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SEDAR41-RD52

7 August 2014

Fisheries Research 147 (2013) 349–358

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Implications of reef fish movement from unreported artificial reef sites in the northern Gulf of Mexico

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ARTICLE INFO

Article history:
Received 8 October 2012
Received in revised form 8 July 2013
Accepted 21 July 2013

Keywords:
Tagging
Artificial reefs
Gulf of Mexico
Reef fishes

ABSTRACT

Artificial reefs were deployed in the northeastern Gulf of Mexico (GOM) by the state of Florida's marine fisheries agency but not reported to the public in an attempt to create no-harvest refuges for exploited fishes. As part of a broader examination of the efficacy of this approach, a tagging study was conducted at a subset ($n = 9$) of these unreported artificial reefs to examine the likelihood that reef fishes would remain associated with them and to test factors affecting species-specific movement. Quarterly tagging trips ($n = 12$) were made between March 2005 and December 2007 during which 3109 fish among 12 species were tagged with internal anchor tags. Red snapper (*Lutjanus campechanus*, $n = 2114$), gray triggerfish (*Balistes capriscus*, $n = 267$), and groupers (Family: Serranidae, $n = 148$), were among the most frequently tagged fishes. Eighty-six fish were recaptured on subsequent tagging trips and fishermen reported 249 recaptures caught away from study sites. Mean (SD) distance moved among recaptures with reported recapture location was 37.1 (6.6) km for red snapper ($n = 173$), 8.8 (3.1) km for gray triggerfish ($n = 47$), and 25.2 (14.9) km for groupers ($n = 26$). During the study, a hurricane passed over the study area, thus adding an unplanned factor to movement analyses. Fish size, reef depth, time free, and hurricane exposure significantly affected the likelihood of red snapper movement ($p < 0.020$), but only fish size significantly affected distance moved ($p = 0.036$). No factors significantly affected gray triggerfish movement, and low sample size precluded statistical tests of grouper movement. Overall, results indicate that large scale (>100 km) red snapper movement was not dependent on hurricane occurrence, while gray triggerfish displayed mostly limited (<10 km) movement irrespective of factors tested. The scale of movement observed suggests the efficacy of unreported artificial reefs to serve as no-harvest refuges is doubtful, especially when regional fishing mortality is high. Marine protected areas may be an effective alternative approach to facilitate the recovery of overfished stocks, but would need to be expansive to account for reef fish movement.

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1. Introduction

Reef fishes are highly susceptible to fishing given their strong association with structured habitat makes them easy to target in the coastal zone (Polunin and Roberts, 1996). Their affinity for structured habitat, the ability of fishers to predict their spatial distribution, and a generally high market demand for reef fish meat have resulted in reef fishes being among the more imperiled groups of marine fishes (Dulvy et al., 2003; Hawkins et al., 2000; Paddack et al., 2009; Sadovy and Domeier, 2005). Reef fishes are highly targeted in waters off the southeastern United States and several species of lutjanids, serranids, carangids, and balistids are estimated to be overfished in the region (Coleman et al., 2004b; NMFS, 2012).

The overfished status of reef fishes is an important fisheries management issue in the eastern Gulf of Mexico (GOM) where numerous species are targeted at artificial reefs (Dance et al., 2011; Patterson and Cowan, 2003). Artificial reefs have been widely deployed as fishing tools in the region and their usage also has become increasingly incorporated into management plans (Lindberg and Seaman, 2011; Seaman, 2007). In the state of Florida, fisheries management strategies have been directed to limit fishing pressure by deploying artificial reefs in areas of little or no fishing activity, creating unpublished artificial reefs, and incorporating reef designs aimed at increasing juvenile survivorship (FWC, 2003; Lindberg and Loftin, 1998; Lindberg and Seaman, 2011). Alternatively, deploying artificial reefs within marine protected areas

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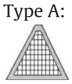
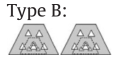
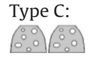
http://dx.doi.org/10.1016/j.fishres.2013.07.011

Table 1
Dimensions of study artificial reef types deployed in the Escambia East Large Area Artificial Reef Site. Reef dimensions are for single modules of all types. Reef volumes are total volumes for solitary type A modules, and for type B and type C paired modules.

