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A Decade of Monitoring Reveals a Dynamic Fish Assemblage on a Substantial Artificial Reef in the Texas Gulf of Mexico

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ABSTRACT

Fish communities on artificial reefs have rarely been monitored over long periods to evaluate success of reef deployment. Here, we used roving diver surveys to assess changes in fish assemblages on a large, reefed vessel during 2008–2017. Multivariate analyses revealed a dynamic community that stabilized after 5 years. Species richness increased and species dominance decreased during 2008–2017. The fish community shifted toward reef-associated species such as hogfish and pufferfish. Species composition shifted, but trophic structure was relatively stable, which suggested that functional groups may not reflect larger community shifts. Our results indicate that fish communities on artificial reefs are temporally dynamic and that long-term monitoring is needed to understand how fish assemblage structure changes through time.

1 | Introduction

Artificial reefs (ARs) are a common tool for marine resource and ecosystem management around the world (Baine 2001; Becker, Taylor, and Lowry 2017). Most ARs are constructed to increase production and expand fishing opportunities (Lindberg 1997; Smith, Lowry, and Suthers 2015; Bracho-Villavicencio, Matthews-Cascon, and Rossi 2023). Secondary production often increases on ARs (e.g., Grossman, Jones, and Seaman Jr. 1997; Cresson, Ruitton, and Harmelin-Vivien 2014; Smith, Lowry, and Suthers 2015) and some ARs are among the most productive marine habitats in the world (Claisse et al. 2014; Smith et al. 2016). As a result, recreational and commercial fishers are often highly supportive of AR development (Lindberg 1997; Tessier et al. 2015; Streich et al. 2017). However, the attraction of fish to ARs, coupled with potentially increased fishing pressure, has prompted researchers to suggest that AR deployment should have specific goals and long-term monitoring plans to measure success (Baine 2001; Dance, Patterson III, and Addis 2011; Becker, Taylor, and Lowry 2017; Becker et al. 2018; Brochier et al. 2021; Pondella, Claisse, and Williams 2022; Bracho-Villavicencio, Matthews-Cascon, and Rossi 2023).

Assessing fish assemblages after AR deployment is a vital component of AR evaluation (Leitao et al. 2008; Becker, Taylor, and Lowry 2017; Lee, Cintra-Buenrostro, and Shively 2018; Bracho-Villavicencio, Matthews-Cascon, and Rossi 2023). Recent research has also studied community composition and structure to inform marine rehabilitation efforts (Lee, Otake, and Kim 2018). Methods that have proven effective for assessing AR communities include visual diver surveys, baited remote underwater videos, and remotely operated vehicles (Bracho-Villavicencio, Matthews-Cascon, and Rossi 2023). Comparisons between ARs and natural reefs are highly important (Carr and Hixon 1997; Becker, Taylor, and Lowry 2017) and some have found that species abundance, density, and richness are higher on ARs than on natural reefs or reference sites (Thanner, McIntosh, and Blair 2006; Boswell et al. 2010; Streich et al. 2017; Bracho-Villavicencio, Matthews-Cascon, and Rossi 2023). However, fish assemblages on ARs tend to differ from nearby natural reefs (Froehlich and Kline 2015; Arney, Froehlich, and Kline 2017; Becker, Taylor, and Lowry 2017). For example, the community composition of reefed platforms differed significantly from adjacent natural reefs in the Gulf of Mexico, largely driven by transient midwater pelagic species at AR sites (Streich et al. 2017). Because ARs do not always perform like natural reefs, they require prior planning and ongoing management (Baine 2001; Becker et al. 2018; Brochier et al. 2021).

Most ARs have not been monitored for more than 4 years, likely due to the effort and resources required to assess communities over time (Cresson, Ruitton, and Harmelin-Vivien 2014; Bracho-Villavicencio, Matthews-Cascon, and Rossi 2023). Studies of faunal communities over a long period have generally documented extended changes in species composition before a steady state is reached (Bohnsack and Sutherland 1985; Coll et al. 1998). In general, equilibrium community structure is usually achieved in 1–5 years (Bohnsack and Sutherland 1985). However, a visual census of fish populations on an AR in Italy found that species richness and diversity increased over a 10-year period, which suggested that community stabilization was a slow, long-term process (Relini et al. 2002). Similarly, trophic groups fluctuated as community structure stabilized over time on ARs in Florida (Dance, Patterson III, and Addis 2011) and France (Cresson et al. 2019). Overall, long-term studies can be effective for assessing AR success based on reefing goals (Baine 2001; Becker, Taylor, and Lowry 2017).

The Gulf of Mexico contains the largest AR complex in the world, consisting mainly of oil and gas platforms, that provide habitat in a region where natural reefs are relatively rare and have become an important part of fishing culture (Streich et al. 2017). In addition, groups around the world have looked to reefing policies in the Gulf of Mexico to inform decisions on decommissioning of reefing platforms elsewhere (Ajemian et al. 2015). The Texas Parks and Wildlife Department (TPWD) operates one of the largest AR programs in the world (Kaiser and Pulsipher 2005). Established in 1990, the Texas Artificial Reef Program (ARP) has a clear goal to enhance fishery resources and commercial and recreational fishing opportunities. To achieve this goal, an AR Biological Monitoring Program gathers baseline fish assemblage data at representative AR sites to characterize temporal community dynamics.

Here, we utilized long-term monitoring data collected from one of Texas' most popular ARs, the Texas Clipper artificial reef, to determine if fish assemblages changed over time to a stable equilibrium. To achieve our objective, we (1) quantified community composition after reef deployment, (2) evaluated assemblage diversity to identify predominant species, and (3) described patterns in fish trophic structure over a 10-year period. We also evaluated the length of time needed for monitoring after AR deployment to gauge reef effectiveness based on project goals.

