Vol. 33: 69–74, 2024
https://doi.org/10.3354/ab00768

AQUATIC BIOLOGY
Aquat Biol

Published May 8

NOTE

Red snapper excavate sediments around artificial reefs: observations of ecosystem-engineering behavior by a widely distributed lutjanid

Theodore S. Switzer[1,*], Sean F. Keenan[1], Ryan T. Munnelly[2], Sheri L. Parks[1], Brett R. Pittinger[1], Theresa K. Warner[1], Richard E. Matheson Jr. [1], Ryan Maloney[3]

[1]Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute 100 8th Avenue Southeast, St. Petersburg, Florida 33701, USA
[2]Coonamessett Farm Foundation, Inc., 277 Hatchville Road, East Falmouth, Massachusetts 02536, USA
[3]Cloudwyze Inc., 1838 Sir Tyler Dr., Wilmington, North Carolina 28402, USA

ABSTRACT: Hard substrate and vertical relief are limited habitat resources for reef-associated species in many regions. On the West Florida Shelf (WFS) of the Gulf of Mexico, red grouper *Epinephelus morio* act as ecosystem engineers by excavating sediments to expose limestone bedrock. Excavations can exceed 25 m in diameter and 2 m in depth and are among the most abundant WFS seafloor features at depths between 40 and 110 m. As part of a survey of hard-bottom habitats and associated reef fish assemblages, 1203 excavations were identified in WFS waters along the Florida Panhandle between 2014 and 2019. These excavations often contained subsided artificial reef material within their interior and infrequently included *E. morio* among observed fishes. We video-identified red snapper *Lutjanus campechanus* excavating sediments around 2 subsided artificial reefs in 2015 and 2017 for a total of approximately 56 min of excavation activity. A total of 24 excavation events were documented around a tire pile in 2015, and 5 were documented around a pyramid-shaped reef module in 2017. These observations help to explain the subsidence of artificial reefs and apparent excavation around their bases despite the scarcity of previously known excavating species. This suggests that *L. campechanus* might be ecosystem engineers on the WFS.

KEY WORDS: Ecosystem engineer · Pockmarks · Artificial reefs · Subsidence · Bioturbation · *Lutjanus campechanus*

1. INTRODUCTION

The cultural, economic, and ecological importance of red snapper *Lutjanus campechanus* in the Gulf of Mexico (GOM) has motivated efforts to understand their complex life history. Through ongoing efforts to rebuild the stock initiated in 1988, *L. campechanus* have been the central focus of fisheries-independent surveys and artificial reef habitat enhancement in the GOM, culminating in recent efforts to estimate their absolute abundance (Stunz et al. 2021). One enigmatic aspect of *L. campechanus* life history is their varying habitat preferences. Juveniles typically settle on unconsolidated sediments and shell hash on the inner shelf (Geary et al. 2007). As they grow, *L. campechanus* transition to hardbottom habitats (Powers et al. 2018), and gradually return to the use of non-reef habitats after the age of 8 yr (Powers et al. 2018). Site fidelity is generally high in both juveniles (Workman et al. 2002) and adults (Topping & Szedlmayer 2011), although large-scale movements have been observed (Patterson et al. 2001, Addis et al. 2013). Despite this ultimate shift toward open sediments, *L. campechanus* maintain at least periodic relation-

*Corresponding author: theodore.switzer@myfwc.com

Publisher: Inter-Research · www.int-res.com

ships with hardbottom habitat (Topping & Szedlmayer 2011). Because of this, there is uncertainty as to whether artificial reefs can aid in stock recovery and long-term fisheries sustainability.

Artificial reef programs in the GOM primarily seek to enhance reef habitat to provide ecological benefits and fishing opportunities. Thousands of artificial reefs have been deployed by governments and anglers across the Florida Panhandle to the Mississippi River (Addis et al. 2013, Keenan et al. 2018). Here, most current artificial reef deployments use fabricated concrete reef modules or construction materials to provide habitat enhancements intended to persist for decades. However, the Florida Panhandle has a 5–8 m thick layer of sandy sediment (Hine & Locker 2011), which is prone to reef subsidence following environmental disturbances (Keenan et al. 2018).

