

**A Review of the Ecological Performance and Habitat Value of Standing versus Reefed Oil
and Gas Platform Habitats in the Gulf of Mexico**

Final Report

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Executive Summary

In the northern Gulf of Mexico (GOM), approximately 1,800 oil and gas production platforms (hereafter “standing platforms”) function as de facto artificial reefs. As a large number of platforms are reaching the end of their production lifespans, some of these structures will be converted to permanent artificial reefs via state Rigs-to-Reefs (RTR) programs (many others have already been “reefed”), which involve partial removal or toppling of the platforms (hereafter “reefed platforms”) either in place or moved to alternate approved locations. The conversion of standing platforms into artificial reefs results in a structure with a lower vertical relief, and no physical connection to the upper water column. As decommissioned standing platforms are increasingly converted into artificial reefs, it is important to evaluate the ecological effects of this physical transformation on platform-associated communities. Furthermore, the number of standing platforms in the northern GOM continues to rapidly decline as removals through the decommissioning process exceed new installations. Thus, there is a central need for science-based decision making on the proper use of these structures and to establish the best management practices to maximize RTR programmatic goals. Here, we review the current state of scientific knowledge comparing the ecological function and habitat value of standing and reefed platforms in the northern GOM and identify critical information gaps in need of future research with special emphasis on the ecological functionality of standing platforms and performance related to upper-water column benefits.

Allowing platforms to remain standing would ameliorate the loss of biodiversity and fish biomass due to the loss of shallow water substrate. While the ~85-ft (26-m) clearance guidelines observed in current RTR practices reduce some aspects of biodiversity (e.g., upper water column species) associated with standing platforms; nevertheless, there is evidence to suggest that partially removed platforms do continue to provide an effective means of preserving the community structure and ecological functions associated with standing platforms, particularly for economically important species. Furthermore, reefed platforms retain the majority of the fish community in the lower depth strata, including species that are targeted by recreational and commercial fisheries. As a result, studies evaluating how standing and reefed platforms function to support fish populations in the GOM have primarily focused on the biological characteristics of the economically important red snapper (*Lutjanus campechanus*) given this species iconic status and importance as the most valuable reef fish in the GOM. As a demersal species, both standing and reefed platforms appear to provide suitable habitat with sufficient resources to support its biological needs. Though, the lack of similar trends among artificial and natural habitats in the northwestern and north-central GOM highlights the complex nature of habitat- and region-specific contributions to the GOM red snapper stock and warrants further investigation, especially into the loss of structure and function of habitat as well as los of species in the upper water column. Nevertheless, increased emphasis on a wider range of species, including other broadly distributed fisheries species of commercial and/or recreational value (e.g., greater amberjack, *Seriola dumerili*), and on whole-community and functional approaches will build towards a more mechanistic understanding of the broader ecosystem values provided by both standing and reefed platforms.

The extensive variability in marine life and environmental conditions such as water depth, distance from shore, size, and many other characteristics associated with existing standing platforms makes it difficult to establish a generic set of predictions regarding the ecological consequences of

different decommissioning alternatives. Hence, decisions should be made on a case-by-case basis using all available scientific information. As standing platforms in the GOM reach the end of their productive lives at an increasing rate, long-term monitoring studies are critically needed to empirically assess changes to community structure and functionality prior to and following reefing or complete removal. These studies will ensure that RTR programs are operating at maximum efficiency and performance as it relates to reefing goals, and facilitate data-driven decisions to determine which standing platforms would be most economically and ecologically viable to remain standing and/or converted to artificial reefs.

In summary, this comprehensive literature review identified several key findings comparing the ecological function and habitat value of standing and reefed platforms in the GOM:

- Allowing platforms to remain standing would ameliorate the decline in biodiversity and fish biomass due to the loss of shallow water (<26 m) substrate.
- Reefed platforms, especially partially removed platforms, continue to provide an effective means of preserving the community structure and ecological functions associated with standing platforms, particularly for economically important species. Thus, even some structure retained is highly valuable.
- At this time, the ecological consequences of different decommissioning alternatives and decisions should be made on a case-by-case basis by the platform owner in conjunction with resource managers until a scientifically informed set of predictions can be formulated based on short- and long-term monitoring studies.
- Future research, including long-term monitoring studies and increased emphasis on a wider range of species, is critically needed to fully understand the impact of decommissioning standing platforms and different reef configurations on the ecology and productivity of the GOM.

Introduction

The continental shelf of the northern Gulf of Mexico (GOM) is composed primarily of soft-bottom habitat with few distinct areas of high-relief natural reef, particularly in the northwestern region (Parker et al. 1983; Rezak et al. 1985). As of April 2019, there are 1,862 oil and gas production platforms¹ (hereafter “standing platforms”; BSEE 2020b) in the northern GOM (Fig. 1) that function as de facto artificial reefs by providing high-relief, hard substrate and the habitat complexity necessary for associated marine communities to thrive. As ‘Idle Iron’ policies have a large number of standing platforms that are reaching the end of their production lifespans slated for removal (Pulsipher et al. 2001; BSEE 2020a), some of these structures will be converted to permanent artificial reefs (hereafter “reefed platforms”) via state Rigs-to-Reefs (RTR) programs as a means to mitigate habitat loss. Decommissioned standing platforms have been converted to artificial reefs in the United States (U.S.), Brunei, and Malaysia and potential RTR options are currently being evaluated and conducted in other regions (Bull and Love 2019). Though, RTR programs have been most popular in the northern GOM where, as of April 2018, 532 decommissioned standing platforms (~11% of total decommissioned platforms since 1986²) have been “reefed” under state artificial reef plans (Bull and Love 2019; BSEE 2020c), with Louisiana and Texas having the largest RTR programs (Kaiser and Pulsipher 2005; Kaiser et al. 2020; Fig. 1). Collectively, these standing and reefed platforms along with other reefed materials (e.g., ships, prefabricated concrete pyramids, reef balls, etc.) comprise the largest artificial reef complex in the world (Dauterive 2000).

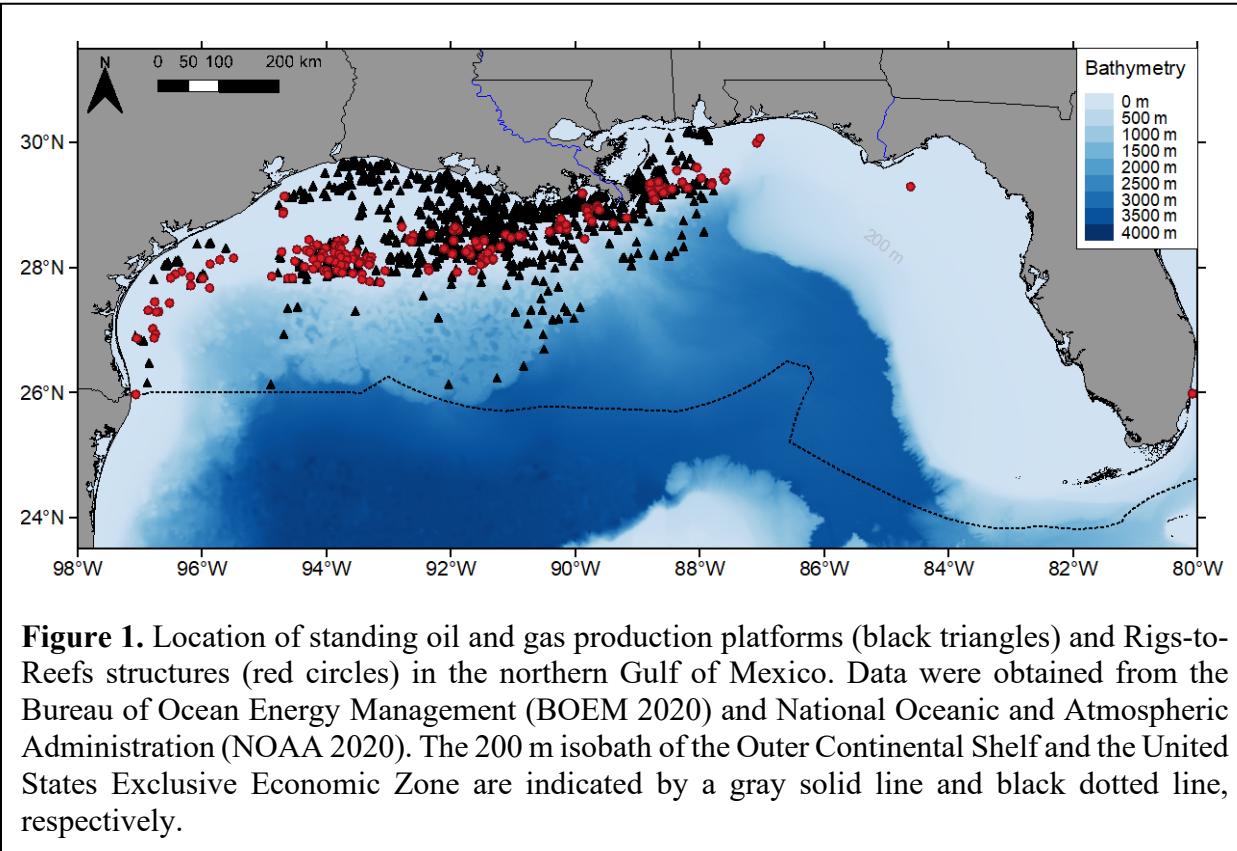
The conversion of standing platforms into artificial reefs results in a structure with a lower vertical relief and no physical connection to the upper water column. Current RTR guidelines generally require reefed platforms to maintain 26 m of clearance depth below the sea surface (without the installation and maintenance of navigational aids) to avoid navigational hazards to large vessels. This is accomplished by either: (1) partial platform removal (cut-off); (2) toppling the structure in place; or, (3) toppling the structure after towing to a designated reefing site (Dauterive 2000). As decommissioned standing platforms are increasingly converted into artificial reefs, it is important to evaluate the ecological effects of this physical transformation on platform-associated communities. Furthermore, the number of standing platforms in the northern GOM continues to decline as removals through the decommissioning process exceed new installations (Pulsipher et al. 2001; Kaiser et al. 2020). Thus, there is a central need for science-based decision making on the proper use of these structures and to establish the best management practices for RTR programs. In other regions of the U.S. and the world, many scientists, managers, and stakeholders look to policies in the GOM to help inform decisions related to decommissioning strategies elsewhere (e.g., Aabel et al. 1997; Jagerroos and Krause 2016).

With a growing source of material for RTR programs worldwide, the ecological benefits provided by standing and reefed platforms compared to the complete removal of platform structures, while debated (Gallaway et al. 2009; Shipp and Bortone 2009; Cowan et al. 2011; Quirolo and Charter 2014; Cowan and Rose 2016), have been thoroughly reviewed (e.g., Schroeder and Love 2004; Scarborough-Bull et al. 2008; Versar 2008; Macreadie et al. 2011; Fortune and Paterson 2018;

¹Includes approximately 456 caissons (~24%; BOEM 2020) that are deemed not suitable reef material and are rarely reefed (Kaiser et al. 2020).

²Increases to ~19% of total decommissioned platforms when excluding caissons (Kaiser et al. 2020).

Fowler et al. 2018; Fowler et al. 2020; Bull and Love 2019; Sommer et al. 2019; van Elden et al. 2019). However, there is presently a limited understanding of the habitat value retained by leaving a standing platform in place as an alternative to current RTR guidelines. Therefore, additional studies, starting with a comprehensive literature review of the current state of scientific knowledge, that compare the ecological function of standing and reefed platforms are especially important and timely. Thus, the **goal** of this review is *to synthesize the results of previous biological studies comparing the habitat value of standing and reefed platforms in the northern GOM and identify critical information gaps in need of future research.*



Methods

The Google ScholarTM database was accessed up to May 2020, to search for peer-reviewed journal publications, book chapters, and gray literature that compared standing and reefed platforms using the keyword combinations “standing toppled oil platform”, “partial removal oil platform”, and “Rigs-to-Reefs”. When available, peer-reviewed publications were the preferred source of information. The topic of oil and gas platforms as de facto artificial reefs and decommissioning strategies is a popular topic across multiple disciplines. The focus of this review is to compare ecological performance and habitat value among standing and reefed platforms in the northern GOM; therefore, we only reviewed biological studies and excluded other disciplines (e.g., socio-economic, political, legal, and engineering studies).

Literature Search Results

The literature search identified 123 publications between 1979 and 2020 focusing on the biological implications of standing platforms and RTR programs (Table A1, Appendix). The majority of these studies (76%) have been published since 2010, highlighting the growing importance of evaluating decommissioning strategies and the need for further research. By region, a total of 93 studies (76%) were conducted in the U.S. with 64 (52%) and 29 (24%) studies focused in the GOM and Southern California Bight (SCB), respectively. Out of 123 publications identified in the literature search, 19 studies (15%) directly compared standing and reefed platforms. We note a few studies combined standing and reefed platforms into a single artificial reef (e.g., Glenn et al. 2017; Schwartzkopf et al. 2017; Schwartzkopf et al. 2017) or platform (e.g., Sluis et al. 2013) category and do not make direct comparisons between them. While acknowledging some degree of overlap, these studies can be best summarized into three main categories: community composition and structure, fish biomass and density, and snapper (family Lutjanidae) biology.

Summary of Comparative Standing vs. Reefed Platform Research in the Gulf of Mexico

Community Composition and Structure

In the northern GOM, community composition and structure associated with standing and reefed platforms has been primarily quantified using visual census techniques combined with SCUBA diver-based surveys, manned submersibles, remotely operated vehicles (ROVs), and/or baited remote underwater video (BRUV) arrays. Dokken et al. (2000) was the first to compare standing and reefed platform communities for development of the most effective management strategies for the Texas Artificial Reef Program. Specifically, Dokken et al. (2000) compared epibenthic (e.g., sessile invertebrates and algae) and fish communities using SCUBA diver-based surveys across five standing platforms and two reefed platforms (toppled in place and cut-off) off the Texas coast. The cut-off platform (North Padre Island [NPI] 72A) was surveyed one year before being converted into an artificial reef (pre-cut), two-weeks post-cut, and one-year post-cut, allowing comparison of pre- and post-cut communities. Epibenthic and fish communities were similarly grouped based on a shallow to deep-water transition (with a few exceptions) across sites. Species diversity and richness declined slightly as soon as NPI 72A was cut-off, due to the physical loss of species (e.g., tree oysters, *Isognomon* spp.) that are confined to the upper portion of the structure; however, both diversity and richness increased one year after it was cut-off. Though, the epibenthic community composition underwent substantial change and may be indicative of successional change due to removal of the upper portion of the structure. The fish community of NPI 72A was overwhelmingly dominated by a large school of lookdowns (*Selene vomer*) occupying the upper portion of the structure during the pre-cut survey, whereas horse-eye jacks (*Caranx latus*) and other pelagic fish species increased in abundance during the post-cut surveys resulting in a more diverse fish community. In addition, some of the non-pelagic reef species encountered most frequently at shallower depths in the pre-cut survey increased in numbers at the deeper depths in the post-cut surveys due to removal of reef habitat above 28 m.

The high fish abundance observed on standing and reefed platforms relative to open, soft-bottom habitats may result in prey depletion as reef-associated predators forage near platforms. Daigle (2011) compared benthic and demersal communities at two standing and two toppled platforms

off the coast of Louisiana to assess potential prey depletion or other platform effects. Benthic and demersal communities were sampled using ponar grabs and bottom trawls, respectively, at sites near (0.25 km) and far (1.5 km) from each platform to evaluate potential differences with regards to distance and platform type. No discernable differences were observed in the benthic and demersal communities surrounding standing and toppled platforms; however, diel and seasonal patterns were detected. Logistical constraints prevented bottom trawls within 0.25 km of the toppled platforms; therefore, additional research is needed to further examine potential platform effects (e.g., prey depletion) on benthic and demersal communities in the area immediately adjacent to platforms (e.g., Montagna et al. 2002).