Reef parameter	Type A: 	Type B: 	Type C: 
Construction material	Concrete/rebar	Concrete	Concrete
Modules per site	1	2	2
Module height (m)	3.05	1.83	1.45
Module base (m)	3.05	3.05	1.83
Reef volume (m^3)	4.09	4.90	2.84

(MPAs) is a management strategy with the potential to protect reef fish populations via gear restrictions or no fishing effort allowed inside MPA boundaries (Albouy et al., 2011; Claudet et al., 2006; McClanahan et al., 2006).

An important ecological component to consider when proposing artificial reefs as a management tool is the site fidelity and movement of reef fish associated with artificial reefs (Patterson and Cowan, 2003; Shipp, 2003). Bohnsack (1989) hypothesized that production of fishes that exhibit low site fidelity and partial reef dependence would be less likely to be enhanced through artificial reef creation. Furthermore, in the context of management strategies, fishes that display greater movement may have increased exposure to fishing mortality when moving between areas of lower and higher fishing effort (Crowder et al., 2000; Hampton and Fournier, 2001; Kaunda-Arara and Rose, 2004).

In 2003, the state of Florida took a new management approach in deploying unpublished artificial reefs (i.e., reef creation and coordinates not reported to the public) in an effort to establish no-harvest refuges for reef fishes in the eastern GOM. The Florida marine resource agency, the Florida Fish and Wildlife Conservation Commission (FWC), constructed 525 of these unreported artificial reefs off northwest Florida which were distributed equally among four Large (~225 km^2) Area Artificial Reef Sites (LAARS). The objective of the program was to create no-harvest refuges to mitigate high regional fishing mortality for overfished reef fishes such as red snapper (*Lutjanus campechanus*), gray triggerfish (*Balistes capriscus*), and gag (*Mycteroperca microlepis*). As part of a broader examination of the efficacy of this approach (Dance et al., 2011), a tagging study was conducted to estimate movement and dispersion of tagged reef fishes. The objective of this study was to determine the likelihood that species of interest would remain associated with unreported reef sites versus displaying movement to other, known reefs targeted by fishers. Factors affecting reef movement also were tested.

2. Materials and methods

2.1. Study area

Study reefs were located in the Escambia East-LAARS (EE-LAARS) approximately 24–32 km south of Pensacola, Florida in the northeastern GOM (Fig. 1). Reefs consisted of three different prefabricated designs (Table 1) and were deployed in spring 2003 at depths between 28 and 38 m. The first, or A-type reefs consisted of a single pyramid module with a concrete frame, open base, and steel rebar in a lattice configuration along their sides. B-type reefs were a pair of concrete modules that shared the same base dimensions as A-type modules but were shorter and had flattened tops. They also had several triangular openings and secondary smaller modules inserted inside the larger modules. C-type reefs consisted of a pair of Reef Ball® modules which were constructed of concrete with several wall openings and an open top.

2.2. Fish tagging

Quarterly tagging trips were made between winter 2005 and fall 2007. Tagging effort was standardized among reefs. Over a given site, five anglers targeted fish to be tagged for 30 min. Four anglers used bottom rigs that consisted of two 3/0 Mustad 34007 J hooks each tied to a 0.5-m leader and baited with squid (*Loligo* sp.) or cut mackerel scad (*Decapterus macarellus*). A fifth angler fished in the water column above the reef using a rig that consisted of two 5/0 Mustad 34007 J hooks snelled 10 cm apart to the end of a 1.5-m leader and baited with a whole mackerel scad. Fish were brought to the surface at a rate of approximately 1 $m s^{-1}$. Fish were immediately removed from hooks and placed into a 475-L holding tank filled with flowing seawater. Fish were removed from the tank and measured to the nearest mm fork length (FL) or total length (TL). Fish >250 mm TL were tagged with an internal anchor tag inserted into a small (<5 mm) incision in the abdominal cavity and then released. Anchor tags were marked with the word "REWARD," an identifying tag number, and a toll free number to report tag recoveries. The tagging study was advertised to recreational and commercial fishers via several media outlets to encourage fisherman to report tag recoveries. Posters advertising the tagging study also were placed in marinas and tackle shops between Bay St. Louis, Mississippi and Panama City Beach, Florida. Those who reported a tag recovery received a $10 reward per tag and were entered into a $500 annual lottery of all tag returnees. Tag recovery information obtained from those who called the toll-free number included the tag number, location of recapture (GPS coordinates if available), date of capture, and fish length.