Localized, small-scale depressions or 'pockmarks' are common seafloor features (Hovland & Judd 1988) and can be geologic (e.g. gas seeps) or biogenic (including formation by fishes) in origin (Scanlon et al. 2005). A diverse suite of fishes is known to excavate or burrow using a variety of mechanisms that are often accompanied by unique physical adaptations (Herrel & Adriaens 2022). Tilefish *Lopholatilus chamaeleonticeps* were the first fish described to excavate (Twitchell et al. 1985); this behavior has since been confirmed for *Hyporthodus flavolimbatus* (Jones et al. 1989) and *Epinephelus morio* (Coleman & Williams 2002, Scanlon et al. 2005, Grasty et al. 2019). *E. morio* is considered the primary excavator of pockmarks on the West Florida Shelf (WFS) (Scanlon et al. 2005). Pockmarks identified in waters off the Florida Panhandle (Keenan et al. 2018) have been difficult to attribute to *E. morio* because they are less common in this region. By contrast, *L. campechanus* are abundant (Addis et al. 2013, Keenan et al. 2018). The purpose of this note is to describe 2 documented occurrences of *L. campechanus* excavation around artificial reefs in Florida Panhandle waters.

2. MATERIALS AND METHODS

Sampling was part of an annual reef fish survey conducted in the eastern GOM by the Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute's Fisheries-Independent Monitoring program (FWRI-FIM). Natural and anthropogenic habitats were identified using randomly distributed, standardized side-scan sonar surveys (approximately 4 km N–S by 0.5 km E–W). Following sonar mapping, reef habitats, including pockmarks, were surveyed with stereo-baited remote underwater video arrays (S-BRUVs) to evaluate fish habitat associations and to ground-truth sonar habitat classifications; 20 min of each 30 min video was annotated. Fishes were identified to the lowest possible taxonomic level, enumerated by the maximum number of fish within a single video frame, and measured. Unusual behaviors were also recorded. Landing of the S-BRUV did not disturb the excavation activity of *Lutjanus campechanus* and so the entire videos were reviewed to characterize excavation. Physical characteristics of excavations were estimated from sonar imagery using the methods of Flemming (1976). For additional methods details, see Keenan et al. (2018) and Switzer et al. (2020).

3. RESULTS

From 2014–2019, a total of 1203 pockmarks were identified by side-scan sonar in waters of the Florida Panhandle at depths between 10 and 180 m (Fig. 1) and S-BRUVs were deployed at 239 pockmarks classified as unidentified depressions. Unidentified depressions were distinguished from grouper excavations (Switzer et al. 2020) by elevated and concentric berms that cast acoustic shadows relative to the shallower grouper excavations (Keenan et al. 2018). Additionally, while grouper excavations often occur in clusters (Wall et al. 2011), these unidentified depressions were primarily isolated.

During a review of the S-BRUV footage, *Lutjanus campechanus* were observed excavating sediment from 2 unidentified depressions on 21 May 2015 and 27 July 2017. The excavation filmed in 2015 (depth: 42 m) was elliptical (see Fig. S1 — and all other supplemental tables and figures — in Supplement 1 at www.int-res.com/articles/suppl/b033p069_supp/) with major and minor axes of 10.0 and 7.5 m, and depth and berm heights of 0.8 m (Table S1). The excavation filmed in 2017 (depth: 30 m) was circular with a 10.0 m diameter, 1.3 m depth, and 0.6 m berm height. The excavations contained a pile of tires and a pyramid-shaped reef module, respectively.