2 | Methods

2.1 | Study Site

The USTS Texas Clipper is one of the most recognized ARs in the western Gulf of Mexico. Located 17 nm off South Padre Island, Texas, USA (26.18° N, 96.98° W) (Figure 1), the Texas Clipper was reefed on November 17, 2007 as part of TPWD's Ships-to-Reef Program. Originally a World War II troop transport vessel, the Texas Clipper is 145-m long and was sunk in 41 m of water as the fourth largest ship in the United States deployed as an AR. During the reefing process, the vessel settled on its port side ~23 m below the surface. The Texas Clipper has since become a very popular fishing and diving location, with significant revenue raised by local charter boats that booked trips to the Texas Clipper (Braddy et al. 2016).

2.2 | Roving Diver Surveys

Long-term monitoring of the Texas Clipper by the University of Texas—Rio Grande Valley is part of the TPWD ARP's Biological Monitoring Program. Fish communities were monitored using visual diver surveys during 2008–2017. Visual surveys have been the preferred method to monitor fish assemblages on ARs (Bracho-Villavicencio, Matthews-Cascon, and Rossi 2023) and surveys on the Texas Clipper followed the roving diver (RD) method that has been widely used as a rapid visual method for surveying reef fish communities (Schmitt and Sullivan 1996; Schmitt, Sluka, and Sullivan-Sealey 2002; Holt et al. 2013). The RD survey method has several advantages over other visual methods (transect-based for example), because it is nondestructive, easily applied to variable forms of ARs, and requires relatively little sampling equipment (Hicks et al. 2016). Roving surveys are better able to quantify fish biodiversity in reef ecosystems because surveyors can range over entire areas (Pattengill-Semmens and Semmens 1998; Holt et al. 2013; Hicks et al. 2016). Before conducting surveys, SCUBA divers were required to participate in proficiency dives and received identification training. Roving diver surveys on the Texas Clipper were quarterly during 2008–2017. ARP biological monitoring methods used to census the Texas Clipper are described in full by Hicks et al. (2016).

Divers conducting RD surveys recorded the presence and abundance of all fish species encountered. Surveys were standardized to 30–40 min and conducted in less than 40-m depth based on allowable bottom time. Fish were identified to the lowest possible taxonomic level, and abundance was categorized as approximate counts (1 = Single, 2–10 = Few, 11–100 = Many, > 100 = Abundant; SFMA). Analyses of SFMA counts have produced similar results to absolute counts and are effective for generating diversity estimates (Hicks et al. 2016). For statistical analyses, each date with a roving diver survey was treated as a sample. When divers conducted paired surveys on the same day, the highest abundance observed by either diver was used for each species. Categorized counts were transformed to log-normal values of rounded midpoint abundance: zero = 0, single = 1, few = 2, many = 4, and abundant = 6 (Hicks et al. 2016). The midpoint of the open-ended 'abundant' category was set at 1000 because surveyor counts rarely exceeded 1000 for any

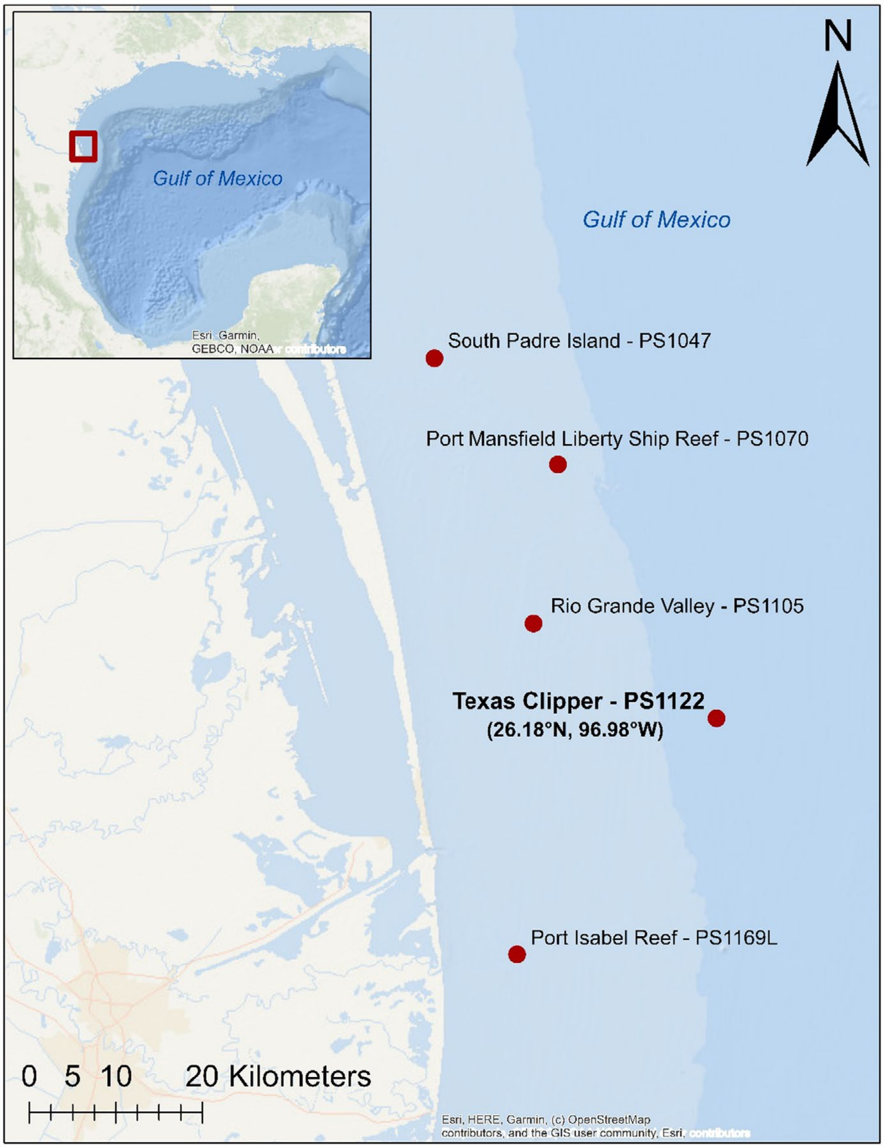

FIGURE 1 | Map of study area indicating the locations of artificial reefs in relation to the Texas Clipper artificial reef where fish species diversity was sampled during 34 roving diver surveys in the Gulf of Mexico during 2008–2017.