It is well established that standing platforms in the northern GOM support substantial coral communities (reviewed by Sammarco 2014). Though, there is limited information on the efficacy of lower-relief reefed platforms to support the growth and development of coral populations. Sammarco et al. (2014a) compared coral communities using ROV surveys across two standing platforms and five toppled platforms off the Texas and Louisiana coast. In contrast to Dokken et al. (2000), ROVs offer a robust survey tool for quantifying community composition and structure across a broader range of depths (>40 m) that are inaccessible to most conventional SCUBA diver-based surveys (Andaloro et al. 2013; Wetz et al. 2020). Overall coral density did not change between standing and toppled platforms due to varying species-specific abundances; however, there were differences in coral community structure as a result of toppling of the platforms. For example, hermatypic (reef-building) ten-ray star coral (*Madracis decactis*) densities did not vary between the two structure types given they are located in shallow water (≤ 50 m bottom depth). In contrast, ten-ray star coral colonies on standing platforms that are transported into deeper waters (>50 m) upon toppling will likely not survive due to colder temperatures and less light availability. Interestingly, some ahermatypic (non-reef-building) coral species (e.g., orange cup coral, *Tubastraea coccinea*) seem to thrive better on toppled platforms compared to standing platforms given their ability to grow particularly well in disturbed habitats. A toppled platform may be considered a disturbed habitat given the mode of severing a standing platform from the seafloor often uses explosives set around the base of the major support pilings. Explosive severance would dislodge and/or kill sessile epibenthic organisms, thus creating newly available space for settlement by incoming larvae or expansion by more robust surviving species (Bull and Kendall 1994). Corals were also distributed more deeply on standing platforms than toppled platforms, which is also likely a result of explosive severance. However, it is important to note that the platforms are not absolutely comparable with respect to date of toppling or whether the reefed platforms were relocated or toppled in place as these factors can influence ecological succession and benthic community structure. Nevertheless, it is clear that toppling of platforms dramatically affects the coral communities on the platforms, changing the species composition and diversity with depth.

Ajemian et al. (2015a) assessed fish communities using ROVs at an array of artificial reef types including fourteen reefed platforms (seven cut-off and seven toppled) and three standing platforms broadly distributed over the Texas continental shelf. Given the visibility constraints on the lower portion of the water column at some locales (i.e., benthic nepheloid layer) and preference for these habitats by demersal red snapper (*Lutjanus campechanus*; Dokken et al. 2000; Ajemian et al. 2015b), Ajemian et al. (2015a) supplemented their ROV methods with fishery-independent vertical line surveys (sensu Gregalis et al. 2012) to estimate the abundance and size of red snapper

across artificial structures. Their findings suggest that the conversion of standing platforms into artificial reefs may significantly alter fish community structure, supporting previous studies (Dokken et al. 2000; Wilson et al. 2003). While overall species diversity, richness, and evenness were stable among standing and reefed platforms, there were key assemblage differences. For example, fish communities at standing platforms were dominated by Bermuda chub (*Kyphosus sectatrix*), a schooling, pelagic herbivore with low economic value. While fish assemblages were different between standing and toppled platforms, no significant differences were observed between standing and cut-off platforms. This finding provides potential evidence that the community characteristics of standing platforms can be best retained by cut-off platforms that maintain an upright orientation and provide relatively high vertical relief. Overall, the effects of converting standing platforms into completely submerged artificial reefs with lower vertical relief are generally limited to pelagic planktivores and piscivores that use the upper water column, and do not affect demersal species (Wilson et al. 2003). For example, there was no strong evidence of structure type affecting demersal red snapper abundance (via ROV and vertical line surveys), biomass (total weight per set), or mean size. Importantly, while structure type and vertical relief were shown to influence species richness and community structure, major trends in species composition were largely explained by the bottom depth where these structures occurred.

As decommissioned standing platforms are increasingly converted into artificial reefs, it is important to evaluate the ecological effects of this physical transformation on platform-associated epibenthic communities and food webs. Rezek et al. (2018) used a combination of stable isotope and community analyses to evaluate the structure and food web functioning of epibenthic communities among two standing platforms at 5 m and 30 m depths and three reefed platforms (one cut-off and two toppled) at 30 m depths (near the top of the structure) off the Texas coast. Standing and reefed platforms supported structurally similar communities at equivalent depths (30 m), which indicate that comparable communities are able to develop at this depth regardless of physical links to shallow substrate. In contrast, the distinct compositional characteristics of shallow (5 m) platform communities are likely to be lost or diminished when standing platforms are converted into artificial reefs. Interestingly, stable isotope analyses revealed epibenthic communities in deep (30 m) standing and reefed platform sites relied on similar food sources as the shallower (5 m) standing platform sites, despite the variation in community composition between these depth zones. These findings demonstrate that the current reefing practice of removal of the upper ~26 m of the structure does not substantially influence the ecological functionality of these systems. Moreover, the retained structure preserves suitable habitat for epibenthic communities and forage resources for important fisheries species (e.g., gray triggerfish [*Balistes capriscus*] and sheepshead [*Archosargus probatocephalus*]) and non-targeted reef-associated species (Daigle et al. 2013; Cowan and Rose 2016; Reeves et al. 2019).

Fish Biomass and Density

The spatial distribution of fish biomass, density, and size associated with standing and reefed platforms has been quantified using hydroacoustic surveys. These non-invasive techniques offer unique advantages over visual census methods by sampling the entire water column at a high spatial and temporal resolution over large areas (Boswell et al. 2010; Reynolds et al. 2018). In addition, studies that contemporaneously collect hydroacoustic and video data can determine the relative contribution of an individual species to the acoustic biomass (Reynolds et al. 2018).

Wilson et al. (2003) was the first to compare fish communities, density and biomass associated with a standing platform, two reefed platforms (toppled and cut-off), and a nearby, large natural reef, the West Flower Garden Banks, using a combination of hydroacoustic and ROV sampling methods off the Texas and Louisiana coast. Overall, Wilson et al. (2003) found that species composition at the standing and reefed platforms were fairly similar at depth but differed from the West Flower Garden Banks. However, fish biomass and density around the standing platform was an order of magnitude higher than the reefed platforms or West Flower Garden Banks. Fish density and size was greater near the surface than the bottom (~90 m) at the standing platform, whereas fish densities at the cut-off and toppled platforms were highest in the lower portion of the water column (>50 m). Though, the cut-off platform also had high fish densities closer to the surface than the toppled platform resembling fish distribution at the standing platform. Similar to Ajemian et al. (2015a), when a standing platform is converted into an artificial reef, it appears that the pelagic planktivores (e.g., Bermuda chub and blue runner [*Caranx cryos*]) make up the greatest biomass that is lost. However, fish biomass and species composition around the reefed platforms was fundamentally similar to the lower portion (>50 m) of the standing platform and included important recreational and commercial reef-associated species such as red snapper, gray triggerfish, greater amberjack (*Seriola dumerili*), and almaco jack (*Seriola rivoliana*). These data suggest that the fish community in the lower depth strata may be uncoupled from the community found in the upper strata and that reefed platforms retain the majority of species targeted by recreational and commercial fisheries after the decommissioning process.

Simonsen (2013) examined the spatial and temporal distribution of fish biomass around two standing and two toppled platforms off the Louisiana coast. In the absence of video data, Simonsen (2013) used a multifrequency hydroacoustic approach to broadly categorize organisms into four acoustic classes (sensu Korneliussen et al. 2009): large pelagic predators (e.g., sharks), schooling planktivores (e.g., Bermuda chub and blue runner), fish (excluded from previous classes), and zooplankton scattering layer. Similar to Wilson et al. (2003), standing platforms supported roughly two times higher fish biomass than toppled platforms. Differences in biomass between structures were observed only in the upper and middle water column and were largely due to the higher observed biomass of large pelagic predators, schooling planktivores, and zooplankton classes at the standing platforms. In contrast, the similarities observed in the lower water column between standing and reefed platforms and across seasons indicate that demersal fish species are likely to be found at both habitats. Similar to the findings described above, Simonsen (2013) demonstrated that the conversion of standing platforms into artificial reef structures will differentially affect species, or classes, of reef-associated fishes.

Harwell (2013) assessed fish density before and after a standing platform was reefed in relation to modifying habitat complexity – defined by vertical relief, footprint and volume of the structure. In contrast to Wilson et al. (2003) and Simonsen (2013), Harwell (2013) examined changes in fish density at the same site before and after reefing using a nearby standing platform as a control. The standing platform was reefed by removing the deck and the upper ~32 m of the jacket (legs) and placing the jacket material on the seafloor approximately 15 m from the original structure. A separate decommissioned standing platform had the deck removed and placed on the seafloor adjacent to the study site after reefing, thus creating a large and complex artificial reef. After reefing, the structure had a vertical relief of 37 m from a bottom depth of ~72 m, which resulted

in a 54% decrease in vertical relief compared to the original standing platform and an overall decline in fish density. However, there was an increase in fish density between 40-60 m, which comprised the highest percentage (~70%) of the reefed platform volume. Although the percent increase in overall footprint (1024%) was an order of magnitude higher than volume (55%) after reefing, ultimately volume accounted for the greatest variability among fish densities. The additional substrate material (platform deck) from the separate decommissioned platform increased the overall volume and provided additional habitat and structural complexity at the site. Similarly, Ajemian et al. (2015a) observed the highest average species richness from a reefed platform deck suggesting that this structure type could provide a high habitat value for fish communities (given more efficient cleaning methods).

Reynolds et al. (2018) expanded on the methodology of Simonsen (2013) by integrating video and hydroacoustic data to determine relative species contribution to biomass observed at three standing and two toppled platforms off the Louisiana coast. Similar to previous results, Reynolds et al. (2018) observed higher species richness, evenness and diversity at standing platforms compared to toppled platforms. Yet, only four species (red snapper, greater amberjack, horse-eye jack, and little tunny [*Euthynnus alletteratus*]) contributed to 90% of fishes observed at both toppled and standing platforms, and fish biomass was highest in the lower portion of the water column (>60 m) across sites. While overall mean biomass remained relatively consistent across seasons, different species contributed to community structure depending on season and depth. Red snapper was the dominant species across seasons at standing and reefed platforms at depths >60 m and in 30-60 m (except during summer), whereas the fish communities changed at depths between 0-30 m during each season. The integration of video and hydroacoustic data to ground-truth which species contributed to relative acoustic biomass at standing and toppled platforms is an important step in understanding the efficacy of these structures as ecological and economically valuable habitat.

Snapper Biology

Red snapper and vermillion snapper (*Rhomboplites aurorubens*) are among the most economically important reef fishes in the northern GOM. These lutjanids associate with hard substrate, occupying natural banks, ridges, and reefs (Gledhill 2001; Wilson et al. 2006; Wells and Cowan 2007; Patterson et al. 2014; Karnauskas et al. 2017; Streich et al. 2017b), and are dominant reef fish species observed at standing and reefed platforms (Stanley and Wilson 1997; Wilson et al. 2003; Ajemian et al. 2015a; Reynolds et al. 2018; Streich et al. 2018; LGL 2019). Given both species are federally managed, and that the GOM red snapper stock continues to rebuild from overfished conditions (Strelcheck and Hood 2007; SEDAR 2018), evaluating potential biological differences among habitats is critical for accurate assessments of stock status and management recommendations (Streich et al. 2017c; Moncrief et al. 2018). To date, Moncrief et al. (2018) is the only study to evaluate how standing and reefed platforms function to support the GOM vermillion snapper stock by comparing the reproductive potential of females among standing and reefed platforms with natural reefs in the north-central GOM. The highest percentage of actively spawning females (26.5%) were captured on natural reefs despite natural reefs containing the lowest percentage of spawning capable females (6.2%). Moreover, the percentage of actively spawning (14.5%, 16.4%) and spawning capable (11.1%, 11.5%) females were similar for reefed and standing platforms, respectively. In comparison, several studies (n = 7) have evaluated how

standing and reefed platforms function to support the GOM red snapper stock, including age and growth (Saari 2011; Streich et al. 2017c), reproductive biology (Kulaw 2012; Downey et al. 2018), trophic ecology (Simonsen et al. 2015; Brewton et al. 2020), and movement (Westmeyer et al. 2007).

Age and growth

While numerous studies have aged red snapper, Saari (2011) was the first to simultaneously compare age structure, size, and growth rates of red snapper among two standing and two toppled platforms with four natural hard-bottom shelf-edge banks on Louisiana's outer continental shelf. Saari (2011) found no difference in the ratio of males to females, mean age, and age frequency between standing and toppled platforms. Red snapper at toppled platforms were on average longer than those from standing platforms; however, there was no difference in terms of weight. Further, no consistent pattern in mean size-at-age was observed between red snapper from standing and toppled platforms. However, total length and total weight at age indicated significantly faster growth rates for red snapper from toppled platforms compared to standing platforms. While these results indicate some habitat-specific differences in red snapper size and growth rates among standing and toppled platforms, the mechanisms underlying these differences remain largely unknown.

Streich et al. (2017c) provided new information for the northwestern GOM by conducting vertical line surveys to assess red snapper relative abundance, size and age structure, and growth parameters at three standing platforms, three reefed platforms (two cut-off and one toppled), and three natural banks off the Texas coast. Red snapper relative abundance (i.e., catch per unit effort) was similar among standing platforms, reefed platforms, and natural banks – a finding that is inconsistent with previous studies demonstrating higher relative abundance of red snapper at artificial habitats than at natural habitats (Patterson et al. 2014; Karnauskas et al. 2017; Streich et al. 2017b). For example, ROV surveys conducted at artificial reefs and natural banks in the same region estimated that red snapper abundance was nearly eight times greater at artificial reefs (Streich et al. 2017b). Video-based surveys are generally less affected by gear saturation (see Streich et al. 2018) and may provide less-biased indices of abundance given adequate visibility (Harvey et al. 2012; Ajemian et al. 2015b). Overall mean red snapper size (length and weight) and age was similar among all three habitat types; however, size and age frequencies revealed that natural banks supported a greater proportion of large and relatively old fish compared to standing or reefed platforms. Moreover, weight frequency distributions were more similar between standing and reefed platforms, as both were dominated by smaller fish. However, growth models suggested that fish from reefed platforms reached larger sizes at age than fish from either standing platforms or natural banks. Importantly, these results indicate that all three habitat types could contribute similarly to GOM red snapper stock productivity on a per-unit-area basis.

Reproductive biology

To better understand the functional role of standing and reefed platforms in supporting the GOM red snapper stock, it is essential to understand whether fish using these different habitat types have similar reproductive potential (Downey et al. 2018). In a companion study to Saari (2011), Kulaw (2012) was the first to compare reproductive biology estimates of female red snapper among

standing and toppled platforms with natural hard-bottom shelf-edge banks on Louisiana's outer continental shelf. Specifically, Kulaw (2012) compared sex ratios, gonadosomatic indices (GSI), size and age at maturity, and spawning frequency among habitats. Similar to Saari (2011), Kulaw (2012) found no difference in the ratio of males to females among standing and toppled platforms. Females at standing platforms were significantly younger and smaller compared to females at toppled platforms and yielded relatively low GSI estimates, which indicates a reduced spawning capacity. In addition, females from standing platforms reached maturity at a slower pace compared to females from toppled platforms. Collectively, these results suggest a reduced spawning frequency at standing platforms compared to toppled platforms.