Recapture location was plotted in a geographic information system (GIS) for tag recoveries for which sufficient information on recapture location was reported by fishermen (ArcView 9.3.1). Fish movement was estimated as the straight-line distance between tagging reef and recapture location, and dispersion rate was estimated as this distance divided by time free. Movement could not be estimated for recaptures for which location was not reported. Tag recoveries for which recapture location was reported imprecisely but in the general direction and area of the EE-LAARS (e.g., 30 km southeast of Pensacola Beach), were conservatively assumed to be caught within the EE-LAARS. For these recoveries and others reported as being caught within the EE-LAARS but without specific GPS coordinates, movement was estimated based on the distributions of taxa-specific movement of fish recaptured within the EE-LAARS for which exact location of recapture was reported. This was performed by generating a random probability and calculating the inverse of the normal cumulative distribution for the mean and variance of taxa-specific movement estimated from fish with exact EE-LAARS recapture locations reported. This was done because omitting samples caught near (<10 km) study reefs but without precise recapture location would bias movement estimates high. Movement analyses described below were computed both with and without these additional samples.

2.3. Movement analysis

Analysis of the effect of fish size, time free, reef depth, and reef type on taxa-specific reef fish movement was planned a priori. During the study, the center of Hurricane Dennis (maximum winds 235 km/h) passed within 10 km of tagging sites and made landfall in northwest Florida on July 10, 2005, thus adding an unplanned factor to movement analyses. Therefore, statistical models of reef fish movement included exposure to hurricane as an independent

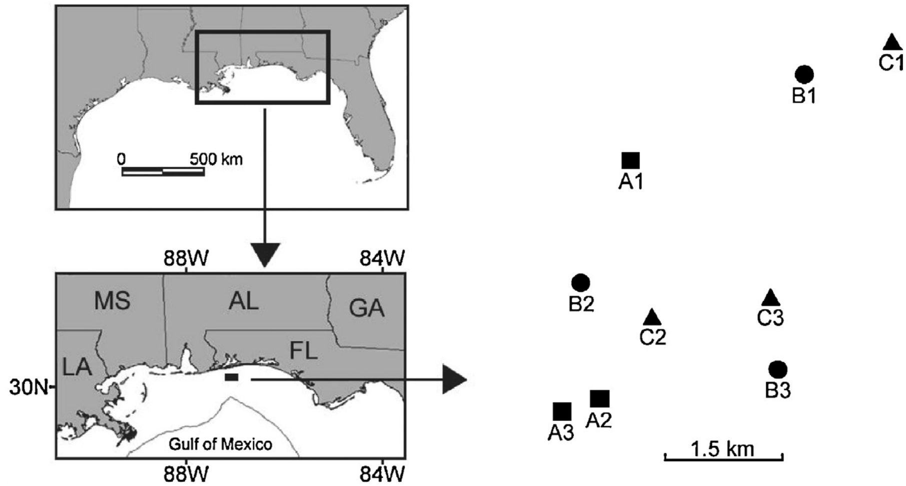


Fig. 1. Map of the northern Gulf of Mexico indicating the location of the Escambia East-Large Area Artificial Reef Site (black rectangle) and artificial reef study sites (n = 9). The letters A, B, and C correspond to artificial reef types listed in Table 1.

variable, and taxa-specific estimates of mean movement and dispersion rates were made separately for tagged fish exposed and not exposed to Hurricane Dennis. To maintain independence, only data from terminal recaptures of fish recaptured more than once were used to compute mean distance moved, mean dispersion rate, or statistical models of movement.