species (Hicks et al. 2016). In addition, previous side-scan sonar counts on the Texas Clipper estimated the total fish abundance of all species combined averaged <1200 (Bollinger and Kline 2017). In addition to fish counts, divers recorded general conditions, including survey depth, temperature, and visibility, based on dive-computer readings (depth and temperature) and visual estimates (visibility).

2.3 | Diversity Metrics

A species accumulation curve was used to evaluate effectiveness of long-term monitoring based on species richness and sampling effort. PRIMER-E was used to create curves that determined the cumulative number of fish species observed across samples (PRIMER-E version 7.0 software). Samples were successively amalgamated in the original chronological order of collection (Clarke and Gorley 2015). Species richness (S), Pielou's evenness (J), and Shannon's diversity (H′) were calculated using the DIVERSE routine (Table S1). Each diversity metric was calculated for all samples and normality was determined by visually assessing whether diversity data fit theoretical quantiles based on normal quantile plots. Since all diversity metrics were normally distributed, the effects of date, season, and the season*-date interaction on each diversity metric were estimated using a two-way analysis of variance. Significance was assumed when $\alpha \leq 0.05$. Temporal trends in diversity metrics over time were tested using linear regression, with date as the independent variable and H′, S, and J′ as dependent variables. The effect of season on each diversity metric was tested using Tukey–Kramer HSD post hoc comparisons. In addition to diversity metrics, k-dominance plots were used to assess effects of highly abundant species on community composition. Species rank (based on abundance) was plotted against cumulative relative abundance. Plots produced curves with samples binned by year to assess dominance across the study period.

2.4 | Community Composition

Fish assemblage data were used to test temporal changes in community composition. To test for temporal change in average community structure, a metric multidimensional scaling (mMDS) plot using Bray–Curtis similarity measures was used with bootstrapped averages among years. For each year, 30 bootstraps were estimated, and a trajectory overlay was used to describe community change over time. A one-way similarity percentage analysis (SIMPER) was used with Bray–Curtis similarity measures to identify which species contributed most to within-year similarity (Clarke and Gorley 2015). A 70% cutoff was used for cumulative species contributions per year. A similarity profile (SIMPROF) was used to test for evidence of multivariate structure based on clustering (Somerfield and Clarke 2013). To conduct the test, average abundance was calculated for each species each year. Similarity profiles identified a posteriori species groups whose standardized abundances were significantly similar across years. The routine used standardized abundances of the 25 most abundant species. A Bray–Curtis similarity matrix was created, and cluster analysis was used to identify groups (Clarke et al. 2014). Groups were then plotted to visualize abundance trends across years.

2.5 | Trophic Structure

To assess trophic structure on the reef and changes across time, all fish were assigned to one of six trophic levels: herbivore, planktivore, planktivore–invertivore, invertivore, piscivore–invertivore, or piscivore (Dance, Patterson III, and Addis 2011; Table 1). The percentage of each trophic group was calculated each year based on number of species. Trends in the percentage of each trophic group across years were used to visualize relative trophic group fluctuations after reef deployment. In addition, the abundance of each trophic group was estimated as the sum of all species in a given group during each survey. Mean abundance (mean ± SE) was then estimated for each trophic group based on all surveys. Herbivores were excluded from analyses because only one herbivorous species was observed during the study.

3 | Results

3.1 | Species Diversity

During 2008–2017, 34 RD surveys were conducted on the Texas Clipper (SM1) artificial reef. Survey depth ranged from 23 to 37 m, temperature ranged 14.4°C–29.4°C, and visibility ranged 1–30 m. Of 82 taxa observed, the average number of species per sample was 28.7 ± 10.6 (mean ± SD). The highest species count for a single diver survey was 47 in August 2016. Red Snapper *Lutjanus campechanus*, Sheepshead *Archosargus probatocephalus*, and Atlantic Spadefish *Chaetodipterus faber* were observed most often and were each only absent on one sample date. Other economically valuable species frequently observed (percentage of surveys observed) included Gag Grouper *Mycteroperca microlepis* (74%), Gray Snapper *Lutjanus griseus* (91%), Vermilion Snapper *Rhomboplites aurorubens* (74%), Rock Hind *Epinephelus adscensionis* (85%), Gray Triggerfish *Balistes capriscus* (74%), and Greater Amberjack *Seriola dumerili* (56%). The species accumulation plot showed that 85% of accumulated species were observed after 5 years (2012, Figure 2). However, new species were observed throughout the 10-year study period and three species were first observed in the last year of the study (2017).

Species richness and diversity, but not evenness, were significantly related to survey date and season (Table 1). The interaction between season and date was not significant for any diversity metric. Richness, evenness, and diversity all increased linearly during 2008–2017. Temporal trends in species richness and diversity were significant, but not species evenness (Figure 3) richness, evenness, and diversity were highest in autumn and lowest in winter. Species richness and diversity differed significantly between seasons, but not evenness (Figure 4). The most abundant species were of low dominance (< 20%) (Figure 5). This pattern was consistent across all years, but the most abundant species were more dominant during early years (> 7%, 2008–2010) than later years (< 7%, 2015–2017).

TABLE 1 | Analysis of variance effects of date, season, and the season×date interaction on species richness, evenness, and diversity (H′) of fish species observed during 34 roving diver surveys at the Texas Clipper artificial reef, Gulf of Mexico, during 2008–2017.