In a companion study to Streich et al. (2017c), Downey et al. (2018) further examined the habitat-specific reproductive potential of red snapper at standing and reefed platforms relative to natural banks off the Texas coast. Comparisons of sex ratios, GSI, fecundity, spawning frequency, and number of spawning-capable individuals indicated that red snapper reproductive biology was similar among standing platforms, reefed platforms, and natural banks. These results suggest that reproductive traits of similar age classes of red snapper are functionally comparable among platform and natural bank habitats. The contrasting results of this study and Kulaw (2012) in the central GOM highlights regional differences in reproductive potential of red snapper among habitat types that warrant further investigation.

Trophic ecology

There has been extensive research on how artificial reefs function in the feeding ecology of red snapper (e.g., Ouzts and Szedlmayer 2003; McCawley and Cowan 2007; Wells et al. 2008; Schwartzkopf et al. 2017; Dance et al. 2018). Though, Simonsen et al. (2015) was the first study to compare the dietary preferences of red snapper associated with standing platforms, toppled platforms, and natural reefs on Louisiana's outer continental shelf using a combination of stomach gut and stable isotope analyses. Stomach gut contents provide an accurate description of recent (hours to days) feeding habits, while stable isotopes are incorporated over several months and therefore provide an integrated assessment of diet over time. While diets of red snapper were more diverse at the natural reefs, they consisted of similar prey items found at the standing and reefed platforms. Fish dominated diets at all three habitat types; however, habitat-specific differences existed in the contribution of major prey items. For example, red snapper collected from standing platforms consumed primarily fish, squid, and shrimp, while greater amounts of crabs, shrimp, and other crustaceans were consumed at toppled platforms. On the natural reefs, diets varied the most, consisting of both fish and crustaceans. Stable isotope analyses revealed red snapper from standing platforms were more enriched in nitrogen, indicating feeding at a higher trophic level compared to other habitats. Though, the diets of red snapper were overall similar among habitat types and are consistently sourced from the surrounding water column and seafloor, as evidenced by phytoplankton serving as the dominant basal resource (see Daigle et al. 2013).

Streich et al. (2017c) demonstrated that reefed platforms in the western GOM support larger size-at-age red snapper relative to natural reefs or standing platforms and that older, larger fish are found on natural reefs. Interestingly, a companion study by Downey et al. (2018) revealed no differences in relative weight or reproductive potential for red snapper among these three habitat types. Thus, while these faster growth rates on reefed platforms do not also translate to

significantly improved reproductive capacity or condition, it is possible that they are explained by higher-quality prey resources at these habitats. In a companion study, Brewton et al. (2020) evaluated the potential trophic enhancement provided by reefed platforms by comparing annual, ontogenetic, and habitat-specific diet and stable isotope signatures of adult red snapper from relic coralgan natural reefs to those from standing and reefed platforms off the Texas coast. Relic coralgan natural reefs supported a more diverse diet for red snapper in the intermediate size class corroborating previous findings on natural salt dome reefs near Louisiana (Simonsen et al. 2015; Schwartzkopf et al. 2017). In contrast to Simonsen et al. (2015), Brewton et al. (2020) identified unique prey items at standing and reefed platforms, which suggests that these artificial habitats may provide red snapper with unique foraging opportunities. For example, the greatest trophic diversity was observed for larger red snapper at reefed platforms. Moreover, reefed platforms supported a more varied prey base compared to standing platforms likely due to their unique structure that combines characteristics of standing platforms and natural low-relief habitats. Furthermore, these results may explain the higher growth rates previously observed for older red snapper at these reefed platforms (Streich et al. 2017c). Yet, standing platforms may provide a more consistent, higher trophic level food resource throughout ontogeny resulting in increased nitrogen enrichment consistent with previous studies (Simonsen et al. 2015; Schwartzkopf et al. 2017). Overall, these findings suggest that region- and habitat-specific effects on red snapper trophic ecology are more complex than previously considered in the GOM, and that reefed platforms provide foraging opportunities more similar to natural reefs than standing platforms.

Movement

Information on red snapper site fidelity and movement patterns around artificial reefs is critical to elucidate the relative importance of these structures as effective fishery enhancement tools. While conventional mark-recapture studies can be informative depending upon the number of recaptures (e.g., Szedlmayer and Shipp 1994; Patterson et al. 2001; Patterson and Cowan 2003; Diamond et al. 2007; Strelcheck et al. 2007), the advent of acoustic telemetry has greatly improved the spatial and temporal resolution of red snapper movement studies. The fidelity and movement patterns of red snapper around standing platforms (McDonough and Cowan 2007; Westmeyer et al. 2007; Curtis 2014; Everett 2018), reefed platforms (Getz and Kline 2019), and low-relief artificial reefs (Szedlmayer and Schroepfer 2005; Schroepfer and Szedlmayer 2006; Topping and Szedlmayer 2011; Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016; Williams-Grove and Szedlmayer 2017; Froehlich et al. 2019) has been examined using acoustic telemetry with varying results. Though, Westmeyer et al. (2007) is the only study to date that compared red snapper site fidelity and movements between standing and toppled platforms. Red snapper had high initial fidelity to release locations that subsequently decreased over time (over a period of months) and exhibited little movement between platforms in the study area. These results are consistent with several previous studies that reported low site fidelity to artificial structures for red snapper (Patterson et al. 2001; Patterson and Cowan 2003; McDonough and Cowan 2007; Westmeyer et al. 2007), whereas others have suggested red snapper exhibit high site fidelity (Szedlmayer and Shipp 1994; Szedlmayer and Schroepfer 2005; Schroepfer and Szedlmayer 2006; Topping and Szedlmayer 2011; Curtis 2014; Piraino and Szedlmayer 2014; Williams-Grove and Szedlmayer 2016; Williams-Grove and Szedlmayer 2017; Froehlich et al. 2019). Though, the methods (mark-recapture versus acoustic telemetry), habitat type, study length, and spatial scales varied among these studies and may affect estimates of site fidelity (Patterson 2007). Furthermore, these varying

results suggest individual variability in site fidelity and movements among red snapper (Diamond et al. 2007). Westmeyer et al. (2007) found relocated red snapper exhibited lower site fidelity and lacked evidence of homing behavior to original capture locations. In addition, red snapper exhibited a diel pattern of movement away from the structures at night which was attributed to foraging excursions. In this study, red snapper movements were monitored at a single toppled platform and seven standing platforms. Therefore, future research evaluating the habitat value of standing and reefed platforms requires additional structures to clarify the site fidelity and connectivity of red snapper, and other species, to these structures.

Comparison with Natural Habitats

Comparisons of standing and reefed platforms with natural habitats are critically needed to contextualize the ecological function and value of these artificial structures. Although several studies have directly compared either standing or reefed platforms with natural habitats (e.g., Rooker et al. 1997; Wilson et al. 2006; Patterson et al. 2014; Streich et al. 2017b), relatively few have contemporaneously compared all three habitat types. Wilson et al. (2003) reported the fish community and biomass associated with standing and reefed platforms differed from the West Flower Garden Banks and recommended future research efforts toward determining the fundamental reasons for this difference. Though, the Flower Garden Banks are unique coral reef habitats that are not representative of other natural banks, ridges, and reefs in the northern GOM (Rezak et al. 1985).

Other than Wilson et al. (2003), previous studies directly comparing standing and reefed platforms to natural habitats in the northern GOM have primarily focused on the biological characteristics of red snapper (but see Moncrief et al. 2018). Recent studies in the northwestern GOM have shown that reefed platforms support larger size-at-age red snapper relative to relic corallal natural reefs or standing platforms and that older, larger fish are found on natural reefs (Streich et al. 2017c). Though, reproductive characteristics were similar for this same collection of red snapper among habitats (Downey et al. 2018). Furthermore, a companion study by Brewton et al. (2020) revealed trophic similarities between reefed platforms and natural reefs compared to standing platforms, which may translate into the faster growth rates reported by Streich et al. (2017c).

However, some region-specific differences in growth rates (Saari 2011), reproductive characteristics (Kulaw 2012; Glenn et al. 2017), and trophic ecology (Simonsen et al. 2015; Schwartzkopf et al. 2017) have been reported for red snapper inhabiting natural salt dome reefs, standing platforms, and reefed platforms in the north-central GOM. For example, Saari (2011) documented no difference in age frequencies of red snapper among these habitat types off the coast of Louisiana, whereas Kulaw (2012) and Glenn et al. (2017) reported differences in reproductive biology. Specifically, natural salt dome reefs yielded the highest GSI estimates for red snapper among habitats (Kulaw 2012) and annual fecundity estimates were almost 20-fold higher in fish collected from these natural habitats (Glenn et al. 2017). In addition, natural salt dome reefs supported a more diverse red snapper diet (Simonsen et al. 2015; Schwartzkopf et al. 2017), which mirrors what has been found on relic corallal reefs in the northwestern GOM near Texas (Brewton et al. 2020). These corroborating studies reveal that multiple types of natural reefs support a broader prey base than do artificial habitats. Moreover, there was no evidence of prey items specific to the artificial structures as compared to the natural habitat on the Louisiana shelf edge

(Simonsen et al. 2015); however, prey items unique to artificial structures were identified off the coast of Texas (Brewton et al. 2020). Lastly, reefed platforms supported a more varied prey base than did standing platforms (Simonsen et al. 2015; Brewton et al. 2020) suggesting the lower relief of reefed platforms may better mimic natural reef habitats.

The differences between these studies may be influenced by the disparate characteristics of each habitat type (e.g., bottom depth, footprint, vertical relief) and documented differences in fish community structure between natural and artificial habitats across the GOM (Rooker et al. 1997; Wilson et al. 2006; Patterson et al. 2014; Streich et al. 2017b). For example, the relic coralgal reefs surveyed in the northwestern GOM are geologically distinct from the salt dome reefs in the north-central GOM (Rezak et al. 1985) and occur in shallower water (72-84 m) compared to the deeper shelf-edge banks (90-150 m) surveyed off Louisiana (Streich et al. 2017c). The lack of similar trends among habitats in Louisiana and Texas highlights the complex nature of habitat- and region-specific contributions to the GOM red snapper stock (e.g., Saari et al. 2014; Kulaw et al. 2017; Brown-Peterson et al. 2019).

Comparison with California Platform Research

Compared to the extensive array of 1,862 standing platforms in the GOM, there are currently 27 standing platforms in the SCB (Bull and Love 2019). Communities associated with standing platforms in the SCB and GOM are characterized by distinct regional faunal assemblages and species associations (Scarborough-Bull et al. 2008; Love et al. 2019a; Love et al. 2019c; Page et al. 2019). For example, standing platforms in the SCB are characterized by three distinct fish assemblages: midwater, bottom, and shell mound, which are associated with these different microhabitats around the platform structure (Love et al. 2019a). Shell mounds are biogenic reefs that surround some of the standing platforms resulting from an accumulation of mollusk shells that have fallen from the shallow portions of the platforms. Further, standing platforms in the SCB have the highest secondary fish production per square meter of seafloor of any marine habitat that has been studied, approximately an order of magnitude higher than fish communities from other marine ecosystems (Claisse et al. 2014). Although several platforms have been installed and removed in the SCB, none have been reefed. With the passage of the California Marine Resources Legacy Act in 2010, the State of California will allow consideration of the partial removal of decommissioned standing platforms as an alternative to complete removal. Because standing platforms in the SCB are scheduled for decommissioning in the near future, a model for estimating biological loss for partial and complete removal is needed to evaluate these decommissioning options (Claisse et al. 2015; Pondella et al. 2015).

Claisse et al. (2015) and Pondella et al. (2015) evaluated the potential effects of partial removal on the biomass and secondary production of fish communities associated with standing platforms in the SCB. Secondary production is the formation of new animal biomass from growth for all individuals in a given area and period of time (Claisse et al. 2014). While complete removal would likely eliminate most of the existing fish biomass and associated secondary production, the potential impacts of partial removal would likely be limited on almost all standing platforms in the SCB. On average 80% of fish biomass and 86% of annual secondary fish production would be retained after partial removal, with above 90% retention expected for both metrics on several platforms (Claisse et al. 2015). Further, these cut-off platforms would retain some of the highest

secondary fish production values of any documented marine habitat globally (Claisse et al. 2014; Claisse et al. 2015). Partial removal would likely result in the loss of fish biomass and production for species typically found residing in the shallow portions of the platform structure. However, these species generally represent a small proportion of the fishes associated with these standing platforms compared to deeper-dwelling rockfishes (*Sebastes* spp.; Love et al. 2012; Love et al. 2019a). Furthermore, many platform-associated rockfishes are important to recreational and commercial fisheries and these results suggest that cut-off platforms will continue to remain viable habitats for these species. In addition, Claisse et al. (2015) found that shell mounds beneath the platform are moderately productive fish habitats, similar to or greater than natural rocky reefs in the region at comparable depths. However, partial removal will diminish the supply of falling mollusk shells from the shallow portions (<26 m) of the platform potentially resulting in reduced shell mound habitats and associated fish biomass and production (Meyer-Gutbrod et al. 2019b). Though, reductions in shell mound habitat and fish production may be mitigated by placing the partially removed portion or additional habitat enrichment material near the base of the existing structure (Claisse et al. 2015).

Current Research Gaps and Future Directions

Despite the vast amount of research on platform and artificial reef habitats in the northern GOM, relatively few studies have directly compared the ecological functions of standing and reefed platforms. While the studies reviewed here were seminal and informative, most did not account for seasonal changes (but see Simonsen (2013) and Reynolds et al. (2018)) and drew comparisons from a relatively small set of sites and reef configurations, largely due to sampling logistics related to offshore field studies. Moreover, several companion studies were conducted contemporaneously at the same sites off Louisiana (Daigle 2011; Daigle et al. 2013; Saari 2011; Kulaw 2012; Simonsen 2013; Simonsen et al. 2015) and Texas (Streich et al. 2017c; Downey et al. 2018; Rezek et al. 2018; Brewton et al. 2020). Ajemian et al. (2015a) provided the most comprehensive comparison of standing and reefed platform-associated fish communities to date; yet, this study was focused solely in the northwestern GOM and relied on ROV methods supplemented with opportunistic vertical line surveys. Ultimately, understanding the association of fish community structure, biomass, density, and size estimates relative to reef configuration will provide a better understanding of the role of standing and reefed platforms as fishery management tools and guide future decommissioning strategies (Boswell et al. 2010; Reynolds et al. 2018; LGL 2019). Therefore, it must be taken into consideration that these studies may not be representative of the entire (sub)region, and inferences regarding the patterns described should be interpreted with regard to the season, spatial extent, and sampling methods of the respective studies. For example, seasonal and oceanographic variability across the northern GOM can have a substantial influence on the vertical distribution of fishes in the water column (Stanley and Wilson 2004; Williams-Grove and Szedlmayer 2017; Reeves et al. 2018c), community composition (Stanley and Wilson 1997; Reynolds et al. 2018), and fish condition (McCawley and Cowan 2007; Schwartzkopf and Cowan 2017). Research directed towards understanding the temporal dynamics of platform-associated communities will greatly inform our understanding of decommissioning decisions. Moreover, future studies may benefit from combining standardized sampling efforts across the GOM to increase the temporal and spatial extent of sampling and help refine our understanding of the ecological function of different habitats.

