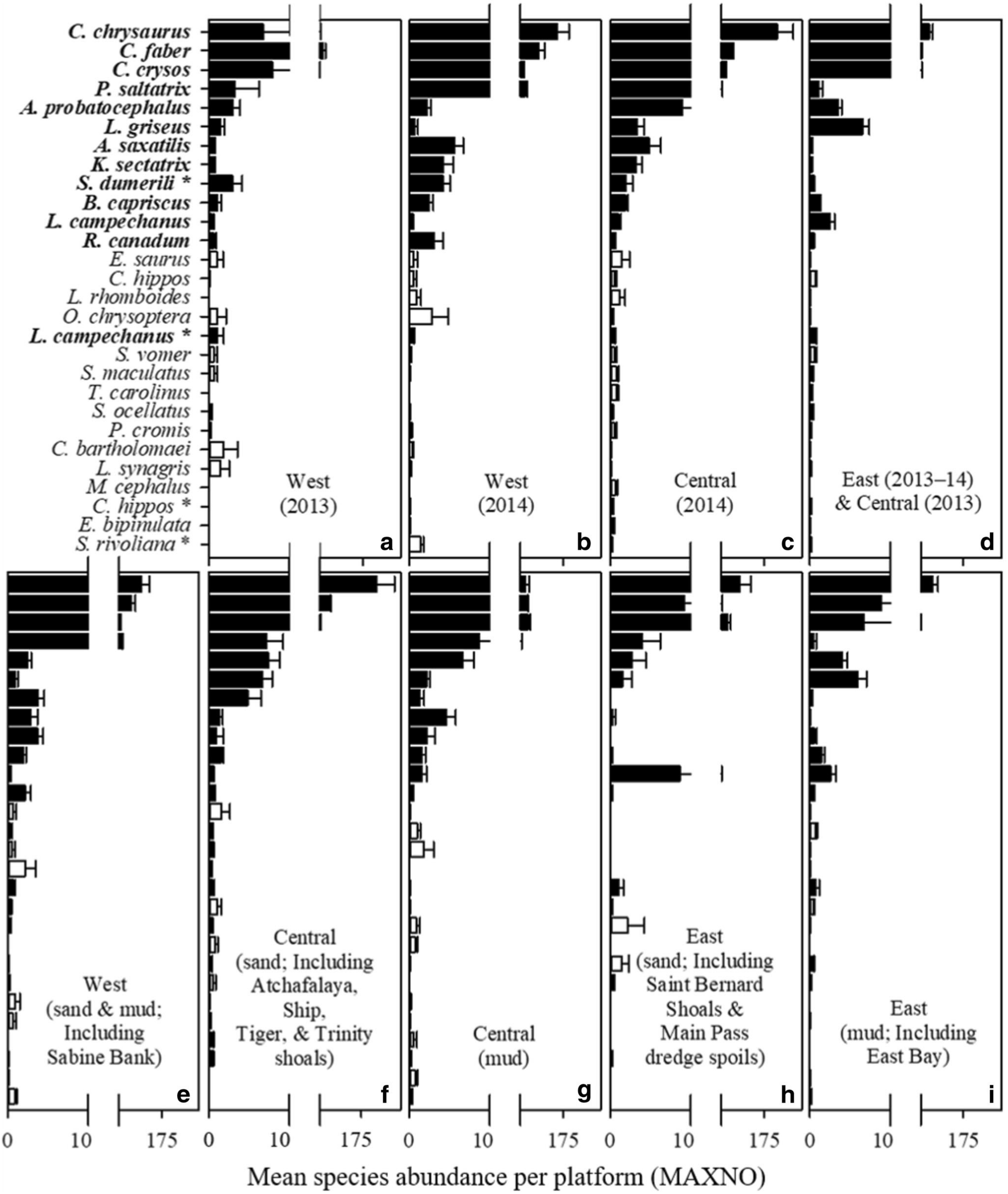

Fig. 5 Fish assemblage composition based on region × year (**a**–**d**) and region × dominant sediment type (**e**–**i**) effects in the permutational multivariate analysis of variance (PERMANOVA) model. Fish abundances reflect the mean peak abundance among one synchronized set of camera frames occurring within each remote video deployment (MAXNO) among comparisons. The thirteen most abundant species responsible for driving differences in assemblage composition based on similarity percentage analysis (SIMPER) and together accounting for > 97% of fishes observed are in bold. Asterisks indicate exclusively juvenile life-history stages (see Online Supplement 4)