Diversity measure	Factor	df	Sum of squares	*F* ratio	Prob > *F*
Species richness	Date	1	1244.61	34.87	< 0.001
	Season	3	1377.86	12.87	< 0.001
	Season*Date	3	211.78	1.98	0.14
Evenness	Date	1	0.01	3.35	0.08
	Season	3	0.01	1.23	0.32
	Season*Date	3	0.01	0.63	0.6
Diversity (H′)	Date	1	2.33	25.35	< 0.001
	Season	3	2.28	8.27	0.001
	Season*Date	3	0.49	1.76	0.18

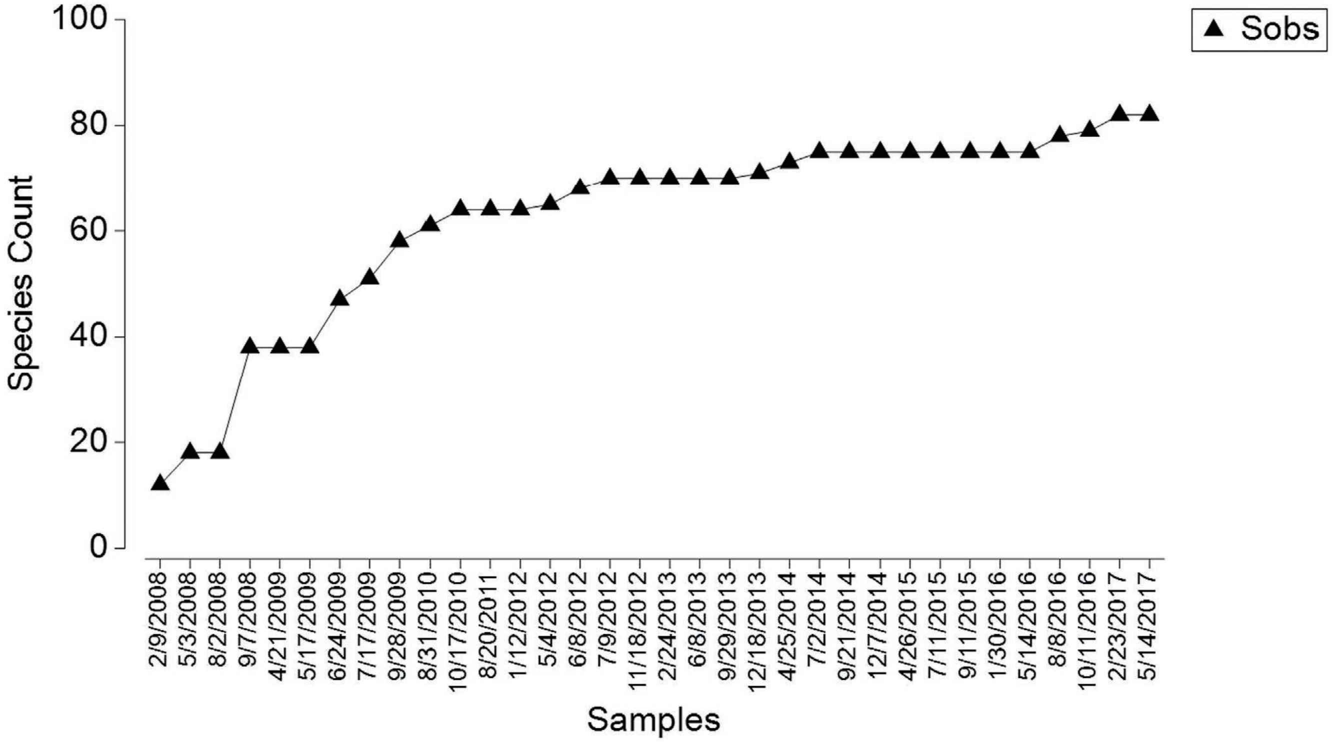

FIGURE 2 | Species accumulation plot for number of species observed during 34 roving diver surveys at the Texas Clipper artificial reef, Gulf of Mexico, during 2008–2017.

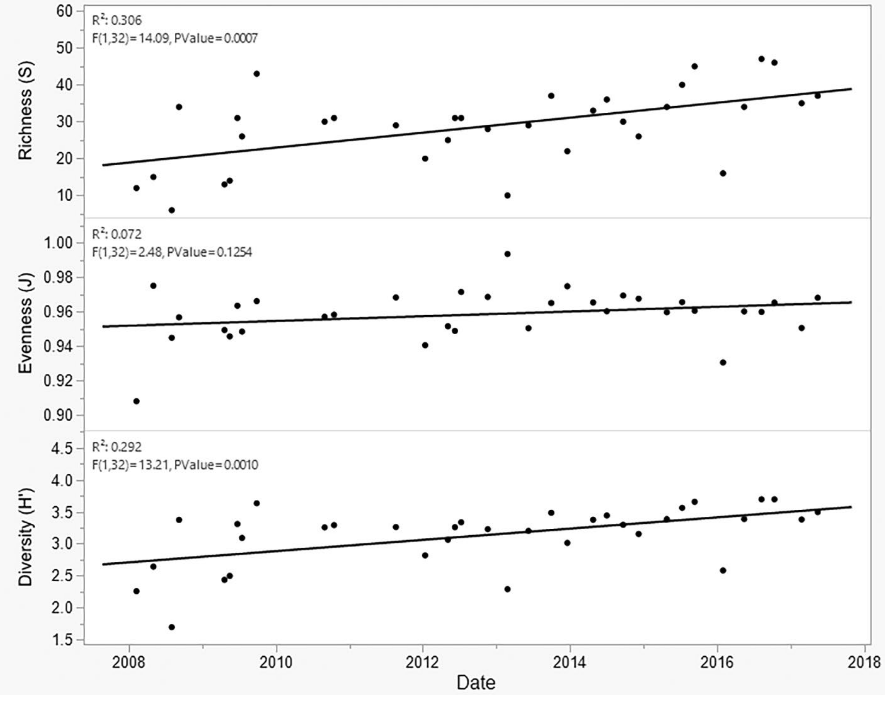

FIGURE 3 | Fish species richness (S), evenness (J), and diversity (H′) observed during 34 roving diver surveys at the Texas Clipper artificial reef, Gulf of Mexico, during 2008–2017. Linear regressions illustrate temporal trends during 2008–2017.