The results of this comprehensive literature review identified several research needs and goals for standing and reefed platforms in the GOM including:

- Comprehensive information on ecosystem structure and function
- Understanding the connectivity between habitats
- Improving assessments of fishing pressure and their biological implications
- Addressing the relative importance of attraction versus production
- Optimal artificial reef design
- Establishing long-term monitoring programs

Ecosystem Structure and Function

In general, research into the ecology of platform structures has primarily focused on only a few descriptive aspects such as fish biomass, density, community composition and structure, which currently limits an overall ecosystem understanding on the effects of decommissioning strategies. More comprehensive studies investigating the functional impacts of different reefing options have done so primarily in relation to the biological characteristics (e.g., life history, trophic ecology) of red snapper. As a demersal species, both standing and reefed platforms appear to provide suitable habitat with sufficient resources to support its biological needs. Increased emphasis on a wider range of species, including other broadly distributed fisheries species of commercial and/or recreational value (e.g., greater amberjack), and on whole-community and functional approaches will build towards a more mechanistic understanding of the broader ecosystem values provided by standing and reefed platforms. For example, Rooker et al. (1997) and Beaver (2002) established the importance of the epibenthic fouling community to provide shelter and forage resources to the fish community. Furthermore, compositional dissimilarity in fish assemblages associated with standing and reefed platforms have been documented, with greater abundance of pelagic schooling planktivores and large, mobile piscivores reported on standing platforms (Wilson et al. 2003; Simonsen 2013; Ajemian et al. 2015a; Reynolds et al. 2018). Yet, important questions remain for these distinct shallow fish assemblages and their subsequent decline in abundance during the decommissioning process. For example, what is the mechanism of attraction/ association? How does the presence of artificial lighting on operating standing platforms influence concealment and foraging behaviors at night (e.g., Rooker et al. 1997; Dokken et al. 2000; Keenan et al. 2007; Foss 2016; Barker and Cowan 2018)? Where do these shallow species go after reefing and do they survive? Does the increased presence of large, mobile piscivores observed at standing platforms influence the movements of reef-associated prey away from refuge (e.g., Rooker et al. 1997)? How does reefing influence predation mortality rates on the remaining species?

Connectivity

Fish and invertebrate species observed at both artificial structures and natural reefs may not reside in these habitats for their entire life history as various developmental stages (egg, larval, juvenile, or adult) may populate different depths or habitats (Cowen and Sponaugle 2009; Bishop et al. 2017; Henry et al. 2018; van der Molen et al. 2018; Nishimoto et al. 2019a; Nishimoto et al. 2019b). Therefore, artificial structures and decommissioning strategies do not only produce localized impacts at the sites of their placement/removal, but may also produce larger-scale impacts through their influence on biological connectivity (i.e., the exchange of individuals among marine populations; Cowen and Sponaugle 2009). The influence of artificial structures on

biological connectivity within and among populations will vary according to the life history of each species, oceanographic patterns, and distribution of natural and artificial habitats (Adams et al. 2014). For example, biological and oceanographic data have been combined to investigate the extent of potential larval connectivity between artificial structures and natural habitat (Lugo-Fernández et al. 2001; Toland 2001) and also how artificial structures may provide patches of habitat or “stepping stones” that facilitate the dispersal of species into new areas (Gallaway and Lewbel 1982; Sammarco et al. 2004; Sammarco et al. 2012a). Genetic and geochemical (e.g., otolith chemistry) techniques to identify source populations and dispersal distances are also utilized in this effort (Atchison et al. 2008; Patterson et al. 2008; Sammarco et al. 2012b; Sluis et al. 2013; Sluis et al. 2015; Puritz et al. 2016). Moreover, conventional and electronic tagging techniques have investigated potential connectivity between artificial and natural habitats by providing direct estimates of movement, site fidelity, and dispersal (e.g., Patterson 2007; Westmeyer et al. 2007; Topping and Szedlmayer 2011). Changes to connectivity may, in turn, influence the genetic structure and size of populations, the distribution of species, and community structure and ecological functioning (Bishop et al. 2017). The presence of standing platforms in the northern GOM have also facilitated the introduction or range expansion of non-native and invasive species (Villareal et al. 2007; Sheehy and Vik 2010; Sammarco et al. 2014b; Bennett et al. 2019). Despite the growing awareness of the capacity of standing platforms to influence biological connectivity, we lack a comprehensive understanding of the spatial and temporal extent to which the present array of standing and reefed platforms, and natural habitats, in the GOM are biologically connected and the consequences of different decommissioning strategies (e.g., Pondella et al. 2015).

Fishing Pressure

In the GOM, standing and reefed platforms inadvertently function as closed reserves to commercial shrimp trawling due to navigational and entanglement hazards; however, they are open to recreational and commercial fishing pressure (Ditton and Auyong 1985). Standing and reefed platforms and other artificial reefs have been suggested to severely increase the vulnerability of red snapper (and other species) to fishing by aggregating fish closer to shore (Cowan et al. 2011; Cowan and Rose 2016). In contrast, others contend the presence of artificial structures serve as fishery enhancement tools by increasing the abundance and harvest potential of economically important species (Gallaway et al. 2009; Shipp and Bortone 2009). Moreover, the conspicuousness of standing and reefed platforms may also direct fishing pressure away from natural reefs, which may help to preserve these natural habitats (Streich et al. 2017b; Brewton et al. 2020). This inference is supported by a recent survey of recreational boaters and anglers in Texas, which reported that ~55% of respondents used artificial reefs, with nearly 40% and 12% primarily targeting standing and reefed platforms, respectively, compared to 21% targeting natural habitats (Schuett et al. 2015). The use of artificial reefs was largely attributed to greater fishing opportunities. Similarly, Reggio (1987) and Gordon (1993) estimated that 70% and 61%, respectively, of recreational fishing trips off Louisiana principally target standing platforms. Moreover, Gordon (1993) reported that nearly 75% off all recreational anglers tie to platforms at some time during the year. Hiett and Milon (2002) also reported over 20% of all recreational fishing trips (including 20% of small private trips, 32% of charter trips, and 51% of head boat trips) and ~94% of dive trips across Texas, Louisiana, Mississippi, and Alabama target standing platforms. Thus, there is a critical need to accurately assess recreational and commercial fishing

pressures and their biological implications among natural habitats, standing platforms, and reefed platforms (e.g., Stanley and Wilson 1989; Stanley and Wilson 1990; Nieland and Wilson 2003; Garner and Patterson 2015; Cowan and Rose 2016; Everett 2018). Furthermore, the role of standing and reefed platforms as pelagic fishery enhancement tools warrants further study including the efficacy of these structures as fish aggregating devices for highly mobile species (Franks 2000) and associated depredation rates (e.g., Hoolihan et al. 2014).

Attraction versus Production

Questions surrounding the ecological value of standing and reefed platforms fall within the broader attraction versus production artificial reef debate (Bohnsack 1989; Gallaway et al. 2009; Shipp and Bortone 2009; Cowan et al. 2011; Cowan and Rose 2016). A key finding from numerous studies are that these two alternatives of attraction versus production are not mutually exclusive and operate along a continuum as some species may be merely attracted to artificial structures, whereas other species may benefit from increased secondary production (Bohnsack 1989). In contrast to fish communities, the epibenthic communities that colonize artificial structures require hard substrate to exist and subsequently increase production at platforms (Beaver et al. 2003; Daigle et al. 2013; Reeves et al. 2018a; Rezek et al. 2018). Thus, the issue of greatest scientific interest is how platform decommissioning strategies may affect existing fish biomass and secondary production. Versar (2008) and Cowan and Rose (2016) estimated fish production attributable to a standing platform based on five abundant species (red snapper, blue runner, sheepshead, Atlantic spadefish [*Chaetodipterus faber*], and bluefish [*Pomatomus saltatrix*]) with sufficient data. Red snapper, bluefish, and blue runner are less dependent upon reef-associated prey and thus had low annual production estimates compared to Atlantic spadefish and sheepshead that depend heavily upon the platform-associated epibenthic community. Furthermore, the net effect on red snapper production is negative when fishing mortality is considered (Versar 2008; Cowan and Rose 2016). Versar (2008) and Gomez (2020) further evaluated the impacts of standing platform removal on red snapper productivity by simulating different scenarios of platform removal, which overall decreased red snapper biomass and production. Because standing platforms attract mostly the younger age-classes of red snapper, their contribution to red snapper biomass and spawning potential is relatively low compared to natural habitats (Karnauskas et al. 2017). Therefore, the simulated removal of standing platforms resulted in relatively minor changes in overall GOM red snapper biomass (Gomez 2020). Despite these results, Versar (2008) and Cowan and Rose (2016) caution against drawing inference about the role of platforms as habitat for red snapper given that much of the work has been done on relatively small, low-relief artificial reefs. Moreover, recent work (as reviewed above) comparing the ecological performance of standing and reefed platforms with natural habitats in the northern GOM has highlighted habitat- and region-specific variation in red snapper biology that must be taken into account.

While complete removal would likely reduce or eliminate most of the existing fish biomass and associated secondary production on standing platforms, the potential impacts of reefing in the northern GOM have only been evaluated for epibenthic communities (Rezek et al. 2018). Claisse et al. (2015) and Pondella et al. (2015) estimated the potential impacts of partial removal on the biomass and secondary production of platform-associated fish communities would likely be limited on almost all standing platforms in the SCB. Though, fish production supported by platforms may vary substantially between structures (Claisse et al. 2014) and regions; therefore,

these results should not be used to inform RTR policies in the GOM or other regions of the world (Fowler et al. 2015). Therefore, future research efforts should be focused towards direct measures of ecosystem productivity for standing and reefed platforms in comparison to natural habitats and to quantify the potential impacts of different decommissioning strategies.

Optimal Artificial Reef Design

Artificial structure type and location play an important role in determining the associated fish community (Ajemian et al. 2015a). Studies suggest that optimal artificial reef configurations exist, but vary depending on the target species (Bohsack and Sutherland 1985; Pickering and Whitmarsh 1997; Campbell et al. 2011; Shipley and Cowan 2011). An evaluation of possible platform orientations (i.e. standing, cut-off, toppled), structural complexity (Wilson et al. 2003; Love et al. 2019b; Meyer-Gutbrod et al. 2019a), and placement (water depth, distance from shore, proximity to natural reefs, number of structures per reef site) warrants further research in order to establish the best management practices for RTR programs. For example, Dokken et al. (2000) suggested having a standing platform as a center point in a designated reefing area in order to maximize vertical relief and supplying additional reefed platforms or smaller-scale habitat enrichment material to enhance fish production. Although the 26 m clearance guidelines observed in current RTR practices may reduce some aspects of biodiversity associated with standing platforms, cut-off platforms may retain similar functionality of standing platforms (Daigle et al. 2013; Rezek et al. 2018). Compared to toppled platforms, cut-off platforms retain higher vertical relief and undergo less disturbance as communities below 26 m are relatively undisturbed during the conversion process and maintain their position in the water column. Moreover, in a partial removal option, the vertical conductor pipes, the conduits carrying the oil and gas to the topside platform structure from below the seafloor, may be left in place and cut off at the same depth as the jacket base (≥ 26 m), depending on Bureau of Safety and Environmental Enforcement (BSEE) approval (Dauterive 2000; Kaiser et al. 2020). Retention of the conductors provides additional habitat complexity and surface area to the remaining structure and eliminates the need for explosive or mechanical severance below the seafloor, which overall diminishes negative impacts to platform-associated communities (Dauterive 2000; Schroeder and 2004; Bull and Love 2019). In addition, placing the cut-off portion adjacent to the remaining standing structure creates additional habitat augmentation on the seafloor and increases the structural footprint (e.g., Harwell 2013), which is the overall benefit attributed to toppled platforms. The number of structures on a designated reefing site may also influence the resulting fish community. Further investigation into structure density effects and optimal network design of artificial reefs is needed as these materials are considerably larger than most artificial reefs examined in previous studies (e.g., Gallaway et al. 1999; Strelcheck et al. 2005; Campbell et al. 2011; Mudrak and Szedlmayer 2012; Froehlich and Kline 2015; but see Shipley et al. 2018).

Long-term Monitoring

Long-term monitoring of standing and reefed platforms is essential and will greatly enhance our understanding of the ecological function and habitat value of these artificial structures, including the ecological succession of marine communities following decommissioning (Sommer et al. 2019). From a technical perspective, reefing a platform in place or towing it to an existing reef site is dependent on the size of the structure, clearance requirements, proximity to navigational safety

fairways, water depth, and tow distance (Kaiser et al. 2020). In addition, individual platforms should be assessed for their ecological performance and habitat value before decommissioning decisions are made (Fowler et al. 2014; Sammarco 2014; Henrion et al. 2015; FGBNMS 2017; Sommer et al. 2019). A model example is the long-term monitoring of standing platform High Island A-389A (HI-A-389A) that was originally installed in 1981 by Mobile Oil and enclosed within the Flower Garden Banks National Marine Sanctuary boundaries in 1992 (Boland et al. 1983; Rooker et al. 1997; Boland 2002). HI-A-389A was recently converted into a cut-off platform in 2018 as part of the Texas Artificial Reef Program and will undergo annual biological monitoring moving forward (FGBNMS 2017). However, not all platforms are good candidates to remain standing or be converted into artificial reefs. For example, some platforms may be exposed to particularly high sediment and nutrient loads derived from the Mississippi River resulting in hypoxic zones (Stanley and Wilson 2004; Reeves et al. 2018c; Munnely et al. 2019) or suboptimal salinity and winter temperatures for epibenthic community growth and survival (Sammarco et al. 2012a). Moreover, platforms in place for under 15 years will likely have less-developed reef communities and thus may be less environmentally valuable than others (Sammarco et al. 2004; Kolian and Sammarco 2019).

Surveying communities prior to decommissioning would permit a before-after control-impact study design to directly quantify the effects of different decommissioning options to the existing community and monitor ecological succession (Harwell 2013; Versar 2008; Streich et al. 2017a). Similarly, this methodological approach can be used prior to the placement of new structures such as the construction of a new standing platform (e.g., Todd et al. 2019) or at the designated reefing site where a tow-and-toppled platform will be placed. Using this approach, platform-associated communities would be evaluated for a minimum of one year to account for seasonality in which a given platform or group of platforms were in place. Marine communities would then be compared to the same area after the platforms had been removed or reefed and to nearby control areas that were unchanged to judge temporal trends.

Summary and Conclusions

These results have important implications for marine resource management, as it demonstrates the potential for reefed platforms left in place to retain habitat value and ecological functions that would otherwise be lost when decommissioned platforms are removed. Overall, allowing platforms to remain standing would ameliorate the decline in biodiversity and fish biomass due to the loss of shallow water substrate. However, the extensive variability in marine life and environmental conditions observed around standing platforms prohibits a generic set of predictions across large ocean basins regarding the ecological consequences of different decommissioning alternatives and decisions should be made on a case-by-case basis (Schroeder and Love 2004) after scientific evaluation. Although the 26-m clearance guidelines observed in current RTR practices may reduce some aspects of biodiversity associated with standing platforms, there is evidence to suggest that partially removed platforms continue to provide an effective means of preserving the ecological functions associated with standing platforms (Ajemian et al. 2015a; Rezek et al. 2018); although, the trade-off is a loss to species richness and diversity. Though, some studies show toppled platforms may better reflect the vertical relief (Versar 2008) and functionality (Simonsen et al. 2015) of low-relief natural reefs. Thus, preserving at least a portion of the structure is highly valuable.

This literature review highlights critical knowledge gaps and research needs to fully understand the impact of decommissioning standing platforms and different reef configurations on the ecology and productivity of the GOM. As standing platforms in the GOM reach the end of their productive lives at an increasing rate, long-term monitoring studies are needed to empirically assess changes to community structure and functionality prior to and following reefing or complete removal. These studies will ensure that RTR programs are operating at maximum efficiency and facilitate data-driven decisions to determine which standing platforms would be most economically and ecologically viable to remain standing and/or converted to artificial reefs.