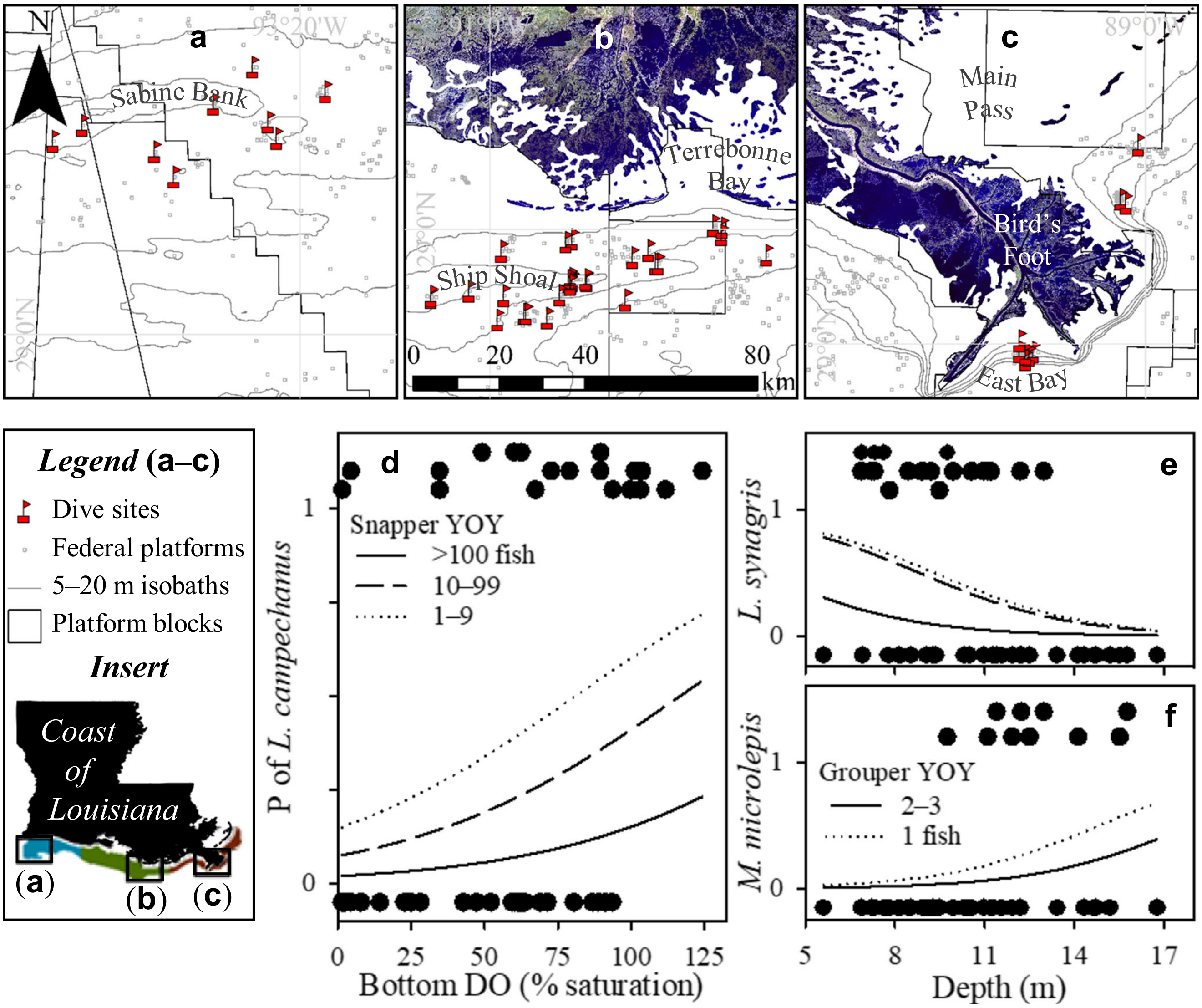

Fig. 6 Diver ordinal abundance data for young-of-the-year (YOY) red snapper (*Lutjanus campechanus*), lane snapper (*L. synagris*), and gag grouper (*Mycteroperca microlepis*) at 49 small nearshore platforms. Dive locations for the West, Central, and East nearshore coastal regions are shown as red flags in plots **a**–**c**, respectively. Hollow gray squares show the distribution of federally managed oil and gas structures. The irregular gridding shows the federal offshore leasing block areas. Contours are shown for the 5–20-m isobaths. Plot (**d**) shows the logistic regression predicting the probability (*p*) of the presence of three abundance categories (1–9, 10–99, and ≥ 100) of YOY *L. campechanus* with % saturation bottom dissolved oxygen (DO). Plot (**e**) shows the logistic regression predicting the probability of the presence of three abundance categories (1–9, 10–99, and ≥ 100) of YOY *L. synagris* with depth. Plot (**f**) shows the logistic regression predicting the probability of the presence of two abundance categories (1 or 2–3) of YOY *M. microlepis* with depth. The presence or absence observations are shown as black dots above (presence) or below (absence) each curve

Discussion

The Nearshore Zone—Louisiana's Offshore Estuary

The estuarine function of nearshore Louisiana is evidenced by the physicochemical characteristics of its waters (Munnelly et al. 2019b) and by the nursery role that it serves for a large number of commercially and ecologically important juvenile fishes. Most species and life-history stages observed in this study occurred coast-wide, with the exception of some rare species, such as dog snapper (*Lutjanus jocu*) and blue angelfish (*Holacanthus bermudensis*), which occurred only in the East, and *Epinephelus itajara* and *Pterois* spp. which were restricted to East Bay. Differences in the assemblage structure and composition occurring among the West, Central, and East regions of the nearshore zone were likely a result of physicochemical differences (salinity, temperature, DO, water clarity, and light penetration) associated with the different hydrographic regimes that characterize these regions (Munnelly et al. 2019b). Bolser et al. (2020) also noted strong alongshore differences in the distributions of platform-associated fishes at larger platforms sited in deeper waters, farther from shore, which coincided with differences in temperature, salinity, and DO. Interestingly, at small platforms in shallow, nearshore waters, more than half of all species observed were represented partially or wholly by age 1–2 or YOY juveniles (Online Supplement 4). Blaber and Blaber (1980) reported that shelf waters of the tropics may serve many of the roles associated with temperate estuaries and that variables such as turbidity are important in extending the nursery