A total of 29 excavation events were documented (Table S2): 24 events over 22 min 28 s occurred at the excavated tire pile in 2015, and 5 events over 25 min 2 s occurred at the pyramid-shaped reef module in 2017. At both sites, 2 *L. campechanus* were present and one was measurable (fork length [FL] = 593 and 744 mm, respectively). In both cases, one of the 2 *L. campechanus* engaged in excavation activity. The

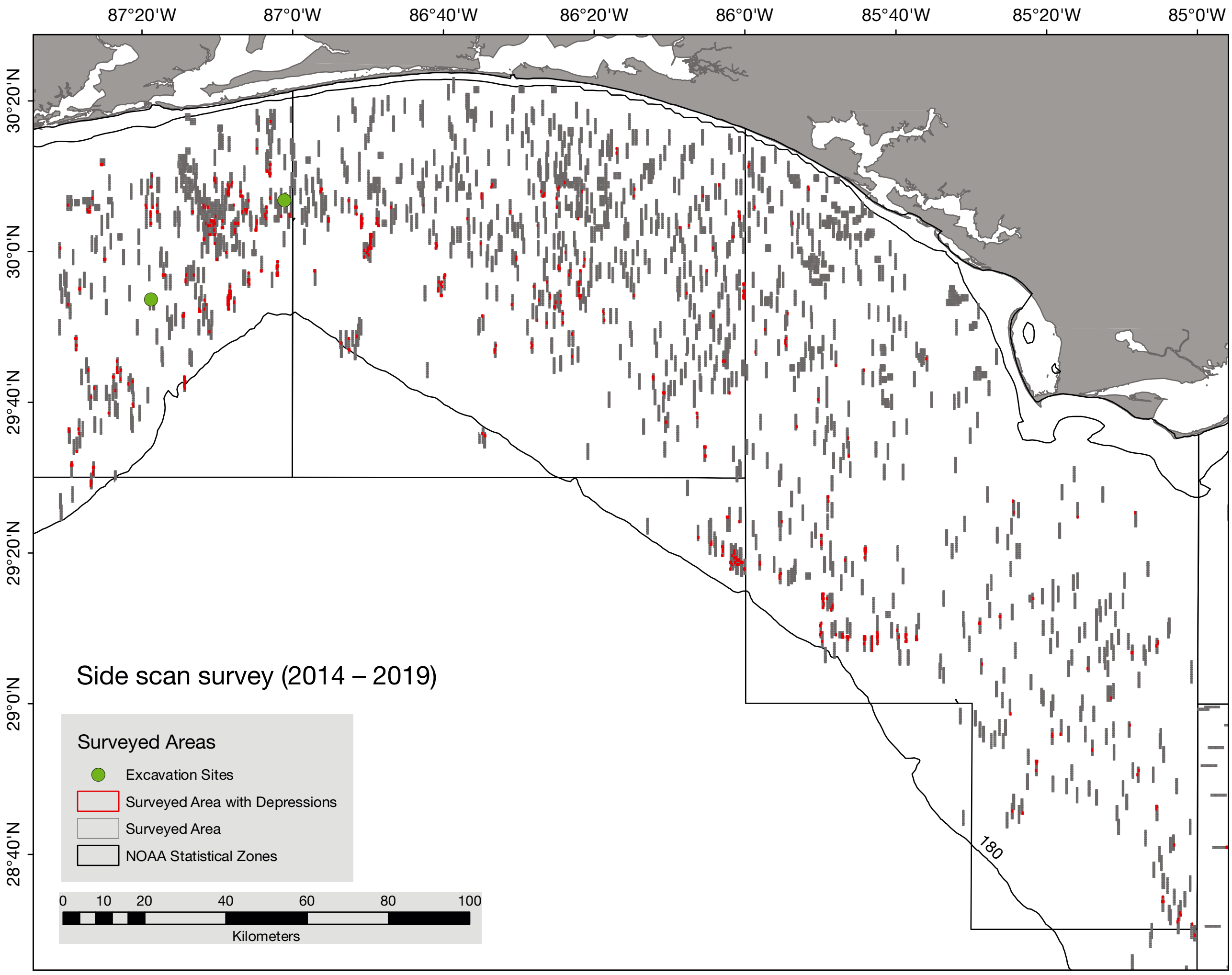

Fig. 1. Locations of the 2 sites where *Lutjanus campechanus* were observed excavating (green circles) and areas where the 1203 depressions were identified (red bars) within the areas surveyed with side-scan sonar (gray bars) from 2014 to 2019. The 180 m isobath is shown along with the boundaries of NOAA's National Marine Fisheries Service statistical zones 8–10 (from east to west)