U.S. federal regulations require that a state agency responsible for managing natural resources assume all liability and costs associated with maintaining standing platforms as artificial reefs in perpetuity (Kaiser and Pulsipher 2005). Alternatively, decommissioned standing platforms may be repurposed for alternative uses such as research, monitoring stations, aquaculture, and a variety of other uses (e.g., Schroeder and Love 2004; FGBNMSAC 2013). Many of these would greatly reduce the logistical challenges associated with traditional ship-based offshore research activities. Although, the cost and benefit considerations must be given to navigational safety, rate of deterioration, cathodic protection and maintenance, increased risk during storm events, and technical feasibility (Schroeder and Love 2004; Bull and Love 2019). Thus, the high costs associated with maintaining decommissioned standing platforms as artificial reefs, or alternate use, have the potential precluded these activities (Schroeder and Love 2004; FGBNMS 2017). However, maintenance costs may be partially or entirely subsidized through alternative uses such as aquaculture and offshore renewable energy (Schroeder and Love 2004; Kaiser et al. 2011; Kolian et al. 2019). Currently, there are programs in the GOM that are showing much promise for viable alternative uses for repurposing standing platforms, and these should be further explored. One such program is the Gulf Offshore Research Institute which has partnered with Peregrine Oil & Gas to apply for a Right of Use and Easement (RUE) from the Bureau of Ocean Energy Management (BOEM) to convert three offshore standing platforms to alternative marine uses.

Partnerships such as these should be further explored to fully understand and integrate various decommissioning options as alternate tools for managers and other decision-makers enabling full utilization of GOM resources.

References

- Aabel JP, Cripps SJ, Jensen AC, Picken G. 1997. Creating artificial reefs from decommissioned platforms in the North Sea: Review of knowledge and proposed programme of research. Stavanger, Norway: Dames & Moore Group.
- Adams TP, Miller RG, Aleynik D, Burrows MT, Frederiksen M. 2014. Offshore marine renewable energy devices as stepping stones across biogeographical boundaries. *Journal of Applied Ecology*. 51(2):330-338.
- Ajemian MJ, Wetz JJ, Shipley-Lozano B, Shively JD, Stunz GW. 2015a. An analysis of artificial reef fish community structure along the northwestern Gulf of Mexico shelf: Potential impacts of "Rigs-to-Reefs" programs. *PloS one*. 10(5):e0126354.
- Ajemian MJ, Wetz JJ, Shipley-Lozano B, Stunz GW. 2015b. Rapid assessment of fish communities on submerged oil and gas platform reefs using remotely operated vehicles. *Fisheries Research*. 167:143-155.
- Andaloro F, Ferraro M, Mostarda E, Romeo T, Consoli P. 2013. Assessing the suitability of a remotely operated vehicle (ROV) to study the fish community associated with offshore gas platforms in the ionian sea: A comparative analysis with underwater visual censuses (UVCS). *Helgoland Marine Research*. 67(2):241-250.
- Anthony KM, Love MS, Lowe CG. 2013. Translocation, homing behavior and habitat use of groundfishes associated with oil platforms in the east Santa Barbara Channel, California. *Bulletin of the Southern California Academy of Sciences*. 111(2):1-27.
- Atchison AD, Sammarco PW, Brazeau DA. 2008. Genetic connectivity in corals on the Flower Garden Banks and surrounding oil/gas platforms, Gulf of Mexico. *Journal of Experimental Marine Biology and Ecology*. 365(1):1-12.
- Aziz NA. 2019. Mobile epifauna associated to artificial substrates in offshore Qatari waters. Qatar University.
- Barker VA, Cowan JH. 2018. The effect of artificial light on the community structure of reef-associated fishes at oil and gas platforms in the northern Gulf of Mexico. *Environmental Biology of Fishes*. 101(1):153-166.
- Beaver C, Childs S, Dokken Q. 2003. Secondary productivity within biotic fouling community elements on two artificial reef structures in the northwestern gulf of mexico. In: Stanley DR, Bull AS, editors. *Fisheries, reefs, and offshore development*. Bethesda, MD: American Fisheries Society Symposium 36. p. 195-204.
- Beaver CR. 2002. Fishery productivity and trophodynamics of platform artificial reefs in the northwestern Gulf of Mexico. Texas A&M University.
- Bennett C, Robertson A, Patterson WF. 2019. First record of the non-indigenous indo-pacific damselfish, *Neopomacentrus cyanomos* (Bleeker, 1856) in the northern Gulf of Mexico. *BioInvasions Records*. 8(1):154-166.
- Bergmark P, Jørgensen D. 2014. *Lophelia pertusa* conservation in the North Sea using obsolete offshore structures as artificial reefs. *Marine Ecology Progress Series*. 516:275-280.
- Bernstein BB. 2015a. Decision framework for platform decommissioning in California. *Integrated Environmental Assessment and Management*. 11(4):542-553.

- Bernstein BB. 2015b. Evaluating alternatives for decommissioning California's offshore oil and gas platforms. *Integrated Environmental Assessment and Management*. 11(4):537-541.
- Bishop MJ, Mayer-Pinto M, Aioldi L, Firth LB, Morris RL, Loke LHL, Hawkins SJ, Naylor LA, Coleman RA, Chee SY et al. 2017. Effects of ocean sprawl on ecological connectivity: Impacts and solutions. *Journal of Experimental Marine Biology and Ecology*. 492:7-30.
- Bohnsack JA. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? *Bulletin of Marine Science*. 44(2):631-645.
- Bohnsack JA, Sutherland DL. 1985. Artificial reef research: A review with recommendations for future priorities. *Bulletin of Marine Science*. 37(1):11-39.
- Boland GS. 2002. Fish and epifaunal community observations at an artificial reef near a natural coral reef: Nineteen years at platform High Island A389-A, from bare steel to coral habitat. In: McKay M, Nides J, Vigil D, editors. *Proceedings: Gulf of Mexico fish and fisheries: Bringing together new and recent research*. New Orleans, LA: United States Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. p. 372-392.
- Boland GS, Gallaway BJ, Baker JS, Lewbel GS. 1983. Ecological effects of energy development on reef fish of the Flower Garden Banks. Galveston, TX: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center. Contract NA80-GA-C-00057.
- Bolser DG, Egerton JP, Grüss A, Loughran T, Beyea T, McCain K, Erisman BE. 2020. Environmental and structural drivers of fish distributions among petroleum platforms across the U.S. Gulf of Mexico. *Marine and Coastal Fisheries*. 12(2):142-163.
- Boswell KM, Wells RJD, Cowan JH, Wilson CA. 2010. Biomass, density, and size distributions of fishes associated with a large-scale artificial reef complex in the Gulf of Mexico. *Bulletin of Marine Science*. 86(4):879-889.
- Brewton RA, Downey CH, Streich MK, Wetz JJ, Ajemian MJ, Stunz GW. 2020. Trophic ecology of red snapper *Lutjanus campechanus* on natural and artificial reefs: Interactions between annual variability, habitat, and ontogeny. *Marine Ecology Progress Series*. 635:105-122.
- Brown-Peterson NJ, Peterson CR, Fitzhugh GR. 2019. Multidecadal meta-analysis of reproductive parameters of female red snapper (*Lutjanus campechanus*) in the northern Gulf of Mexico. *Fishery Bulletin*. 117(1):37-49.
- Bureau of Ocean Energy Management (BOEM). 2020. Platform structures. Washington, D.C.: U.S. Department of the Interior, BOEM; [accessed May 2020]. <http://www.data.boem.gov/Platform/PlatformStructures/Default.aspx>.
- Bureau of Safety and Environmental Enforcement (BSEE). 2020a. Decommissioning. Washington, D.C.: U.S. Department of the Interior, BSEE; [accessed May 2020]. <http://www.bsee.gov/what-we-do/environmental-focuses/decommissioning>.
- Bureau of Safety and Environmental Enforcement (BSEE). 2020b. How many platforms are in the Gulf of Mexico? Washington, D.C.: U.S. Department of the Interior, BSEE; [accessed May 2020]. <http://www.bsee.gov/faqs/how-many-platforms-are-in-the-gulf-of-mexico>.
- Bureau of Safety and Environmental Enforcement (BSEE). 2020c. Rigs to reefs. Washington, D.C.: U.S. Department of the Interior, BSEE; [accessed May 2020]. <http://www.bsee.gov/what-we-do/environmental-focuses/rigs-to-reefs>.
- Bull AS, Kendall JJ. 1994. An indication of the process: Offshore platforms as artificial reefs in the Gulf of Mexico. *Bulletin of Marine Science*. 55(2-3):1086-1098.
- Bull AS, Love MS. 2019. Worldwide oil and gas platform decommissioning: A review of practices and reefing options. *Ocean & Coastal Management*. 168:274-306.

- Campbell MD, Rose KA, Boswell KM, Cowan J. 2011. Individual-based modeling of an artificial reef fish community: Effects of habitat quantity and degree of refuge. Ecological Modelling. 222(23-24):3895-3909.
- Claisse JT, Love MS, Meyer-Gutbrod EL, Williams CM, Pondella DJ. 2019. Fishes with high reproductive output potential on California offshore oil and gas platforms. Bulletin of Marine Science. 95(4):515-534.
- Claisse JT, Pondella DJ, Love M, Zahn LA, Williams CM, Bull AS. 2015. Impacts from partial removal of decommissioned oil and gas platforms on fish biomass and production on the remaining platform structure and surrounding shell mounds. PloS one. 10(9):e0135812.
- Claisse JT, Pondella DJ, Love M, Zahn LA, Williams CM, Williams JP, Bull AS. 2014. Oil platforms off California are among the most productive marine fish habitats globally. Proceedings of the National Academy of Sciences. 111(43):15462-15467.
- Consoli P, Romeo T, Ferraro M, Sarà G, Andaloro F. 2013. Factors affecting fish assemblages associated with gas platforms in the Mediterranean Sea. Journal of Sea Research. 77:45-52.
- Cowan JH, Grimes CB, Patterson WF, Walters CJ, Jones AC, Lindberg WJ, Sheehy DJ, Pine WE, Powers JE, Campbell MD et al. 2011. Red snapper management in the Gulf of Mexico: Science- or faith-based? Reviews in Fish Biology and Fisheries. 21(2):187-204.
- Cowan JH, Rose KA. 2016. Oil and gas platforms in the Gulf of Mexico: Their relationship to fish and fisheries. In: Mikkola H, editor. Fisheries and aquaculture in the modern world. Rejika, Croatia: Intech. p. 95-122.
- Cowen RK, Sponaugle S. 2009. Larval dispersal and marine population connectivity. Annual review of marine science. 1:443-466.
- Cripps SJ, Aabel JP. 2002. Environmental and socio-economic impact assessment of Ekoreef, a multiple platform rigs-to-reefs development. ICES Journal of Marine Science. 59:S300-S308.
- Curtis JM. 2014. Discard mortality, recruitment, and connectivity of red snapper (*Lutjanus campechanus*) in the northern Gulf of Mexico. Texas A&M University-Corpus Christi.
- Daigle ST. 2011. What is the importance of oil and gas platforms in the community structure and diet of benthic and demersal communities in the Gulf of Mexico? Louisiana State University.
- Daigle ST, Fleeger JW, Cowan JH, Pascal P-Y. 2013. What is the relative importance of phytoplankton and attached macroalgae and epiphytes to food webs on offshore oil platforms? Marine and Coastal Fisheries. 5(1):53-64.
- Dance KM, Rooker JR, Shipley JB, Dance MA, Wells RJD. 2018. Feeding ecology of fishes associated with artificial reefs in the northwest Gulf of Mexico. PloS one. 13(10):e0203873.
- Dauterive L. 2000. Rigs-to-reefs policy, progress, and perspective. New Orleans, LA: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office. OCS Report MMS 2000-073.
- Diamond SL, Campbell MD, Olson DE, Wang YU, Zeplin JA, Qualia ST. 2007. Movers and stayers: Individual variability in site fidelity and movements of red snapper off Texas. In: Patterson WF, Cowan JH, Fitzhugh GR, Nieland DL, editors. Red snapper: Ecology and fisheries in the U.S. Gulf of Mexico. Bethesda, MD: American Fisheries Society Symposium 60. p. 149-170.

- Ditton RB, Auyong J. 1985. Fishing offshore platforms, central Gulf of Mexico: An analysis of recreational and commercial fishing use at 164 major offshore petroleum structures. Metairie, LA: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico Regional Office.
- Dokken QR, Withers K, Childs S, Riggs T. 2000. Characterization and comparison of platform reef communities off the Texas coast. Prepared by the Center for Coastal Studies, Texas A&M University-Corpus Christi, Corpus Christi, TX. Austin, TX: Texas Parks and Wildlife Department. TAMU-CC-0007-CCS.
- Downey CH, Streich MK, Brewton RA, Ajemian MJ, Wetz JJ, Stunz GW. 2018. Habitat-specific reproductive potential of red snapper: A comparison of artificial and natural reefs in the western Gulf of Mexico. *Transactions of the American Fisheries Society*. 147(6):1030-1041.
- Driessen P. 1986. Offshore oil platforms - an invaluable ecological resource. *Proceedings of the Oceans 1986 Conference Record*; 1986; Washington, D.C. New York, NY: Institute of Electrical and Electronics Engineers.
- Everett A. 2018. Red snapper (*Lutjanus campechanus*) movement patterns based on acoustic positioning around oil and gas platform in the northern Gulf of Mexico. Auburn Univeristy.
- Flower Garden Banks National Marine Sanctuary (FGBNMS). 2017. Environmental assessment for authorization of U.S. Army Corps of Engineers permit SWG-2015-00068 to Texas Parks and Wildlife Department and Bureau of Safety and Environmental Enforcement approval of platform decommissioning and site clearance verification plan (2012-217a) to W&T Offshore Inc. For the creation of an artificial reef through the abandonment of a partially removed gas platform in the Outer Continental Shelf Block High Island A-389A (HI-A-389A). Galveston, TX: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, FGBNMS.
- Flower Garden Banks National Marine Sanctuary Advisory Council (FGBNMSAC). 2013. Artificial reef study report. Galveston, TX: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Flower Garden Banks National Marine Sanctuary.
- Firth LB, Knights AM, Bridger D, Evans A, Mieskowska N, Moore PJ, O'Connor NE, Sheehan EV, Thompson RC, Hawkins SJ. 2016. Ocean sprawl: Challenges and opportunities for biodiversity management in a changing world. *Oceanography and Marine Biology: an Annual Review*. 54:189-262.
- Fortune IS, Paterson DM. 2018. Ecological best practice in decommissioning: A review of scientific research. *ICES Journal of Marine Science*. 77(3):1079-1091.
- Foss KL. 2016. Feeding ecology of red snapper and greater amberjack at standing platforms in the northern Gulf of Mexico: Disentangling the effects of artificial light. Louisiana State University.
- Fowler AM, Jørgensen A-M, Coolen JWP, Jones DOB, Svendsen JC, Brabant R, Rumes B, Degraer S. 2020. The ecology of infrastructure decommissioning in the North Sea: What we need to know and how to achieve it. *ICES Journal of Marine Science*. 77(3):1109-1126.
- Fowler AM, Jørgensen A-M, Svendsen JC, Macreadie PI, Jones DOB, Boon AR, Booth DJ, Brabant R, Callahan E, Claisse JT et al. 2018. Environmental benefits of leaving offshore infrastructure in the ocean. *Frontiers in Ecology and the Environment*. 16(10):571-578.
- Fowler AM, Macreadie PI, Booth DJ. 2015. Should we "reef" obsolete oil platforms? *Proceedings of the National Academy of Sciences*. 112(2):E102.