function beyond inshore waters. Within estuarine environments, distributions of marine species and life-history stages are influenced by tolerances to many physicochemical variables (Remmert 1983; Livingston 1988; Baltz et al. 1997; Baltz and Jones 2003) but are particularly sensitive to salinity gradients (Günter 1956). Freshwater influence is substantial in nearshore waters of the LCS ≤ 18 m deep, leading to varying brackish conditions throughout the coastal zone (Munnelly et al. 2019b). The nursery function that estuarine-marine ecotones like this serve is a defining characteristic that makes the shallow-water nearshore zone an important part of the coastal system (Able 2005).

The abundance of YOY *Lutjanus campechanus* and *L. synagris* was an important finding. Despite the abundance of juvenile fishes observed in this study, it has long been thought that juvenile fishes are largely absent from platforms in the Gulf (Scarborough-Bull et al. 2008). This was thought to contrast with the findings of Love et al. (2006, 2007), who reported high abundances of juvenile fishes at platforms within the nearshore Santa Barbara coast of California, including YOY for several species. Small platforms in nearshore waters of the LCS also provide a nursery function for juvenile fishes, albeit different than that provided by platforms in California waters for rockfishes. The most abundant YOY were *L. campechanus* and *L. synagris*, which numbered in the thousands at some small platforms sampled during this study (and in 2015 and 2016 as part of a related study). Severe hypoxia seemed to drive the bulk of them from our study sites by August of both summers, with a slight rebound in numbers occurring in September when bottom DO increased. This is expressed well in the logistic regression predicting the probability of occurrence of low to high abundance categories of YOY *L. campechanus* at small nearshore platforms (Fig. 6D).YOY *L. campechanus* are demersal and years of severe hypoxia have been linked to low recruitment in nearshore Louisiana waters (Switzer et al. 2015). Because patches of low DO are continuously shifting with variation in wind speed and direction, these and other site-loyal fishes (Workman et al. 2002) are likely to be forced to stay on the move in response to DO gradients that lead to suitably oxygenated bottom waters. It is also likely that many perish during severe events when they are forced to move up in the water column (Munnelly et al. 2019a), where they become more exposed to predators. Similarly, the greater probability of occurrence for YOY *L. synagris* as water depth decreased (Fig. 6E) might have been related to the shallower depths and reduced susceptibility to DO depletion encountered over sand shoals within nearshore waters. Alternatively, this could reflect the stronger estuarine association of *L. synagris*.