The delta method was employed to estimate unbiased taxa-specific estimates of mean distance moved and mean dispersion rate, as well as their standard deviation (SD) (Aitchison, 1955; Patterson and Cowan, 2003). Delta lognormal models were computed to test whether factors significantly affected the probability and magnitude of distance moved by tagged fish away from release sites (Lo et al., 1992). Models were only run for red snapper and gray triggerfish due to the low sample size for groupers and other species. The tested main effects included fish size, reef type, depth, time free, and hurricane exposure on distance moved. Movement data with zero inflation from true zeros were modeled with a combination of two distinct generalized linear submodels computed within the delta lognormal model. A binomial submodel (Proc GLIMMIX, SAS Inc., 2008) was computed to test factors affecting the proportion of positive movement values (i.e., movement versus non-movement), and a lognormal submodel (Proc MIXED, SAS Inc., 2008) was computed to test the effect of the same factors on the magnitude of movement among fish recaptured away from tagging sites (Lo et al., 1992). Significance was evaluated at α = 0.05 based on results of type 3 tests.

3. Results

3.1. Fish tagging

Twelve tagging trips were conducted quarterly from March 2005 to December 2007. A total of 3109 fish among 12 species were tagged with internal anchor tags (Table 2). An additional 345 fish were caught but not tagged due to small size or being non-target species. The most frequently tagged species was red snapper (n = 2114), followed by red porgy (*Pagrus pagrus*, n = 422), gray triggerfish (n = 267), and gag (n = 96), respectively (Table 2). A total of 620 fish were tagged during the first two tagging events before Hurricane Dennis passed through the study area.

3.2. Tag recaptures, movement, and dispersion

Eighty-six tagged fish were recaptured at study reefs during subsequent tagging trips, and fisherman reported 249 fish recaptured away from study reefs through September 2009 (fisher return rate = 8.0%). The most commonly recaptured species was red snapper (n = 44 at study sites, n = 188 reported by fishermen), followed by gray triggerfish (n = 30 at study sites, n = 25 reported by fishermen) and gag (n = 5 at study sites, n = 14 reported by fishermen). Movement was generated for imprecisely reported EE-LAARS recapture locations for 38 red snapper (18% of recaptures), 6 gray triggerfish (11% of recaptures), and 3 grouper (10% of recaptures). The inclusion of movement estimates for these fish resulted in lower estimates of mean distance moved and dispersion rate (Table 3). Red snapper displayed the highest movement among all species (Table 3; Fig. 2A and B). Mean distance moved by individuals not exposed to Hurricane Dennis (n = 157) was 25.2 (4.7) km (Fig. 5A), while mean movement of individuals exposed to the hurricane (n = 53) was 44.0 (12.5) km (Fig. 5B). The estimated mean dispersion rate (SD) for red snapper was the highest among all species (Table 3), with a rate of 119.9 (27.1) m d^{-1} for individuals not exposed to the hurricane (Fig. 6A) and 132.8 (39.6) m d^{-1} for individuals exposed to the hurricane (Fig. 6B). One red snapper was recaptured during two separate tagging events, and 16 red snapper moved farther than 100 km away from release sites. The farthest movement observed among all tagged fish was 320 km for a red snapper free for 395 d, which was one of 7 red snapper recaptured south or east of Cape San Blas, Florida. The longest time free among all tagged fish was displayed by a red snapper exposed to the hurricane and recaptured 1566 days post tagging and 238 km away from its release site.