- Fowler AM, Macreadie PI, Jones DOB, Booth DJ. 2014. A multi-criteria decision approach to decommissioning of offshore oil and gas infrastructure. *Ocean & Coastal Management*. 87:20-29.
- Franks JS. 2000. A review: Pelagic fishes at petroleum platforms in the northern Gulf of Mexico; diversity, interrelationships, and perspectives. In: Le Gall J-Y, Cayré P, Taquet M, editors. *Pêche thonière et dispositifs de concentration de poissons*. Issy-les-Moulineaux, France: IFREMER Actes de Colloque. p. 502-515.
- Friedlander AM, Ballesteros E, Fay M, Sala E. 2014. Marine communities on oil platforms in Gabon, West Africa: High biodiversity oases in a low biodiversity environment. *PloS one*. 9(8):e103709.
- Froehlich CY, Kline RJ. 2015. Using fish population metrics to compare the effects of artificial reef density. *PloS one*. 10(9):e0139444.
- Froehlich CYM, Garcia A, Kline RJ. 2019. Daily movement patterns of red snapper (*Lutjanus campechanus*) on a large artificial reef. *Fisheries Research*. 209:49-57.
- Gallaway BJ, Cole JG, Meyer R, Roscigno P. 1999. Delineation of essential habitat for juvenile red snapper in the northwestern Gulf of Mexico. *Transactions of the American Fisheries Society*. 128(4):713-726.
- Gallaway BJ, Lewbel GS. 1982. The ecology of petroleum platforms in the Gulf of Mexico: A community profile. Washington, D.C.: U.S. Department of the Interior, U.S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-82/27. New Orleans, LA: U.S. Department of the Interior, Bureau of Land Management, Gulf of Mexico OCS Regional Office. Open-File Report 82-03.
- Gallaway BJ, Szedlmayer ST, Gazey WJ. 2009. A life history review for red snapper in the Gulf of Mexico with an evaluation of the importance of offshore petroleum platforms and other artificial reefs. *Reviews in Fisheries Science*. 17(1):48-67.
- Garner SB, Patterson WF. 2015. Direct observation of fishing effort, catch, and discard rates of charter boats targeting reef fishes in the northern Gulf of Mexico. *Fishery Bulletin*. 113(2):157-166.
- Getz ET, Kline RJ. 2019. Utilizing accelerometer telemetry tags to compare red snapper (*Lutjanus campechanus* [Poey, 1860]) behavior on artificial and natural reefs. *Journal of Experimental Marine Biology and Ecology*. 519.
- Gitschlag GR, Herczeg BA. 1994. Sea turtle observations at explosive removals of energy structures. *Marine Fisheries Review*. 56(2):1-8.
- Gledhill CT. 2001. Reef fish assemblages on Gulf of Mexico shelf-edge banks. University of South Alabama.
- Glenn HD, Cowan JH, Powers JE. 2017. A comparison of red snapper reproductive potential in the northwestern Gulf of Mexico: Natural versus artificial habitats. *Marine and Coastal Fisheries*. 9(1):139-148.
- Goddard JHR, Love MS. 2010. Megabenthic invertebrates on shell mounds associated with oil and gas platforms off California. *Bulletin of Marine Science*. 86(3):533-554.
- Gomez V. 2020. An Ecopath with Ecosim analysis on offshore petroleum platform influences on Gulf of Mexico red snapper. Louisiana State University.
- Gordon WR. 1993. Travel characteristics of marine anglers using oil and gas platforms in the central Gulf of Mexico. *Marine Fisheries Review*. 55(1):25-31.

- Gregalis KC, Schlenker LS, Drymon JM, Mareska JF, Powers SP. 2012. Evaluating the performance of vertical longlines to survey reef fish populations in the northern Gulf of Mexico. *Transactions of the American Fisheries Society*. 141(6):1453-1464.
- Guerin AJ. 2009. Marine communities of North Sea offshore platforms, and the use of stable isotopes to explore artificial reef food webs. University of Southampton.
- Harvey ES, Newman SJ, McLean DL, Cappo M, Meeuwig JJ, Skepper CL. 2012. Comparison of the relative efficiencies of stereo-BRUVs and traps for sampling tropical continental shelf demersal fishes. *Fisheries Research*. 125-126:108-120.
- Harwell GE. 2013. Acoustic biomass of fish associated with an oil and gas platform before, during, and after reefing it in the northern Gulf of Mexico. Louisiana State University.
- Henrion M, Bernstein B, Swamy S. 2015. A multi-attribute decision analysis for decommissioning offshore oil and gas platforms. *Integrated Environmental Assessment and Management*. 11(4):594-609.
- Henry LA, Mayorga-Adame CG, Fox AD, Polton JA, Ferris JS, McLellan F, McCabe C, Kutt T, Roberts JM. 2018. Ocean sprawl facilitates dispersal and connectivity of protected species. *Scientific Reports*. 8(1):11346.
- Hiett RL, Milon JW. 2002. Economic impact of recreational fishing and diving associated with offshore oil and gas structures in the Gulf of Mexico: Final report. New Orleans, LA: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. OCS Study MMS 2002-010.
- Holbrook SJ, Ambrose RF, Botsford L, Carr MH, Raimondi PT, Tegner MJ. 2000. Ecological issues related to decommissioning of California's offshore production platforms. Report to the University of California Marine Council by the Select Scientific Advisory Committee on Decommissioning, University of California.
- Hoolihan JP, Wells RJD, Luo J, Falterman B, Prince ED, Rooker JR. 2014. Vertical and horizontal movements of yellowfin tuna in the Gulf of Mexico. *Marine and Coastal Fisheries*. 6(1):211-222.
- Jagerroos S, Krause PR. 2016. Rigs-to-reef; impact or enhancement on marine biodiversity. *Journal of Ecosystem & Ecography*. 6(2):1000187.
- Jensen AC, Collins KJ, Lockwood APM. 2000. Artificial reefs in European seas. Dordrecht, Netherlands: Springer Science+Business Media.
- Jones DOB, Gates AR, Huvenne VAI, Phillips AB, Bett BJ. 2019. Autonomous marine environmental monitoring: Application in decommissioned oil fields. *Science of the Total Environment*. 668:835-853.
- Kaiser MJ, Pulsipher AG. 2005. Rigs-to-reef programs in the Gulf of Mexico. *Ocean Development & International Law*. 36(2):119-134.
- Kaiser MJ, Shively JD, Shipley JB. 2020. An update on the Louisiana and Texas rigs-to-reefs programs in the Gulf of Mexico. *Ocean Development & International Law*. 51(1):73-93.
- Kaiser MJ, Snyder B, Yu Y. 2011. A review of the feasibility, costs, and benefits of platform-based open ocean aquaculture in the Gulf of Mexico. *Ocean & Coastal Management*. 54(10):721-730.
- Karnauskas M, Walter JF, Campbell MD, Pollack AG, Drymon JM, Powers SP. 2017. Red snapper distribution on natural habitats and artificial structures in the northern Gulf of Mexico. *Marine and Coastal Fisheries*. 9(1):50-67.
- Kasprzak RA. 1998. Use of oil and gas platforms as habitat in Louisiana's artificial reef program. *Gulf of Mexico Science*. 16(1):37-45.

- Keenan SF, Benfield MC, Blackburn JK. 2007. Importance of the artificial light field around offshore petroleum platforms for the associated fish community. *Marine Ecology Progress Series*. 331:219-231.
- Kolian S. 2011. The benefits of leaving oil and gas rigs intact to serve as artificial reefs. *Exploration & Production: The Oil & Gas Review*. 9(2):59-62.
- Kolian SR, Godec M, Sammarco PW. 2019. Alternate uses of retired oil and gas platforms in the Gulf of Mexico. *Ocean & Coastal Management*. 167:52-59.
- Kolian SR, Sammarco PW. 2019. Densities of reef-associated fish and corals on offshore platforms in the Gulf of Mexico. *Bulletin of Marine Science*. 95(3):393-407.
- Kolian SR, Sammarco PW, Porter SA. 2018. Use of retired oil and gas platforms for fisheries in the Gulf of Mexico. *Environment Systems and Decisions*. 38(4):501-507.
- Korneliussen RJ, Heggelund Y, Eliassen IK, Johansen GO. 2009. Acoustic species identification of schooling fish. *ICES Journal of Marine Science*. 66(6):1111-1118.
- Kulaw DH. 2012. Habitat- and region-specific reproductive biology of female red snapper (*Lutjanus campechanus*) in the Gulf of Mexico. Louisiana State University.
- Kulaw DH, Cowan JH, Jackson MW. 2017. Temporal and spatial comparisons of the reproductive biology of northern Gulf of Mexico (USA) red snapper (*Lutjanus campechanus*) collected a decade apart. *PloS one*. 12(3):e0172360.
- LGL Ecological Research Associates, Inc. (LGL). 2019. Characterization of fish assemblages associated with offshore oil and gas platforms in the Gulf of Mexico. New Orleans, LA: U.S. Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region. Contract M16PC00005.
- Lima JS, Zalmon IR, Love M. 2019. Overview and trends of ecological and socioeconomic research on artificial reefs. *Marine Environmental Research*. 145:81-96.
- Love MS. 2019. Fishes and invertebrates of oil and gas platforms off California: An introduction and summary. *Bulletin of Marine Science*. 95(4):463-476.
- Love MS, Brothers E, Schroeder DM, Lenarz WH. 2007. Ecological performance of young-of-the-year blue rockfish (*Sebastodes mystinus*) associated with oil platforms and natural reefs in California as measured by daily growth rates. *Bulletin of Marine Science*. 80(1):147-157.
- Love MS, Claisse JT, Roeper A. 2019a. An analysis of the fish assemblages around 23 oil and gas platforms off California with comparisons with natural habitats. *Bulletin of Marine Science*. 95(4):477-514.
- Love MS, Goldberg SR. 2009. A histological examination of the ovaries of Pacific sanddab, *Citharichthys sordidus*, captured at two oil platforms and two natural sites in the Southern California Bight. *Bulletin of the Southern California Academy of Sciences*. 108(2):45-51.
- Love MS, Kui L, Claisse JT. 2019b. The role of jacket complexity in structuring fish assemblages in the midwaters of two California oil and gas platforms. *Bulletin of Marine Science*. 95(4):597-616.
- Love MS, Nishimoto M, Clark S, Schroeder DM. 2012. Recruitment of young-of-the-year fishes to natural and artificial offshore structure within central and southern California waters, 2008–2010. *Bulletin of Marine Science*. 88(4):863-882.
- Love MS, Nishimoto MM, Snook L, Kui L. 2019c. An analysis of the sessile, structure-forming invertebrates living on California oil and gas platforms. *Bulletin of Marine Science*. 95(4):583-596.

- Love MS, Schroeder DM, Nishimoto M. 2003. The ecological role of oil and gas production platforms and natural outcrops on fishes in southern and central California: A synthesis of information. Seattle, WA: U.S. Department of the Interior, U.S. Geological Survey, Biological Resources Division. OCS Study MMS 2003-032.
- Lowe CG, Anthony KM, Jarvis ET, Bellquist LF, Love MS. 2009. Site fidelity and movement patterns of groundfish associated with offshore petroleum platforms in the Santa Barbara Channel. *Marine and Coastal Fisheries*. 1(1):71-89.
- Lugo-Fernández A, Deslarzes KJ, Price JM, Boland GS, Morin MV. 2001. Inferring probable dispersal of Flower Garden Banks coral larvae (Gulf of Mexico) using observed and simulated drifter trajectories. *Continental Shelf Research*. 21(1):47-67.
- Macreadie PI, Fowler AM, Booth DJ. 2011. Rigs-to-reefs: Will the deep sea benefit from artificial habitat? *Frontiers in Ecology and the Environment*. 9(8):455-461.
- Martin CJB, Lowe CG. 2010. Assemblage structure of fish at offshore petroleum platforms on the San Pedro Shelf of Southern California. *Marine and Coastal Fisheries*. 2(1):180-194.
- McCawley JR, Cowan JH. 2007. Seasonal and size specific diet and prey demand of red snapper on artificial reefs. In: Patterson WF, Cowan JH, Fitzhugh GR, Nieland DL, editors. *Red snapper: Ecology and fisheries in the U.S. Gulf of Mexico*. Bethesda, MD: American Fisheries Society Symposium 60. p. 77-104.
- McDonough M, Cowan J. 2007. Tracking red snapper movements around an oil platform with an automated acoustic telemetry system. *Proceedings of the Gulf and Caribbean Fisheries Institute*. 59:159-163.
- McLean DL, Taylor MD, Giraldo Ospina A, Partridge JC. 2019. An assessment of fish and marine growth associated with an oil and gas platform jacket using an augmented remotely operated vehicle. *Continental Shelf Research*. 179:66-84.
- Meyer-Gutbrod EL, Kui L, Nishimoto MM, Love MS, Schroeder DM, Miller RJ. 2019a. Fish densities associated with structural elements of oil and gas platforms in southern California. *Bulletin of Marine Science*. 95(4):639-656.
- Meyer-Gutbrod EL, Love MS, Claisse JT, Page HM, Schroeder DM, Miller RJ. 2019b. Decommissioning impacts on biotic assemblages associated with shell mounds beneath southern California offshore oil and gas platforms. *Bulletin of Marine Science*. 95(4):683-702.
- Mireles C, Martin CJB, Lowe CG. 2019. Site fidelity, vertical movement, and habitat use of nearshore reef fishes on offshore petroleum platforms in southern California. *Bulletin of Marine Science*. 95(4):657-682.
- Moncrief T, Brown-Peterson NJ, Peterson MS. 2018. Age, growth, and reproduction of vermilion snapper in the north-central Gulf of Mexico. *Transactions of the American Fisheries Society*. 147(5):996-1010.
- Montagna PA, Jarvis SC, Kennicutt MC. 2002. Distinguishing between contaminant and reef effects on meiofauna near offshore hydrocarbon platforms in the Gulf of Mexico. *Canadian Journal of Fisheries and Aquatic Sciences*. 59(10):1584-1592.
- Mudrak PA, Szedlmayer ST. 2012. Proximity effects of larger resident fishes on recruitment of age-0 red snapper in the northern Gulf of Mexico. *Transactions of the American Fisheries Society*. 141(2):487-494.
- Munnelly RT, Reeves DB, Chesney EJ, Baltz DM, Marx BD. 2019. Habitat suitability for oil and gas platform-associated fishes in Louisiana's nearshore waters. *Marine Ecology Progress Series*. 608:199-219.