Relationships Between Fish Assemblages and Large-scale Habitat Characteristics

The striking differences between assemblages on shoals and the surrounding muddy seafloor may be attributed to a variety of factors. Physicochemical differences similar to those among the three nearshore regions of the LCS occur on a mesoscale over shoals, which additionally convey resistance to bottom water DO depletion (DiMarco et al. 2010; Reeves et al. 2018a; Munnelly et al. 2019b). The association with sand-dominated sediments by the majority of the 13 most abundant platform-associated fishes further suggests that sand shoals are important. Differences between shoal and non-shoal habitat could be related to their potential role as DO refugia for fishes within the hypoxic zone (Chesney and Baltz 2001; Craig and Bosman 2013; Reeves et al. 2018a), higher prey abundances and diversity on sand shoals (Dubois et al. 2009; Reeves et al. 2019), and species-specific preference for coarser sediments or shallower depths. While accounted for in our modeling approach, the greater number of sand shoals in the Central and West regions could in part explain higher diversity in these regions. It is possible that there is a spill-over effect of shoals that contributes to diversity on shoal and non-shoal habitat. For instance, larger refugia for benthic species impacted by hypoxia, such as red drum (*Sciaenops ocellatus*), black drum (*Pogonias cromis*), and Southern stingray (*Dasyatis americana*), could help promote the persistence of these species on shoal and non-shoal habitats in the central and western regions.

The number of pilings influenced Shannon-Weiner diversity and assemblage composition, but its ecological impact was not substantial at the 1–10 piling range of complexity for the small platforms sampled. Shannon-Weiner diversity increased slightly with platform complexity. At the species level, higher numbers of *Archosargus probatocephalus*, *Lutjanus griseus*, and adult *L. campechanus* were associated with higher numbers of pilings. Barnacles are the primary fouling organism on platforms (Reeves et al. 2018c), and stone crabs reside on platforms in high abundances (Reeves et al. 2017). *A. probatocephalus* primarily feed on barnacles and to a lesser degree, stone crabs (Reeves et al. 2018b, 2019). More off-bottom submerged structure likely provides them with a larger foraging base. Similarly, *L. griseus* are piscivorous and are known to graze on organisms associated with platforms (Reeves et al. 2018b). Conversely, adult *L. campechanus* seem to derive little nutrition from platform fouling and fouling-associated fauna (Davis et al. 2015;

Simonsen et al. 2015; Schwartzkopf et al. 2017; Dance et al. 2018), and probably aggregate at these sites for other reasons, although platform-dwelling amphipods (Beaver et al. 2003) might provide a foraging base for YOY fishes.

The most distinctive fish assemblage observed during this study was located in East Bay. East Bay is a small (~ 25 km across at its widest location) triangular embayment located between the Southwest and South passes of the "Bird's Foot" of the Mississippi River (Figs. 2 and 6C). Within East Bay are hundreds of Federal and state-managed platforms (Liu et al. 2018; BOEM 2019). Platforms in East Bay contained benthic invertebrates that were indicative of an area with consistently high salinities and stable temperatures, such as spiny lobster (*Panulirus argus*) and sun coral (*Tubastarea coccinea*). East Bay was the only location in shallow, nearshore waters of the LCS where *Pterois spp.* occurred. In East Bay we also documented the presence of three *E. itajara*, which marked the first confirmed identification of *E. itajara* in Louisiana waters in over 20 years (Louisiana Department of Wildlife and Fisheries, personal communication). Before they were fished to near extinction, *E. itajara* were commonly observed off the Louisiana coast around platforms in waters < 50 m water depth (Sonnier et al. 1976; Franks 2005). They are now believed to be recovering in the nGOM (Porch and Eklund 2004; NMFS 2006; Collins et al. 2015) and their presence in East Bay may be an indicator of this recovery. Additionally, the mature-sized *E. itajara* were observed during peak spawning season (Bullock et al. 1992). *E. itajara* tend to aggregate around high-relief artificial and natural habitats to spawn (Porch and Eklund 2004; NMFS 2006; Collins et al. 2015), and evidence has shown that their spawning range may be expanding northward (Malinowski et al. 2019). Although we cannot confirm spawning, all this evidence suggests that these fish may have been aggregating to spawn around platforms in East Bay.