3.2 | Community Composition

Community composition shifted over time (Figure 6). Community composition was greatest during early years (2008–2011) and was relatively stable after 2012. Average within-year similarity ranged 46.2%–75.3%. Species that contributed most to within-year similarity were Red Snapper (2008, 2013, and 2016), Gray Snapper (2010, 2012, and 2017), Blue Runner (2009), and Atlantic Spadefish (2014 and 2015). Community composition was least similar between 2011 and 2012 (36.9%) and most similar between 2008 and 2015

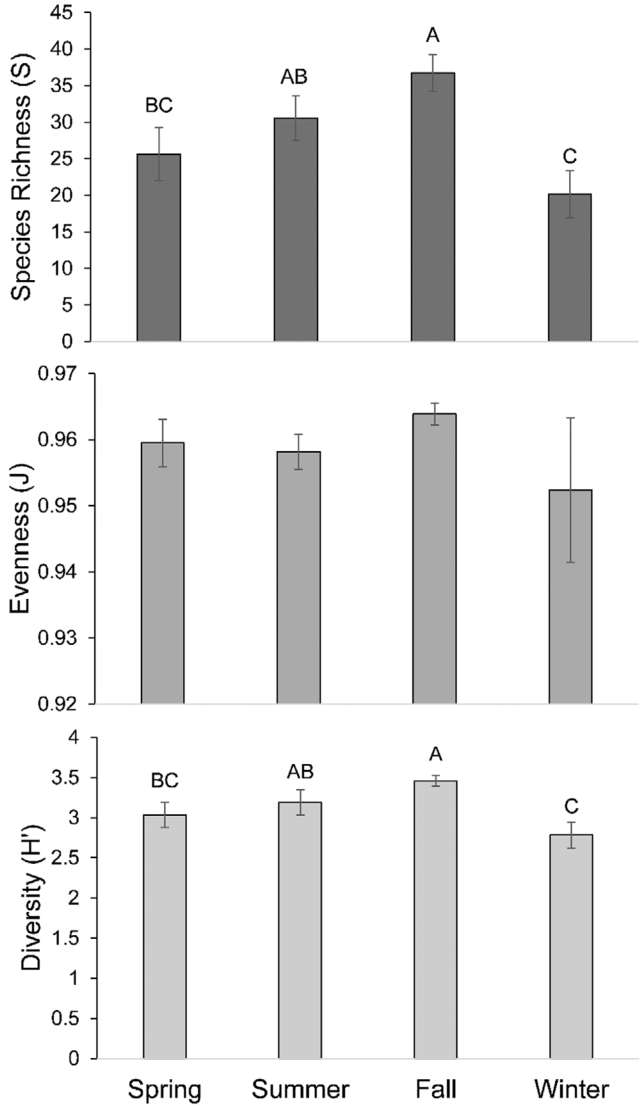

FIGURE 4 | Average fish species richness (S), evenness (J), and diversity (H′) in spring, summer, fall, and winter observed during 34 roving diver surveys at the Texas Clipper artificial reef, Gulf of Mexico, during 2008–2017. Values are means with error bars representing standard error. Connecting letters indicate significance at $p < 0.05$.

(69.9%). A variety of species contributed to dissimilarity among years, but reef-associated species like Hogfish *Bodianus* spp. and Pufferfish *Canthigaster* spp. generally contributed most to dissimilarity between early years (2007, 2008) and later years (2013–2017), when abundance was higher.

Nine clusters were identified based on standardized abundances among years (Figure 7). Clusters included many economically valuable species, including some that decreased in abundance (Red Snapper, Gray Triggerfish) and others that increased in abundance (Gray Snapper and Vermilion Snapper) during 2008–2017. The largest defined cluster (seven species) contained many reef-associated species like Hogfish and Pufferfish that were more abundant later in the study (2014–2017) than early in the study (2008–2009). Of nine defined clusters, four contained only one species and were characterized by highly variable abundance.

3.3 | Trophic Structure

Species from every trophic group were observed during each year of the study (Figure 8). Invertivores were the most common of all species during 2008–2017 (38.4%), followed by invertivore–piscivores (27.5%), planktivores (12.2%), piscivores (11.0%), and planktivore–invertivores (10.9%). Mean abundance was highest for piscivore–invertivores (844.4 ± 577.0), followed by invertivores (776.5 ± 569.3), planktivore–invertivores (631.3 ± 566.8), planktivores (164.1 ± 253.8), and piscivores (40.2 ± 38.0). Abundance was highly variable for each trophic group, without temporal trends during 2008–2017. Overall, some trophic groups were more predominant, but the number of species was relatively consistent across years.

4 | Discussion

4.1 | Fish Community

Reef species such as hogfish, damselfishand pufferfish that were observed in greater numbers during later years likely increased due to the development of complex encrusting communities on the Texas Clipper after its deployment (Dance, Patterson III, and Addis 2011). Epibenthic communities that include macroalgae, bryozoans, sponges, corals, and barnacles facilitate increased species diversity on ARs (Redman and Szedlmayer 2009). These organisms likely provide food resources for reef fish on ARs and support greater abundance of multiple species (Redman and Szedlmayer 2009; Dance, Patterson III, and Addis 2011; Becker, Taylor, and Lowry 2017). In addition, epibenthic community composition can change on ARs over long periods of time that may affect fish species utilizing specific habitats (Perkol-Finkel and Benayahu 2005; Thanner, McIntosh, and Blair 2006). In addition to epibenthic community development, increased species diversity on the Texas Clipper could have been driven by environmental conditions (i.e., increased water temperature) (Fujiwara et al. 2019). Regardless, reef-associated species were largely responsible for increased species diversity and decreased species dominance over the study period.