- National Oceanic and Atmospheric Administration (NOAA). 2020. Artificial reefs. Charleston, SC: U.S. Department of Commerce, NOAA, Office for Coastal Management; [accessed May 2020]. <http://data.noaa.gov/dataset/dataset/artificial-reefs3>.
- Nieland DL, Wilson CA. 2003. Red snapper recruitment to and disappearance from oil and gas platforms in the northern Gulf of Mexico. In: Stanberg DR, Bull AS, editors. *Fisheries, reefs, and offshore development*. Bethesda, MD: American Fisheries Society Symposium 36. p. 73-81.
- Nishimoto MM, Simons RD, Love MS. 2019a. Offshore oil production platforms as potential sources of larvae to coastal shelf regions off southern California. *Bulletin of Marine Science*. 95(4):535-558.
- Nishimoto MM, Washburn L, Love MS, Schroeder DM, Emery BM, Kui L. 2019b. Timing of juvenile fish settlement at offshore oil platforms coincides with water mass advection into the Santa Barbara Channel, California. *Bulletin of Marine Science*. 95(4):559-582.
- Nugraha RB, Basuki R, Oh JS, Cho IH, Naibaho N, Secasari Y, Mbay LO. 2019. Rigs-to-reef (R2R): A new initiative on re-utilization of abandoned offshore oil and gas platforms in Indonesia for marine and fisheries sectors. *IOP Conference Series: Earth and Environmental Science*. 241:012014.
- Ouzts AC, Szedlmayer ST. 2003. Diel feeding patterns of red snapper on artificial reefs in the north-central Gulf of Mexico. *Transactions of the American Fisheries Society*. 132:1186-1193.
- Page HM, Dugan JE, Dugan DS, Richards JB, Hubbard DM. 1999. Effects of an offshore oil platform on the distribution and abundance of commercially important crab species. *Marine Ecology Progress Series*. 185:47-57.
- Page HM, Zaleski SF, Miller RJ, Dugan JE, Schroeder DM, Doheny B. 2019. Regional patterns in shallow water invertebrate assemblages on offshore oil and gas platforms along the Pacific continental shelf. *Bulletin of Marine Science*. 95(4):617-638.
- Parker RO, Colby DR, Willis TD. 1983. Estimated amount of reef habitat on a portion of the U.S. South Atlantic and Gulf of Mexico continental shelf. *Bulletin of Marine Science*. 33(4):935-940.
- Patterson WF. 2007. A review of movement in Gulf of Mexico red snapper: Implications for population structure. In: Patterson WF, Cowan JH, Fitzhugh GR, Nieland DL, editors. *Red snapper: Ecology and fisheries in the U.S. Gulf of Mexico*. Bethesda, MD: American Fisheries Society Symposium 60. p. 221-235.
- Patterson WF, Cowan JH. 2003. Site fidelity and dispersion of red snapper associated with artificial reefs in the northern Gulf of Mexico. In: Stanley DR, Scarborough-Bull A, editors. *Fisheries, reefs, and offshore development*. Bethesda, MD: American Fisheries Society Symposium 36. p. 181-193.
- Patterson WF, Cowan JH, Wilson CA, Chen Z. 2008. Temporal and spatial variability in juvenile red snapper otolith elemental signatures in the northern Gulf of Mexico. *Transactions of the American Fisheries Society*. 137(2):521-532.
- Patterson WF, Tarnecki JH, Addis DT, Barbieri LR. 2014. Reef fish community structure at natural versus artificial reefs in the northern Gulf of Mexico. *Proceedings of the Gulf and Caribbean Fisheries Institute*. 66:4-8.
- Patterson WF, Watterson JC, Shipp RL, Cowan JH. 2001. Movement of tagged red snapper in the northern Gulf of Mexico. *Transactions of the American Fisheries Society*. 130(4):533-545.

- Pickering H, Whitmarsh D. 1997. Artificial reefs and fisheries exploitation: A review of the 'attraction versus production' debate, the influence of design and its significance for policy. *Fisheries Research*. 31(1-2):39-59.
- Piraino MN, Szedlmayer ST. 2014. Fine-scale movements and home ranges of red snapper around artificial reefs in the northern Gulf of Mexico. *Transactions of the American Fisheries Society*. 143(4):988-998.
- Plumlee JD, Dance KM, Dance MA, Rooker JR, TinHan TC, Shipley JB, Wells RJD. 2020. Fish assemblages associated with artificial reefs assessed using multiple gear types in the northwest Gulf of Mexico. *Bulletin of Marine Science*. 96:1-23.
- Pondella DJ, Zahn LA, Love MS, Siegel D, Bernstein BB. 2015. Modeling fish production for southern California's petroleum platforms. *Integrated Environmental Assessment and Management*. 11(4):584-593.
- Pulsipher AG, Iledare OO, Mesyanzhinov DV, Dupont A, Zhu QL. 2001. Forecasting the number of offshore platforms on the Gulf of Mexico OCS to the year 2023. Prepared by the Center for Energy Studies, Louisiana State University, Baton Rouge, LA. New Orleans, LA: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. OCS Study MMS 2001-013.
- Puritz JB, Gold JR, Portnoy DS. 2016. Fine-scale partitioning of genomic variation among recruits in an exploited fishery: Causes and consequences. *Scientific Reports*. 6:36095.
- Quirolo D, Charter R. 2014. Bring back the gulf: A better plan than dumping abandoned oil rigs into the Gulf of Mexico. Washington, D.C.: Coastal Coordination Program, The Ocean Foundation.
- Reeves DB, Chesney EJ, Munnely RT, Baltz DM. 2018a. Barnacle settlement and growth at oil and gas platforms in the northern Gulf of Mexico. *Marine Ecology Progress Series*. 590:131-143.
- Reeves DB, Chesney EJ, Munnely RT, Baltz DM. 2018b. Sheepshead foraging patterns at oil and gas platforms in the northern Gulf of Mexico. *North American Journal of Fisheries Management*. 38(6):1258-1274.
- Reeves DB, Chesney EJ, Munnely RT, Baltz DM, Maiti K. 2019. Trophic ecology of sheepshead and stone crabs at oil and gas platforms in the northern Gulf of Mexico's hypoxic zone. *Transactions of the American Fisheries Society*. 148(2):324-338.
- Reeves DB, Chesney EJ, Munnely RT, Baltz DM, Marx BD. 2018c. Abundance and distribution of reef-associated fishes around small oil and gas platforms in the northern Gulf of Mexico's hypoxic zone. *Estuaries and Coasts*. 41(7):1835-1847.
- Reggio VC. 1987. Rigs-to-reefs: The use of obsolete petroleum structures as artificial reefs. New Orleans, LA: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office. MMS87-0015.
- Reynolds EM, Cowan JH, Lewis KA, Simonsen KA. 2018. Method for estimating relative abundance and species composition around oil and gas platforms in the northern Gulf of Mexico, U.S.A. *Fisheries Research*. 201:44-55.
- Rezak R, Bright TJ, McGrail DW. 1985. Reefs and banks of the northwestern Gulf of Mexico: Their geological, biological, and physical dynamics. New York, NY: Wiley.
- Rezek RJ, Lebreton B, Palmer TA, Stunz GW, Pollack JB. 2018. Structural and functional similarity of epibenthic communities on standing and reefed platforms in the northwestern Gulf of Mexico. *Progress in Oceanography*. 168:145-154.

- Rooker JR, Dokken QR, Pattengill CV, Holt GJ. 1997. Fish assemblages on artificial and natural reefs in the Flower Garden Banks National Marine Sanctuary, USA. *Coral Reefs*. 16(2):83-92.
- Saari CR. 2011. Comparison of the age and growth of red snapper (*Lutjanus campechanus*) amongst habitats and regions in the Gulf of Mexico. Louisiana State University.
- Saari CR, Cowan JH, Boswell KM. 2014. Regional differences in the age and growth of red snapper (*Lutjanus campechanus*) in the U.S. Gulf of Mexico. *Fishery Bulletin*. 112(4):261-273.
- Sammarco PW. 2014. Coral community development on offshore platforms in the Gulf of Mexico: What we now know. In: Bortone SA, editor. *Interrelationships between corals and fisheries*. Boca Raton, FL: CRC Press. p. 113-126.
- Sammarco PW, Atchison AD, Boland GS. 2004. Expansion of coral communities within the northern Gulf of Mexico via offshore oil and gas platforms. *Marine Ecology Progress Series*. 280:129-143.
- Sammarco PW, Atchison AD, Boland GS, Sinclair J, Lurette A. 2012a. Geographic expansion of hermatypic and ahermatypic corals in the Gulf of Mexico, and implications for dispersal and recruitment. *Journal of Experimental Marine Biology and Ecology*. 436-437:36-49.
- Sammarco PW, Brazeau DA, McKoin M, Strychar KB. 2017. *Tubastraea micranthus*, comments on the population genetics of a new invasive coral in the western Atlantic and a possible secondary invasion. *Journal of Experimental Marine Biology and Ecology*. 490:56-63.
- Sammarco PW, Brazeau DA, Sinclair J. 2012b. Genetic connectivity in scleractinian corals across the northern Gulf of Mexico: Oil/gas platforms, and relationship to the Flower Garden Banks. *PloS one*. 7(4):e30144.
- Sammarco PW, Lurette A, Tung YF, Boland GS, Genazzio M, Sinclair J. 2014a. Coral communities on artificial reefs in the Gulf of Mexico: Standing vs. toppled oil platforms. *ICES Journal of Marine Science*. 71(2):417-426.
- Sammarco PW, Porter SA, Cairns SD. 2010. A new coral species introduced into the Atlantic Ocean - *Tubastraea micranthus* (Ehrenberg 1834) (Cnidaria, Anthozoa, Scleractinia): An invasive threat? *Aquatic Invasions*. 5(2):131-140.
- Sammarco PW, Porter SA, Sinclair J, Genazzio M. 2014b. Population expansion of a new invasive coral species, *Tubastraea micranthus*, in the northern Gulf of Mexico. *Marine Ecology Progress Series*. 495:161-173.
- Sayer MD, Baine MS. 2002. Rigs to reefs: A critical evaluation of the potential for reef development using decommissioned rigs. *Journal of the Society for Underwater Technology*. 25(2):93-98.
- Scarborough-Bull A, Love MS, Schroeder DM. 2008. Artificial reefs as fishery conservation tools - contrasting the roles of offshore structures between the Gulf of Mexico and the Southern California Bight. In: Nielsen J, Dodson JJ, Friedland K, Hamon TR, Musick J, Verspoor E, editors. *Reconciling fisheries with conservation: Proceedings of the fourth world fisheries congress*. Bethesda, MD: American Fisheries Society Symposium 49. p. 899-915.
- Schroeder DM, Love MS. 2004. Ecological and political issues surrounding decommissioning of offshore oil facilities in the Southern California Bight. *Ocean & Coastal Management*. 47(1-2):21-48.
- Schroepfer RL, Szedlmayer ST. 2006. Estimates of residence and site fidelity for red snapper *Lutjanus campechanus* on artificial reefs in the northeastern Gulf of Mexico. *Bulletin of Marine Science*. 78(1):93-101.

- Schuett MA, Kyle GT, Dudensing R, Ding C, van Riper C, Park J. 2015. Attitudes, behavior, and management preferences of Texas artificial reef users. Prepared by Texas A&M University, College Station, TX. Austin, TX: Texas Parks and Wildlife Department, Artificial Reef Program.
- Schwartzkopf BD, Cowan JH. 2017. Seasonal and sex differences in energy reserves of red snapper *Lutjanus campechanus* on natural and artificial reefs in the northwestern Gulf of Mexico. *Fisheries Science*. 83(1):13-22.
- Schwartzkopf BD, Langland TA, Cowan JH. 2017. Habitat selection important for red snapper feeding ecology in the northwestern Gulf of Mexico. *Marine and Coastal Fisheries*. 9(1):373-387.
- Sheehy DJ, Vik SF. 2010. The role of constructed reefs in non-indigenous species introductions and range expansions. *Ecological Engineering*. 36(1):1-11.
- Shipley JB, Cowan JH. 2011. Artificial reef placement: A red snapper, *Lutjanus campechanus*, ecosystem and fuzzy rule-based model. *Fisheries Management and Ecology*. 18(2):154-167.
- Shipley MF, Coy SP, Shipley JB. 2018. Utilizing statistical significance in fuzzy interval valued evidence sets for assessing artificial reef structure impact. *Journal of the Operational Research Society*. 69(6):905-918.
- Shipp RL, Bortone SA. 2009. A perspective of the importance of artificial habitat on the management of red snapper in the Gulf of Mexico. *Reviews in Fisheries Science*. 17(1):41-47.
- Shively JD, Culbertson JC, Peter DD, Embesi JA, Hammerschmidt PC. 2003. The Texas artificial reef program: Over 50 years of marine habitat enhancement in the Gulf of Mexico. Austin, TX: Texas Parks and Wildlife Department, Coastal Fisheries Division.
- Simonsen KA. 2013. Reef fish demographics on Louisiana artificial reefs: The effects of reef size on biomass distribution and foraging dynamics. Louisiana State University.
- Simonsen KA, Cowan JH, Boswell KM. 2015. Habitat differences in the feeding ecology of red snapper (*Lutjanus campechanus*, Poey 1860): A comparison between artificial and natural reefs in the northern Gulf of Mexico. *Environmental Biology of Fishes*. 98(3):811-824.
- Sink KJ, Atkinson LJ, Kerwath S, Samaai T. 2010. Assessment of offshore benthic biodiversity on the Agulhas Bank and the potential role of petroleum infrastructure in offshore spatial management. Report prepared for WWF South Africa and PetroSA through a SANBI initiative.
- Sluis MZ, Barnett BK, Patterson WF, Cowan JH, Shiller AM. 2015. Application of otolith chemical signatures to estimate population connectivity of red snapper in the western Gulf of Mexico. *Marine and Coastal Fisheries*. 7(1):483-496.
- Sluis MZ, Boswell KM, Chumchal MM, Wells RJ, Soulen B, Cowan JH. 2013. Regional variation in mercury and stable isotopes of red snapper (*Lutjanus campechanus*) in the northern Gulf of Mexico, USA. *Environmental Toxicology and Chemistry*. 32(2):434-441.
- Sluis MZ, Cowan JH. 2013. Platform recruited reef fish, phase II: Do platforms provide habitat that increases the survival of reef fishes? New Orleans, LA: U.S. Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region. OCS Study BOEM 2013-0120.
- Soldal AV, Bronstad O, Humborstad O, Jørgensen T, Løkkeborg S, Svellingen I. 1998. Oil production structures in the North Sea as fish aggregating devices. Paper presented at: International Council for Exploration of the Sea.