Interestingly, we never observed bottom water DO concentrations of East Bay to fall below 2.0 mg l^{-1} and rarely observed water depleted below 50% saturation (~ 3.0–3.5 mg l^{-1}; only 9% of samples). The 50% threshold is stressful for many fishes (Breitburg 2002) and commonly avoided by platform-associated fishes in nearshore Louisiana waters (Munnelly et al. 2019a). Waters of East Bay were the most highly stratified sampled, with nearly fresh water occurring within 3 m of the surface and fully marine conditions below. Upwelling of well-oxygenated waters may reduce the frequency and intensity of bottom water DO depletion in East Bay despite its most immediate proximity to the source of eutrophication in the region (i.e., river nutrients and strong stratification). Well-oxygenated bottom waters made the relatively high salinities, low temperatures, and low light levels (due to high surface turbidity) of the bay accessible to fishes which appeared to be larger than other areas sampled across the coast (although we lack length data to provide quantitative comparisons). Although there were differences in the occurrence of rare species between East Bay and the rest of the East region, they were grouped in the analyses because many features of East Bay embodied the most extreme characteristics that typified the East region: intensely stratified waters over a narrow part of the LCS. There were fundamental similarities between the common species that occupied both locations, namely abundant adult *L. campechanus* and *L. griseus*. Also, some uncommon species, adult *L. jocu* and *H. bermudensis*, were found in both locations, but nowhere else in the nearshore coastal zone.

Variation of Platform-Associated Fishes Between the Summers of 2013 and 2014

Inter-annual changes in fish assemblages were substantial and likely related to a number of factors known to influence recruitment dynamics, including freshwater discharge and the abundance of *Sargassum*. Characterizing inter-annual changes was not an objective of our study, as the study's duration (2 years) prevents this type of analysis; however, it was necessary to account for inter-annual effects because they were the largest source of variation for all analyses. Below, we briefly discuss some of the potential drivers of the differences we observed between 2013 and 2014.

Inter-annual differences in freshwater discharge may partly explain differences observed in the fish assemblages. The East is the most highly stratified region due to the large amount of freshwater discharge and the deep point of entry into the Gulf. The high stability of density and salinity stratification (Munnelly et al. 2019b) might explain the lack of a difference between East fish assemblages sampled in 2013 and 2014. The Central region of the nearshore zone is subject to greater variability from river discharge than the East or West regions due to the shallow point of entry of the Atchafalaya River into the Gulf and the presence of high-relief sand shoals that promote mixing but can also allow strong stratification with high dishcharge and south or west winds (Munnelly et al. 2019b). Freshwater discharge from May through September was ~ 25% higher in 2013 than in 2014 (USGS 2019), and stratification patterns in the Central region were more similar to those in the East (Munnelly et al. 2019b). Because freshwater on this part of the shelf is known to have a protracted residence time during these months (Cochrane and Kelly 1986), higher spring and summer discharge in 2013 and predominance of south and west winds might explain the similarity of fish assemblages at platforms in the Central and East regions in 2013. The West region receives the lowest quantity of freshwater discharge and appeared to be more strongly influenced by Loop Current eddies that can deliver offshore water masses and *Sargassum* drifts from the interior of the Gulf to the Texas and Louisiana coastlines (Gower et al. 2006; Gower and King 2011; Zhong et al. 2012; Webster and Linton 2013).

Inter-annual variation in fish assemblages at shallow, nearshore platforms may have also been related to differences in the abundance and distribution of *Sargassum* drifts. In 2013, substantial windrows of *Sargassum* were only observed in the West region, while in 2014, a notable influx of *Sargassum* was observed throughout most of Louisiana's nearshore coastal zone (Reeves 2015; Munnelly 2016). The 2014 event is currently the largest on record for the Gulf (Hill 2016). Many *Sargassum*-associated fishes made up the majority of fishes observed at platforms during this study and were responsible for driving most of the regional differences in assemblage composition, including the following: *Chloroscombrus chrysurus*, *Caranx crysos*, *Pomatomus saltatrix*, *Abudefduf saxatilis*, *Kyphosus sectatrix*, *Balistes capriscus*, and YOY *Seriola dumerili* (Dooley 1972; Bortone et al. 1977; SAFMC 2002; Wells and Rooker 2004a, b; Taylor 2015). Platforms in Louisiana's highly productive nearshore waters seemed to have provided habitat for young *Sargassum*-associated species when the drifts they were following dispersed or become wracked upon beaches.