Trophic structure was more consistent and relatively balanced early in our study, despite fluctuations in the number of species within some groups, similar to an earlier study (Dance, Patterson III, and Addis 2011) in which invertivore-piscivores and invertivores were most abundant on the Texas Clipper. Piscivores were a consistently small percentage of the community over time, while invertivores and invertivore-planktivores were the only trophic groups whose percent abundance fluctuated noticeably across years, but without temporal trends. After a neighboring offshore petroleum platform (~3 km away) was removed in 2013, divers anecdotally noted a substantial increase in the number of Great Barracuda (*Sphyraena barracuda*) inhabiting the Texas Clipper. Great Barracuda are well known for their affinity to ARs and may have moved to the Texas Clipper as other structures were removed. While difficult to assess here, establishment of resident piscivores like Great Barracuda on ARs has been known to affect the densities of other fishes and may have influenced other

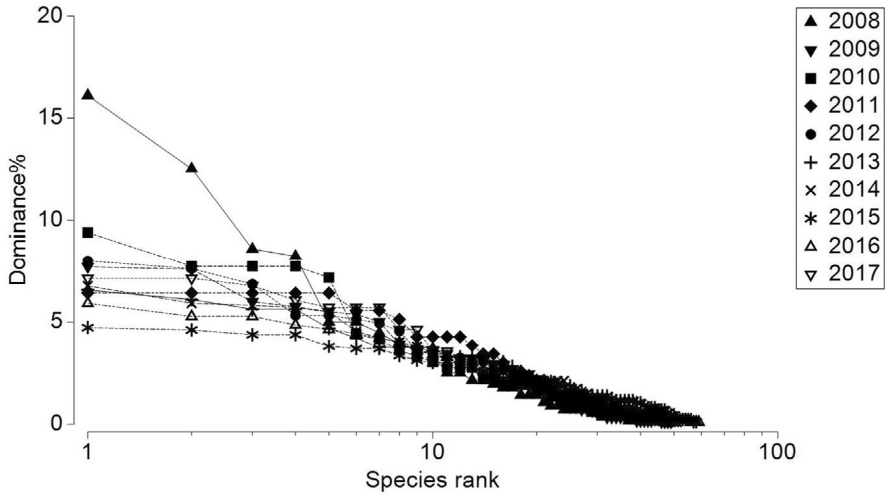

FIGURE 5 | K-dominance plot displaying cumulative ranked abundance for species observed during 34 roving diver surveys at the Texas Clipper artificial reef, Gulf of Mexico, during 2008–2017.

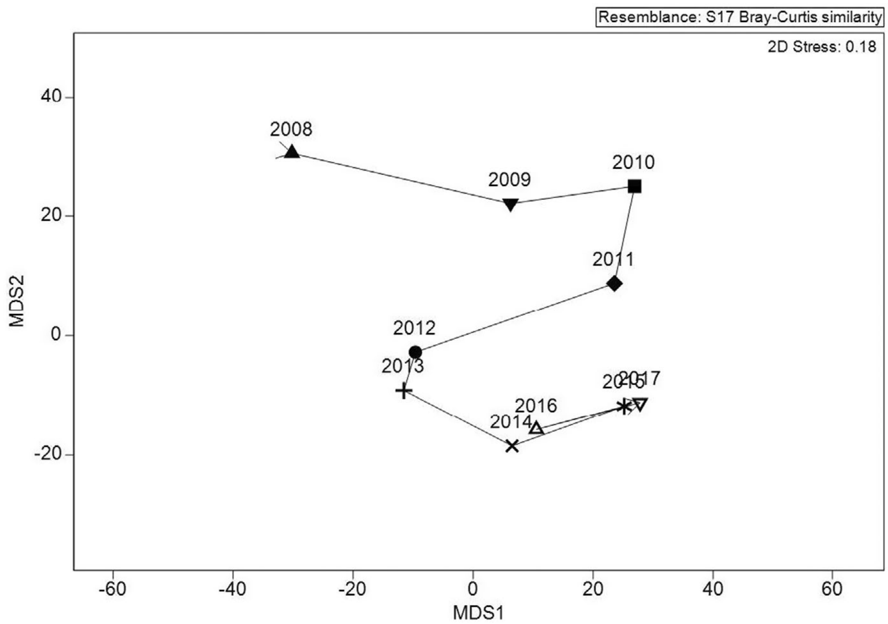

FIGURE 6 | Multiple dimension scaling (MDS) axes 1 and 2 of species observed during roving diver surveys at the Texas Clipper artificial reef, Gulf of Mexico, during 2008–2017. Points are group means of bootstrapped averages repeated 30 times and a trajectory line connects years.

species or trophic groups significantly (Carr and Hixon 1997; Herrera et al. 2002).

Evidence for the fluctuation of several trophic groups could have major implications for the functional ecology of ARs. Based on the numbers of species and abundance, a balance between trophic groups was apparent after 5 years after deployment of the Texas Clipper. The species accumulation curve also indicated that most species had been observed at year 5, although new species were found later due to continued sampling efforts or succession. These results align well with the relatively balanced community composition observed after year 5 of our study and justify long-term monitoring of ARs for at least 5 years. Assessing structural and functional community changes on ARs may be important for determining effectiveness because functional groups may display different responses than the fish community as a whole (Cresson et al. 2019). In addition, exploring effects of habitat loss in surrounding areas on reef community composition could help to explain some temporal variation in fish assemblages.