time spent excavating during each event was determined as the time from *L. campechanus* entering the excavation (Fig. 2A) to the time the sediment was deposited from its gill arches and mouth at the edge of the excavation (Fig. 2E). Individual excavation events were 16–46 s in duration (mean ± SE: 30.4 ± 1.2 and 35.4 ± 4.2 s, respectively). A total of 9 min 44 s (39% of the video) and 2 min 57 s (10% of the video) were spent excavating, respectively (see Video S1 in Supplement 2).

In total, 13 genera of fishes were observed at the excavations: 4 genera in addition to *L. campechanus* were common to both sites, including tomtate *Haemulon aurolineatum*, unidentified wrasses (Labridae), lionfish *Pterois* spp., and vermilion snapper *Rhomboplites aurorubens* (Table S3).

4. DISCUSSION

Epinephelus morio commonly excavate sediments from rocky outcroppings and solution holes on the WFS (Coleman & Williams 2002). Documentation of excavation behavior by *Lutjanus campechanus* in association with artificial reefs suggests that *L. campechanus* might share this behavior for a part or all of their life history, although the current observations have been limited to 2 relatively large individuals (593 and 744 mm FL). Sediment excavation is energetically costly, particularly for *L. campechanus*, which occupy a large home range and spend a lot of time over open sediments (Addis et al. 2013, Powers et al. 2018). Like *E. morio*, excavating behavior may benefit *L. campechanus* by providing spawning habitat or