- Sommer B, Fowler AM, Macreadie PI, Palandro DA, Aziz AC, Booth DJ. 2019. Decommissioning of offshore oil and gas structures - environmental opportunities and challenges. *Science of the Total Environment*. 658:973-981.
- Southeast Data, Assessment, and Review (SEDAR). 2018. SEDAR 52 Gulf of Mexico red snapper stock assessment report. North Charleston, SC: SEDAR.
- Stanley DR, Wilson CA. 1989. Utilization of offshore platforms by recreational fishermen and scuba divers off the Louisiana coast. *Bulletin of Marine Science*. 44(2):767-776.
- Stanley DR, Wilson CA. 1990. A fishery-dependent based study of fish species composition and associated catch rates around oil and gas structures off Louisiana. *Fishery Bulletin*. 88(4):719-730.
- Stanley DR, Wilson CA. 1997. Seasonal and spatial variation in the abundance and size distribution of fishes associated with a petroleum platform in the northern Gulf of Mexico. *Canadian Journal of Fisheries and Aquatic Sciences*. 54(5):1166-1176.
- Stanley DR, Wilson CA. 1998. Spatial variation in fish density at three petroleum platforms as measured with dual-beam hydroacoustics. *Gulf of Mexico Science*. 16(1):73-82.
- Stanley DR, Wilson CA. 2004. Effect of hypoxia on the distribution of fishes associated with a petroleum platform off coastal Louisiana. *North American Journal of Fisheries Management*. 24(2):662-671.
- Streich MK, Ajemian MJ, Wetz JJ, Shively JD, Shipley JB, Stunz GW. 2017a. Effects of a new artificial reef complex on red snapper and the associated fish community: An evaluation using a before-ffter control-impact approach. *Marine and Coastal Fisheries*. 9(1):404-418.
- Streich MK, Ajemian MJ, Wetz JJ, Stunz GW. 2017b. A comparison of fish community structure at mesophotic artificial reefs and natural banks in the western Gulf of Mexico. *Marine and Coastal Fisheries*. 9(1):170-189.
- Streich MK, Ajemian MJ, Wetz JJ, Stunz GW. 2018. Habitat-specific performance of vertical line gear in the western Gulf of Mexico: A comparison between artificial and natural habitats using a paired video approach. *Fisheries Research*. 204:16-25.
- Streich MK, Ajemian MJ, Wetz JJ, Williams JA, Shipley JB, Stunz GW. 2017c. A comparison of size structure, age, and growth of red snapper from artificial and natural habitats in the western Gulf of Mexico. *Transactions of the American Fisheries Society*. 146(4):762-777.
- Strelcheck A, Hood P. 2007. Rebuilding red snapper: Recent management activities and future management challenges. In: Patterson WF, Cowan JH, Fitzhugh GR, Nieland DL, editors. *Red snapper: Ecology and fisheries in the U.S. Gulf of Mexico*. Bethesda, MD: American Fisheries Society Symposium 60. p. 385–396.
- Strelcheck AJ, Cowan JH, Patterson WF. 2007. Site fidelity, movement, and growth of red snapper: Implications for artificial reef management. In: Patterson WF, Cowan JH, Fitzhugh GR, Nieland DL, editors. *Red snapper: Ecology and fisheries in the U.S. Gulf of Mexico*. Bethesda, MD: American Fisheries Society Symposium 60. p. 135-148.
- Strelcheck AJ, Cowan JH, Shah A. 2005. Influence of reef location on artificial-reef fish assemblages in the northcentral Gulf of Mexico. *Bulletin of Marine Science*. 77(3):425-440.
- Szedlmayer ST, Schroepfer RL. 2005. Long-term residence of red snapper on artificial reefs in the northeastern Gulf of Mexico. *Transactions of the American Fisheries Society*. 134(2):315-325.

- Szedlmayer ST, Shipp RL. 1994. Movement and growth of red snapper, *Lutjanus campechanus*, from an artificial reef area in the northeastern Gulf of Mexico. Bulletin of Marine Science. 55(2-3):887-896.
- Thomson PG, Fowler AM, Davis AR, Pattiarratchi CB, Booth DJ. 2018. Some old movies become classics – a case study determining the scientific value of rov inspection footage on a platform on Australia's north west shelf. Frontiers in Marine Science. 5:471.
- Todd VLG, Lavallin EW, Macreadie PI. 2018. Quantitative analysis of fish and invertebrate assemblage dynamics in association with a north sea oil and gas installation complex. Marine Environmental Research. 142:69-79.
- Todd VLG, Lazar L, Williamson LD, Peters IT, Hoover AL, Cox SE, Todd IB, Macreadie PI, McLean DL. 2020. Underwater visual records of marine megafauna around offshore anthropogenic structures. Frontiers in Marine Science. 7:230.
- Todd VLG, Pearse WD, Tregenza NC, Lepper PA, Todd IB. 2009. Diel echolocation activity of harbour porpoises (*Phocoena phocoena*) around North Sea offshore gas installations. ICES Journal of Marine Science. 66(4):734-745.
- Todd VLG, Williamson LD, Cox SE, Todd IB, Macreadie PI. 2019. Characterizing the first wave of fish and invertebrate colonization on a new offshore petroleum platform. ICES Journal of Marine Science. 77(3):1127-1136.
- Toland JM. 2001. Patterns of reef fish larval supply to petroleum platforms in the northern Gulf of Mexico. Louisiana State University.
- Topping DT, Szedlmayer ST. 2011. Site fidelity, residence time and movements of red snapper *Lutjanus campechanus* estimated with long-term acoustic monitoring. Marine Ecology Progress Series. 437:183-200.
- van der Molen J, García-García LM, Whomersley P, Callaway A, Posen PE, Hyder K. 2018. Connectivity of larval stages of sedentary marine communities between hard substrates and offshore structures in the North Sea. Sci Rep. 8(1):14772.
- van der Stap T, Coolen JW, Lindeboom HJ. 2016. Marine fouling assemblages on offshore gas platforms in the southern North Sea: Effects of depth and distance from shore on biodiversity. PloS one. 11(1):e0146324.
- van Eeden S, Meeuwig JJ, Hobbs RJ, Hemmi JM. 2019. Offshore oil and gas platforms as novel ecosystems: A global perspective. Frontiers in Marine Science. 6.
- Versar, Inc. 2008. Literature search and data synthesis of biological information for use in management decisions concerning decommissioning of offshore oil and gas structures in the gulf of mexico. Herndon, VA: U.S. Department of the Interior, Minerals Management Service. Contract 1435-01-05-39082.
- Villareal TA, Hanson S, Qualia ST, Jester ELE, Granade HR, Dickey RW. 2007. Petroleum production platforms as sites for the expansion of ciguatera in the northwestern Gulf of Mexico. Harmful Algae. 6(2):253-259.
- Wells RJD, Cowan JH. 2007. Video estimates of red snapper and associated fish assemblages on sand, shell, and natural reef habitats in the north-central Gulf of Mexico. In: Patterson WF, Cowan JH, Fitzhugh GR, Nieland DL, editors. Red snapper: Ecology and fisheries in the U.S. Gulf of Mexico. Bethesda, MD: American Fisheries Society Symposium 60. p. 39-57.
- Wells RJD, Cowan JH, Fry B. 2008. Feeding ecology of red snapper *Lutjanus campechanus* in the northern Gulf of Mexico. Marine Ecology Progress Series. 361:213-225.

- Wells RJD, TinHan TC, Dance MA, Drymon JM, Falterman B, Ajemian MJ, Stunz GW, Mohan JA, Hoffmayer ER, Driggers WB et al. 2018. Movement, behavior, and habitat use of a marine apex predator, the scalloped hammerhead. *Frontiers in Marine Science*. 5:321.
- Westmeyer MP, Wilson CA, Nieland DL. 2007. Fidelity of red snapper to petroleum platforms in the northern Gulf of Mexico. In: Patterson WF, Cowan JH, Fitzhugh GR, Nieland DL, editors. *Red snapper: Ecology and fisheries in the U.S. Gulf of Mexico*. Bethesda, MD: American Fisheries Society Symposium 60. p. 105-121.
- Wetz JJ, Ajemian MJ, Shipley B, Stunz GW. 2020. An assessment of two visual survey methods for documenting fish community structure on artificial platform reefs in the Gulf of Mexico. *Fisheries Research*. 225.
- Williams-Grove LJ, Szedlmayer ST. 2016. Acoustic positioning and movement patterns of red snapper, *Lutjanus campechanus*, around artificial reefs in the northern Gulf of Mexico. *Marine Ecology Progress Series*. 553:233-251.
- Williams-Grove LJ, Szedlmayer ST. 2017. Depth preferences and three-dimensional movements of red snapper, *Lutjanus campechanus*, on an artificial reef in the northern Gulf of Mexico. *Fisheries Research*. 190:61-70.
- Wilson CA, Miller MW, Allen YC, Boswell KM, Nieland DL. 2006. Effect of depth, location, and habitat type, on relative abundance and species composition of fishes associated with petroleum platforms and Sonnier Bank in the northern Gulf of Mexico. New Orleans, LA: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. OCS Study MMS 2006-037.
- Wilson CA, Pierce A, Miller MW. 2003. Rigs and reefs: A comparison of the fish communities at two artificial reefs, a production platform, and a natural reef in the northern Gulf of Mexico. New Orleans, LA: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. OCS Study MMS 2003-009.
- Wolfson A, Van Blaricom G, Davis N, Lewbel GS. 1979. The marine life of an offshore oil platform. *Marine Ecology Progress Series*. 1:81-89.
- Yeung CW, Law BA, Milligan TG, Lee K, Whyte LG, Greer CW. 2011. Analysis of bacterial diversity and metals in produced water, seawater and sediments from an offshore oil and gas production platform. *Marine Pollution Bulletin*. 62(10):2095-2105.

Appendix

Table A1. Summary of literature search results. References in the United States are assigned to the Gulf of Mexico (GOM) and Southern California Bight (SCB) regions. Study type assignments correspond to review, standing oil and gas production platforms, Rigs-to-Reefs (RTR) structures, other artificial reef materials, and natural habitats.

Reference	Region	Study Type
Aabel et al. (1997)	North Sea	Review
Ajemanian et al. (2015a)	GOM	Standing, RTR, Artificial
Ajemanian et al. (2015b)	GOM	RTR, Artificial
Anthony et al. (2013)	SCB	Standing
Atchison et al. (2008)	GOM	Standing, Natural
Aziz (2019)	Persian Gulf	Standing
Barker and Cowan (2018)	GOM	Standing
Bergmark and Jørgensen (2014)	North Sea	Standing
Bernstein (2015a)	SCB	Review
Bernstein (2015b)	SCB	Review
Bolser et al. (2020)	GOM	Standing
Boswell et al. (2010)	GOM	RTR
Brewton et al. (2020)	GOM	Standing, RTR, Natural
Brown-Peterson et al. (2019)	GOM	Standing, RTR, Artificial ^a
Bull and Kendall (1994)	GOM	RTR, Natural
Bull and Love (2019)	SCB	Review
Claisse et al. (2014)	SCB	Standing, Natural
Claisse et al. (2015)	SCB	Standing, RTR
Claisse et al. (2019)	SCB	Standing, Natural
Consoli et al. (2013)	Mediterranean Sea	Standing
Cowan and Rose (2016)	GOM	Standing
Cripps and Aabel (2002)	North Sea	Review
Daigle (2011)	GOM	Standing, RTR
Daigle et al. (2013)	GOM	Standing
Dokken et al. (2000)	GOM	Standing, RTR
Downey et al. (2018)	GOM	Standing, RTR, Natural
Driessens (1986)	GOM	Review
Firth et al. (2016)	North Sea	Review
Fortune and Paterson (2018)	North Sea	Review
Foss (2016)	GOM	Standing
Fowler et al. (2014)	North Sea	Review
Fowler et al. (2015)	North Sea	Review
Fowler et al. (2018)	North Sea	Review
Fowler et al. (2020)	North Sea	Review
Friedlander et al. (2014)	West Africa	Standing
Getz and Kline (2019)	GOM	RTR, Artificial, Natural

Table A1. continued.

Reference	Region	Study Type
Gitschlag and Herczeg (1994)	GOM	Standing
Glenn et al. (2017)	GOM	Standing, RTR, Natural ^b
Goddard and Love (2010)	SCB	Standing
Gomez (2020)	GOM	Standing
Guerin (2009)	North Sea	Standing
Harwell (2013)	GOM	Standing, RTR
Henrion et al. (2015)	SCB	Review
Holbrook et al. (2000)	SCB	Review
Jagerroos and Krause (2016)	Southeast Asia	Review
Jensen et al. (2000)	North Sea	Review
Jones et al. (2019)	North Sea	Standing
Karnauskas et al. (2017)	GOM	Standing, RTR, Artificial, Natural ^c
Kasprzak (1998)	GOM	Review
Keenan et al. (2007)	GOM	Standing
Kolian (2011)	GOM	Review
Kolian et al. (2018)	GOM	Review
Kolian et al. (2019)	GOM	Review
Kulaw (2012)	GOM	Standing, RTR, Natural
Kulaw et al. (2017)	GOM	Standing, RTR, Artificial, Natural ^a
Lima et al. (2019)	SCB	Review
Love (2019)	SCB	Review
Love and Goldberg (2009)	SCB	Standing, Natural
Love et al. (2003)	SCB	Review
Love et al. (2007)	SCB	Standing, Natural
Love et al. (2019a)	SCB	Standing
Love et al. (2019b)	SCB	Standing
Lowe et al. (2009)	SCB	Standing
Macreadie et al. (2011)	Australia	Review
Martin and Lowe (2010)	SCB	Standing
McLean et al. (2019)	Australia	Standing
Meyer-Gutbrod et al. (2019b)	SCB	Standing
Meyer-Gutbrod et al. (2019a)	SCB	Standing
Mireles et al. (2019)	SCB	Standing
Moncrief et al. (2018)	GOM	Standing, RTR, Natural
Munnelly et al. (2019)	GOM	Standing
Nishimoto et al. (2019a)	SCB	Standing
Nugraha et al. (2019)	Indonesia	Review
Page et al. (1999)	SCB	Standing
Page et al. (2019)	SCB	Standing
Plumlee et al. (2020)	GOM	RTR, Artificial
Pondella et al. (2015)	SCB	Standing, RTR
Quirolo and Charter (2014)	GOM	Review

Table A1. continued.

Reference	Region	Study Type
Reeves et al. (2018c)	GOM	Standing
Reeves et al. (2018a)	GOM	Standing
Reeves et al. (2018b)	GOM	Standing
Reeves et al. (2019)	GOM	Standing
Reggio (1987)	GOM	Review
Reynolds et al. (2018)	GOM	Standing, RTR
Rezek et al. (2018)	GOM	Standing, RTR
Saari (2011)	GOM	Standing, RTR, Natural
Sammarco (2014)	GOM	Review
Sammarco et al. (2010)	GOM	Standing
Sammarco et al. (2014a)	GOM	Standing, RTR
Sammarco et al. (2014b)	GOM	Standing
Sammarco et al. (2017)	GOM	Standing
Sayer and Baine (2002)	North Sea	Review
Scarborough-Bull et al. (2008)	SCB	Review
Schroeder and Love (2004)	SCB	Review
Schwartzkopf and Cowan (2017)	GOM	Standing, RTR, Natural ^b
Schwartzkopf et al. (2017)	GOM	Standing, RTR, Natural ^b
Sheehy and Vik (2010)	GOM	Review
Shipley et al. (2018)	GOM	Standing, RTR, Artificial ^a
Shively et al. (2003)	GOM	Review
Simonsen (2013)	GOM	Standing, RTR, Natural
Simonsen et al. (2015)	GOM	Standing, RTR, Natural
Sink et al. (2010)	South Africa	Standing, Natural
Sluis and Cowan (2013)	GOM	Standing
Sluis et al. (2013)	GOM	Standing, RTR, Artificial, Natural ^b
Soldal et al. (1998)	North Sea	Standing
Sommer et al. (2019)	Australia	Review
Stanley and Wilson (1998)	GOM	Standing
Streich et al. (2017b)	GOM	RTR, Natural
Streich et al. (2017c)	GOM	Standing, RTR, Natural
Streich et al. (2018)	GOM	Standing, RTR, Natural ^d
Thomson et al. (2018)	Australia	Standing
Todd et al. (2009)	North Sea	Standing
Todd et al. (2018)	North Sea	Standing
Todd et al. (2020)	North Sea	Standing
van der Stap et al. (2016)	North Sea	Standing
van Elden et al. (2019)	Australia	Review
Villareal et al. (2007)	GOM	Standing
Wells et al. (2018)	GOM	Standing, RTR, Artificial ^a
Westmeyer et al. (2007)	GOM	Standing, RTR
Wilson et al. (2003)	GOM	Standing, RTR, Natural

Table A1. continued.

Reference	Region	Study Type
Wilson et al. (2006)	GOM	Standing, Natural
Wolfson et al. (1979)	SCB	Standing
Yeung et al. (2011)	Canada	Standing

^aNo comparison between habitat types

^bStanding oil and gas production platforms and RTR structures combined into a single category

^cRTR structures and other artificial reef materials combined into a single category

^dCompanion study to Streich et al. (2017c)