Despite community shifts, species composition on the Texas Clipper was similar to other ARs in the Texas Gulf of Mexico (Ajemian et al. 2015; Froehlich and Kline 2015; Arney, Froehlich, and Kline 2017; Streich et al. 2017). High site fidelity of species like Red Snapper has been previously recorded on Ars, including the Texas Clipper, and many fishes we recorded are classified as resident species (Dance, Patterson III, and Addis 2011; Froehlich et al. 2021). Many economically valuable species could be considered residents but contributed greatly to dissimilarity in community composition among years. For example, Red Snapper and Gray Triggerfish were highly abundant, but their numbers declined during 2008–2017. Conversely, Vermilion Snapper and

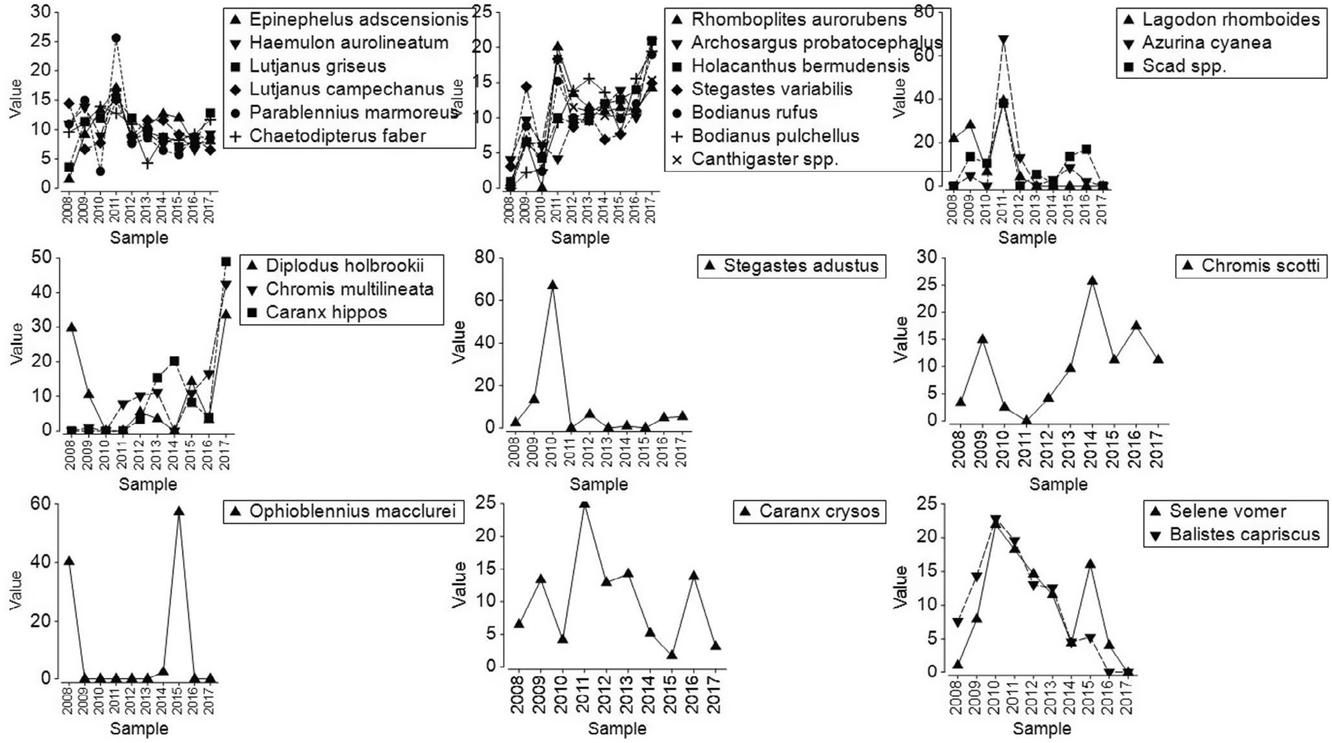

FIGURE 7 | Groups of coherent curves based on standardized Single, Few, Many, Abundant (SFMA) abundance data for species observed during roving diver surveys at the Texas Clipper artificial reef, Gulf of Mexico, during 2008–2017. Type 3 SIMPROF tests at a 5% significance level used the 25 most abundant species and yielded nine distinct groups. Groups were plotted to identify suites of species with similar trends in relative abundance during 2008–2017.

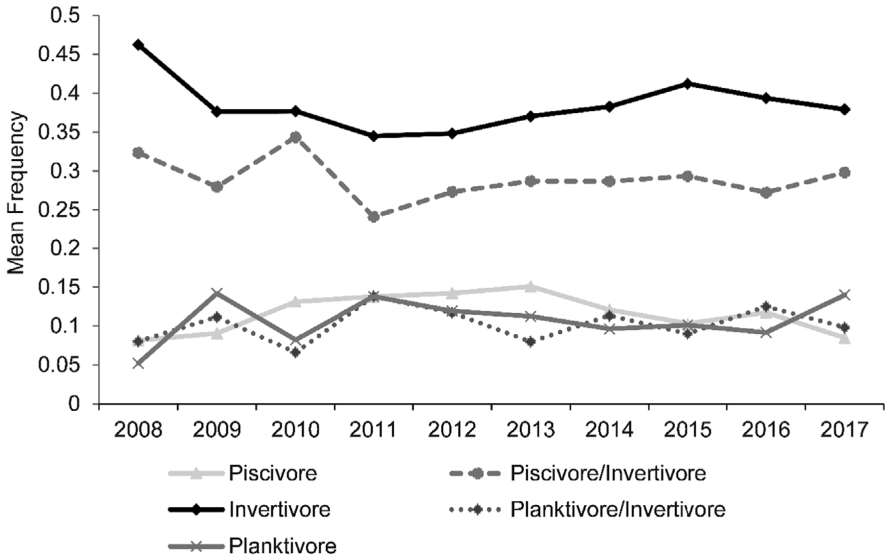

FIGURE 8 | Percent contribution of the number of species within trophic groups (excluding herbivores) observed during 34 roving diver surveys at the Texas Clipper artificial reef, Gulf of Mexico, during 2008–2017.