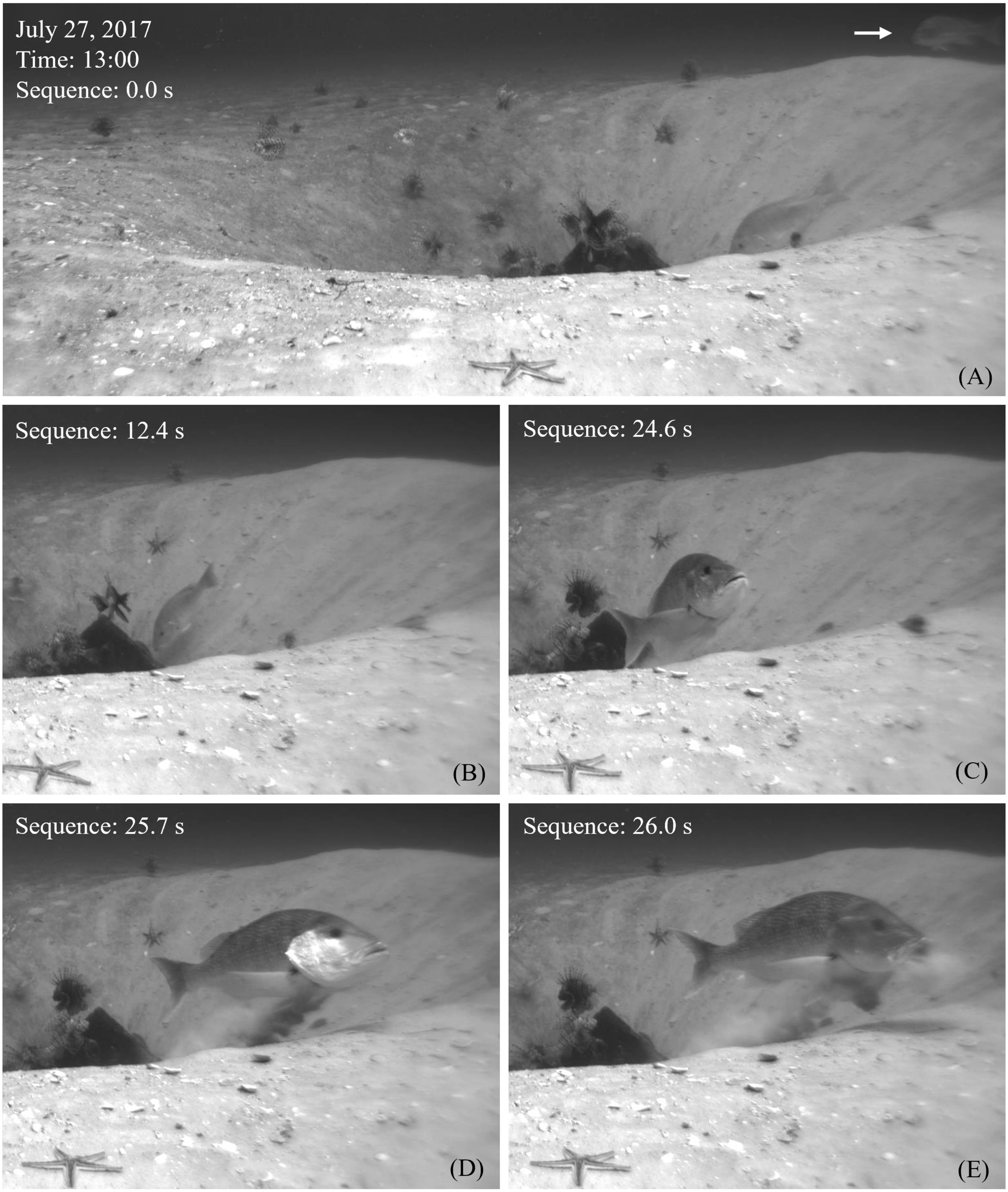

Fig. 2. One of the 29 *Lutjanus campechanus* excavation events at a subsided pyramid-shaped reef module. (A) *L. campechanus* approaches the excavation, (B) swims to the central artificial structure to uptake a mouthful of sediment, (C) swims to the edge of the excavation, (D) flares its gill arches to begin depositing sediment, and (E) finishes depositing the sediment by contracting its gill arches and spitting

increasing prey diversity (Coleman & Williams 2002). This behavior also increases the availability of hard substrate for subadult juveniles (age 1–3) and young adults, which has been described as a potential population bottleneck (Shipp & Bortone 2009).

Unlike excavation of natural habitats, which may expose rock, excavation around artificial reefs can contribute to subsidence. Unidentified depressions were observed throughout the Florida Panhandle (Fig. 1) with unknown relationships with artificial reef materials; however, at the sites where *L. campechanus* were observed excavating, the artificial material had subsided below the surrounding seafloor level where continued excavation was required to prevent burial. Ultimately, behaviors that have evolved to expose hard substrate may instead reduce habitat availability at artificial reefs.

The rate of excavation observed suggests that excavations could be formed over short temporal scales. Additionally, these features were first identified via side-scan sonar mapping surveys conducted 95 and 349 d prior to S-BRUV sampling, indicating a degree of temporal persistence. Grasty et al. (2019) showed that the temporal persistence of *E. morio* excavations can exceed a decade, and Coleman et al. (2010) and Ellis et al. (2017) have proposed that some *E. morio* excavations might be maintained over multiple generations.

The fish assemblages present at the 2 excavations were typical of the region. Keenan et al. (2018) compared the fish assemblage compositions at 92 unidentified depressions along the Florida Panhandle with those at other habitats and found similarities between unidentified depressions and artificial reefs. *L. campechanus* were among the species driving the similarities among the fish assemblages at these habitats, while *E. morio* were absent entirely.