Implications of Platform Removals and Considerations for Artificial Reef Deployment

It is important to thoroughly understand the ecological role of any habitat type, be it man-made or natural. This is particularly relevant for platforms because of the high densities of fishes and other sea life associated with them and the unique nature of the habitat they provide. Under federal law, oil and gas platforms are required to be removed within 1 year of ceasing production (Reggio 1987). About 65% of the < 5300 decommissioned platforms in the nGOM have been removed using explosives (BSEE 2019). The majority of fish biomass associated with platforms sampled in this study is located within close proximity of the jacket (Stanley and Wilson 1998; Reeves et al. 2018a). Because explosive removal mortally concusses or outright kills fishes within 50 m of the structure (Gitschlag 1997)—which would include the vast majority of the fishes observed throughout this study—explosive removal results in an unfortunate loss of life that is likely representative of a much larger area of occupancy for some species (such as *L. campechanus*). Current precautions to avoid harming protected species are limited to surface-based sea turtle and marine mammal monitoring (Kaiser et al. 2002). Of the 50 federally managed platforms that have been removed in East Bay since the 1960s (BOEM 2019), 22 platform removals, or 44%, have used explosives (BSEE 2019). This is concerning given the presence of the once critically endangered and still threatened *E. itajara* in the area and its strong association with complex artificial structure (Porch and Eklund 2004; NMFS 2006; Collins et al. 2015).

The high-relief profiles of platforms extending to the surface and beyond provide a unique resource. For reef-associated species, platforms have traditionally been the only features prominent enough to offer refuge over hypoxic bottom waters (Stanley and Wilson 2004; Reeves et al. 2017, 2018a; Munnelly et al. 2019a); however, lower relief artificial reefs might provide adequate replacements if carefully sited to ensure that the vertical relief is sufficient to provide habitat in suitably oxygenated water column strata. The reduced susceptibility of major sand shoals of the LCS to sustained and severe DO depletion makes them good locations for artificial reef planning to help mitigate some of the reduction of platforms. Artificial reef deployments over mud bottoms create additional challenges with subsidence and the increased prevalence of hypoxia (Munnelly et al. 2019b), which is particularly intense just west of the Mississippi River (Rabalais et al. 2002b). The only mud-bottom location in the East and Central regions where moderate-relief artificial reef deployment might be effective is East Bay, as bottom waters there tended to be well-oxygenated. East Bay may be a particularly ideal deployment area given the abundance of biofouling organisms such as soft corals, the presence of spiny lobster, and potentially high abundances of *E. itajara*.

Since the mid-twentieth century, the nearshore waters of Louisiana have been in a state of constant change due to many large-scale anthropogenic stressors. The system has proven resilient, owing in part to community-level changes in the biota (Chesney et al. 2000; Cowan et al. 2008). The construction of 7152 federally managed platforms (thousands more exist in state waters) in the nGOM from 1942 to 2018 (BOEM 2019) has undoubtedly altered the overall community composition of the nGOM (Gallaway and Lewbel 1982; Krahl 1986; Gallaway and Cole 1999; Scarborough-Bull et al. 2008), and numbers of reef and reef-associated fishes in the nGOM may decline with continued platform removal (Krahl 1986; Gallaway and Cole 1999; Scarborough-Bull et al. 2008). At the end of 2018, there were 1868 federally managed platforms (discounting 81 without installation or removal date information). This is a dramatic decline from nearly 4000 platforms in 2006. A total of 64 of the 150 platforms videoed during this study have since been removed, of which 29 were removed using explosives (BSEE 2019). Platform removal probably constitutes a significant disturbance to platform-associated biota. Although efforts are underway to replace some of this habitat through placements of reef modules and other lower relief artificial reef materials, it is uncertain how populations of reef fishes will respond, especially in shallow, nearshore waters of the LCS where the vertical relief of platforms often spans a wide range of environmental conditions that are continuously changing.

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