Gray Snapper increased in abundance. Such temporal trends may be caused by changes in fishing pressure after the Texas Clipper was reefed. Fishing pressure likely increased in years after deployment as anglers became more familiar with the site. Red Snapper and Gray Triggerfish are two of the most-sought fish in the Gulf and were likely among the most exploited species on the reef. Conversely, Gray Snapper and Vermilion Snapper may have been less targeted by anglers and able to take advantage of a less competitive environment. While valuable species were always present, shifts in composition may have implications for managers seeking to increase fishing opportunities.

Compared to diver surveys of ARs around the world, species richness on the Texas Clipper was high (Herrera et al. 2002; Relini et al. 2002; Leitao et al. 2008). Despite different survey methods, other studies in the northern Gulf of Mexico generally recorded fewer species than the 82 we observed (Dance, Patterson III, and Addis 2011; Ajemian et al. 2015; Froehlich and Kline 2015; Streich et al. 2017). However, earlier studies were all conducted on either different reefing materials (concrete culvert patches) or surveyed for a shorter period. Species richness in the northern Gulf of Mexico was higher on platforms than other platform types and ships (Ajemian et al. 2015). Here, mean species richness was higher than in earlier studies of standing and toppled platforms or ships (Ajemian et al. 2015). Similarly, species richness on reefed platforms included 30 species during a single survey (Streich et al. 2017). At the Texas Clipper, 56% of surveys recorded 30 or more species. Structures sampled previously either had high vertical relief (platforms) or large areas (ships with < 5 m vertical relief) but not both. High species richness at the Texas Clipper could be due to its high vertical relief coupled with its very large size, which provided diverse microhabitats and trophic niches (Becker, Taylor, and Lowry 2017). In addition, the Texas Clipper is farther south than other ARs studied in the northern Gulf of Mexico and may have more species due to settlement of both sub-tropical and tropical species.

4.2 | Roving Diver Surveys and Study Design

Roving diver survey methods, paired with SFMA fish counts, were an effective way to survey the Texas Clipper community composition. A decade of monitoring was successfully completed in part because divers were able to efficiently use SFMA counts for a variety of species, rather than spending survey time counting each individual fish. Roving diver surveys were successful in censusing resident species, but some functional groups may have been underrepresented in the data. Order-of-magnitude fish counts we used tend to record higher estimates of diversity than exact counts that underrepresent cryptic reef fishes and pelagic schooling species (Hicks et al. 2016). However, surface or midwater fishes that swarm to a reef, but generally stay at a considerable distance away from the structure (Bohnsack and Sutherland 1985), were difficult to observe. Large pelagic predators such as sharks were absent from RD surveys on the Texas Clipper despite being observed by at the site when surveys were not being conducted. These species were present in the area and have been documented on other ARs in the Gulf of Mexico (Dance, Patterson III, and Addis 2011). RD surveys were relatively ineffective for assessing pelagic species abundance and lack of nocturnal effort may have limited community structure metrics and trophic groups reported here. Last, due to the inaccessible depth that the Texas Clipper was reefed in (40 m), divers could not complete surveys near the bottom and may have fully represented the abundance of demersal species. Not only is long-term monitoring critical, but assessing communities with multiple gear types may be important to accurately describe the full range of species and trophic groups present on a reef (Plumlee et al. 2020).

The lack of a reference site or natural reef for comparison to the fish community on the Texas Clipper could be addressed by future research. However, previous studies have assessed natural reefs and bare areas in the northern Gulf of Mexico (Froehlich and Kline 2015; Arney, Froehlich, and Kline 2017; Streich et al. 2017). In general, much of the Gulf of Mexico is characterized by featureless mud-bottom and low species richness. In studies that compared ARs to nearby natural reefs, community composition differed between the two, but ARs attracted a high number of species at densities that exceeded natural reefs (Bracho-Villavicencio, Matthews-Cascon, and Rossi 2023). Other variables, such as visibility and temperature, can be important but were not examined in detail here. The presence of a strong nephloid layer on the Texas Clipper meant that visibility was not always consistent during a single dive. Season was evaluated and was closely tied to temperature, but future reseach should aim to determine how confounding variables like these, and larger climatic shifts, influence succession on artificial reefs or the effectiveness of roving diver surveys.

The high species richness and abundance of economically valuable species and high biomass on the Texas Clipper suggested that deployment met previously determined goals. Rapid colonization has generally been observed after deployment of most ARs, regardless of reef size or location (Bohnsack and Sutherland 1985; Leitao et al. 2008; Paxton et al. 2018). The Texas Clipper was reefed in November 2007 and the first visual dive survey in February 2008 recorded 12 species. In addition, all trophic groups were present and well-balanced during early years of the study. These results indicate that colonization was rapid in the Gulf of Mexico and the immediate presence of species like Red Snapper suggests that opportunities for anglers began soon after deployment.

Shifts in diversity and community composition reported here strengthen the assertion that long-term monitoring is essential when evaluating AR success. In our study, monitoring for at least 5 years was required to observe most succession, although new species were observed throughout the study through the last year. In addition, disturbances like hurricanes or harmful algal blooms could significantly impact the composition of stable communities. While the 10 years of monitoring in our study captured most of the initial succession on the Texas Clipper after deployment, additional changes would likely have been detected if monitoring continued.

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Ethics Statement

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available in Texas Parks and Wildlife Department at https://tpwd.texas.gov/.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.