Sediment excavation around artificial reefs has also been documented on the Northwest Australian Shelf, by Mueller (2015), who attributed pockmark formations associated with petroleum infrastructure to excavation by the goldspotted rockcod *Epinephelus coioides*, which was indicated as the likely excavator based on the known excavating behavior of *E. morio* and *Hyporthodus flavolimbatus* in the GOM, and because *E. coioides* was among the most common fish present. Mueller (2015), however, also noted that lutjanid snappers, including *Lutjanus erythropterus*, *L. malabaricus*, *L. argentimaculatus*, *L. russellii*, and *L. sebae* were common. Given our observations, lutjanids might contribute to excavation in Australian waters or elsewhere.

Some fishes are sensitive to disturbances from camera arrays, altering their natural behavior. *L. campechanus* frequently approach S-BRUVs, so it is unsurprising that excavation behavior has not been observed previously. Direct observation of excavation behavior by *E. morio*, a well-known excavator, has only been described by Coleman et al. (2010) and Ellis et al. (2017) and has not been observed during the FWRI-FIM survey. Interestingly, the S-BRUVs that recorded the 2 excavation occurrences landed just meters from the excavations but did not disrupt the excavating *L. campechanus*, providing some of the best direct evidence of the excavation behavior of any fish.

As a long-lived, aggressive, and abundant species, *L. campechanus* are already considered to be highly ecologically important. Excavation behavior adds to their importance. This further incentivizes current efforts to rebuild the *L. campechanus* stock in the GOM and suggests that recovery efforts beyond meeting sustainable fishery levels would benefit many associated species. Florida Panhandle pockmarks comprise a reef-fish monitoring strata that should continue to be studied. Examining the frequency of these features across the spatial distribution of *L. campechanus* may facilitate modeling abundance indices. Finally, artificial reef deployments would be well advised to monitor sites for potential subsidence due to excavation.

Acknowledgements. We gratefully acknowledge the staff of the Florida Fish and Wildlife Conservation Commission, who contributed countless hours collecting and processing side-scan sonar and underwater video data. We thank R. Ellis and D. Adams for thoughtful insights. This project was supported by funding from the US Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service, Southeast Monitoring and Assessment Program (grant numbers NA11NMF 4350047 and NA16NMF4350165), the US Department of the Interior, US Fish and Wildlife Service, Federal Aid for Sportfish Restoration (grant numbers F14AF00328, F15AF01222, F16AF00898, and F17AF00932), the National Fish and Wildlife Foundation (NFWF) Gulf Environmental Benefit Fund (grant numbers FL 40624, FL 45766, FL 50347, FL 54269, and FL 58101), and from the sale of State of Florida saltwater recreational fishing licenses. The statements, findings, views, conclusions, and recommendations contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US government or NFWF.

LITERATURE CITED

Addis DT, Patterson WF III, Dance MA, Ingram GW Jr (2013) Implications of reef fish movement from unreported artificial reef sites in the northern Gulf of Mexico. Fish Res 147:349–358

Coleman FC, Williams SL (2002) Overexploiting marine ecosystem engineers. Trends Ecol Evol 17:40–44

Coleman FC, Koenig CC, Scanlon KM, Heppell S, Heppell S, Miller M (2010) Benthic habitat modification through excavation by red grouper, *Epinephelus morio*, in the northeastern Gulf of Mexico. Open Fish Sci J 3:1–15

Ellis RD, Coleman FC, Koenig CC (2017) Effects of habitat manipulation by red grouper, *Epinephelus morio*, on faunal communities associated with excavations in Florida Bay. Bull Mar Sci 93:961–983

Flemming BW (1976) Side-scan sonar: a practical guide. Int Hydrogr Rev 53:65–82

Geary BW, Mikulas JJ, Rooker JR, Landry AM (2007) Patterns of habitat use by newly settled red snapper in the northwestern Gulf of Mexico. Am Fish Soc Symp 60: 25–38

Grasty SE, Wall CC, Gray JW, Brizzolara J, Murawski S (2019) Temporal persistence of red grouper holes and analysis of associated fish assemblages from towed camera data in the Steamboat Lumps Marine Protected Area. Trans Am Fish Soc 148:652–660

Herrel A, Adriaens D (2022) Burrowing in fishes: anatomy, physiology, function and ecology. In: Alderman SL, Gillis TE (eds) Encyclopedia of fish physiology, 2nd edn. Academic Press, New York, NY, p 649–653

Hine AC, Locker SD (2011) Florida continental shelf: great contrasts and significant transitions. In: Buster NA, Holmes CW (eds) Gulf of Mexico: origin, waters and biota, Vol 3: geology. Texas A&M University Press, College Station, TX, p 101–127

Hovland M, Judd AG (1988) Seabed pockmarks and seepages: impact on geology, biology and the marine environment. Graham and Trotman, London

Jones RS, Gutherz EJ, Nelson WR, Matlock GC (1989) Burrow utilization by yellowedge grouper, *Epinephelus flavolimbatus*, in the northwestern Gulf of Mexico. Environ Biol Fishes 26:277–284

Keenan SF, Switzer TS, Thompson KA, Tyler-Jedlund AJ, Knapp AR (2018) Comparison of reef-fish assemblages between artificial and geologic habitats in the Northeastern Gulf of Mexico: implications for fishery-independent surveys. Am Fish Soc Symp 86:141–163

Mueller RJ (2015) Evidence for the biotic origin of seabed pockmarks on the Australian continental shelf. Mar Pet Geol 64:276–293

Patterson WF III, Watterson JC, Shipp RL, Cowan JH Jr (2001) Movement of tagged red snapper in the northern Gulf of Mexico. Trans Am Fish Soc 130:533–545

Powers SP, Drymon JM, Hightower CL, Spearman T, Bosarge GS, Jefferson A (2018) Distribution and age composition of red snapper across the inner continental shelf of the north-central Gulf of Mexico. Trans Am Fish Soc 147:791–805

Scanlon KM, Coleman FC, Koenig CC (2005) Pockmarks on the outer shelf in the Northern Gulf of Mexico: Gas-release features or habitat modifications by fish? Am Fish Soc Symp 41:301–312

Shipp RL, Bortone SA (2009) A perspective of the importance of artificial habitat on the management of red snapper in the Gulf of Mexico. Rev Fish Sci 17:41–47

Stunz GW, Patterson WF III, Powers SP, Cowan JH Jr and others (2021) Estimating the absolute abundance of age-2+ red snapper (*Lutjanus campechanus*) in the US Gulf of Mexico. Mississippi–Alabama Sea Grant Consortium. https://repository.library.noaa.gov/view/noaa/48520

Switzer TS, Tyler-Jedlund TJ, Keenan SF, Weather EJ (2020) Benthic habitats, as derived from classification of side-scan-sonar mapping data, are important determinants of reef-fish assemblage structure in the Eastern Gulf of Mexico. Mar Coast Fish 12:21–32

Topping DT, Szedlmayer ST (2011) Home range and movement patterns of red snapper (*Lutjanus campechanus*) on artificial reefs. Fish Res 112:77–84

Twitchell DC, Grimes CB, Jones RS, Able KW (1985) The role of erosion by fish in shaping topography around Hudson Submarine Canyon. J Sediment Petrol 55: 712–719

Wall CC, Donahue BT, Naar DF, Mann DA (2011) Spatial and temporal variability of red grouper holes within Steamboat Lumps Marine Reserve, Gulf of Mexico. Mar Ecol Prog Ser 431:243–254

Workman I, Shah A, Foster D, Hataway B (2002) Habitat preferences and site fidelity of juvenile red snapper (*Lutjanus campechanus*). ICES J Mar Sci 59(Suppl):S43–S50

Editorial responsibility: Vladimir Laptikhovsky, Lowestoft, UK
Reviewed by: A. Herrel and 1 anonymous referee

Submitted: December 8, 2023
Accepted: March 19, 2024
Proofs received from author(s): May 2, 2024