Gray triggerfish had the highest percentage of recaptures made at tagging reefs (54.5%) and showed the least movement among tagged species (Table 3; Fig. 3A and B). Individuals not exposed to Hurricane Dennis (n = 34) moved a mean distance of 5.9 (2.7) km (Fig. 5C) and individuals exposed to the hurricane (n = 11) moved 18.4 (6.8) km (Fig. 5D). Gray triggerfish displayed the lowest movement overall, with a mean dispersion rate of 55.9 (30.5) m d^{-1} for individuals not exposed to the hurricane (Fig. 6C) and 69.6 (17.8) m d^{-1} for individuals exposed to the hurricane (Fig. 6D). Five recaptured gray triggerfish were free for longer than a year, all of which were recaptured at tagging sites. The longest time free (616 d) was for a fish exposed to the hurricane and recaptured 61 km to the east southeast of its initial tagging site. Four gray triggerfish were recaptured multiple times during tagging events.

Collectively, grouper movement was intermediate to that of red snapper and gray triggerfish (Table 3; Fig. 4A and B). However, grouper movement was highly variable, especially among individuals exposed to the hurricane. Individuals not exposed to Hurricane

Table 2
List of reef fish species tagged at artificial reef study sites in the northeastern Gulf of Mexico. Lengths (mm) are total length for all species except gray triggerfish, for which fork length is reported.

Species	Number tagged	Mean length at tagging (SD)	Reported by fishermen (% total tagged)	Recaptures at study sites (% total recaptures)	Mean days free among all recaptures (SD)
Red snapper	2114	358 (55.8)	188 (8.9%)	44 (19.0%)	313 (278.6)
Red porgy	422	300 (26.3)	12 (2.8%)	2 (14.3%)	81 (135.5)
Gray triggerfish	267	344 (50.6)	25 (9.4%)	30 (54.5%)	195 (137.9)
Gag	96	518 (83.2)	14 (14.6%)	5 (26.3%)	257 (348.7)
Vermilion snapper	84	327 (34.4)	2 (2.4%)	1 (33.3%)	310 (233.0)
Almaco jack	32	357 (41.6)	0 (0%)	0 (0%)	–
Red grouper	31	521 (90.4)	2 (6.5%)	4 (66.7%)	93 (66.0)
Scamp	21	409 (58.5)	5 (23.8%)	0 (0%)	273 (251.0)
Greater amberjack	21	414 (65.9)	0 (0%)	0 (0%)	–
Lane snapper	10	327 (67.2)	1 (10%)	0 (0%)	–
Other species	11	426 (141.0)	0 (0%)	0 (0%)	–
Total	3109		249	86	

Table 3
Delta mean taxa-specific estimates of mean (SD) distance moved and mean (SD) dispersion rate of recaptured tagged fish. Additional movement estimates were generated for red snapper ($n = 38$), gray triggerfish ($n = 6$), and groupers ($n = 3$) recaptured within the Escambia East Large Area Artificial Reef Site (EE-LAARS) for which imprecise recapture location was reported based on taxa-specific movement distribution of recaptures made within the EE-LAARS for which latitude and longitude of recapture location were reported.

Taxon	No additional EE-LAARS estimates included			Additional EE-LAARS estimates included		
	n	Distance (km) (SD)	Dispersion (m d^{-1}) (SD)	n	Distance (km) (SD)	Dispersion (m d^{-1}) (SD)
Red snapper	173	37.1 (6.6)	140.2 (27.7)	211	29.5 (4.6)	123.1 (23.3)
Gray triggerfish	47	8.8 (3.1)	51.7 (20.3)	53	7.9 (2.6)	47.8 (16.5)
Groupers	26	25.2 (14.9)	98.3 (39.9)	29	19.5 (10.3)	93.1 (37.5)

Dennis ($n = 19$) moved 2.2 (1.0) km (Fig. 5E) and individuals exposed to the hurricane ($n = 10$) moved 63.8 (37.3) km (Fig. 5F). Dispersion rates for groupers were also variable, with a rate of 58.3 (29.3) m d^{-1} for individuals not exposed to the hurricane (Fig. 6E) and 130.0 (64.9) m d^{-1} for individuals exposed to the hurricane (Fig. 6F). The farthest movement observed among groupers was for a gag that moved 259 km and was recaptured just west of the mouth of the Mississippi River after being free for 806 d. Of the nine groupers recaptured at release sites, the longest residency observed was for a gag free for 353 d.

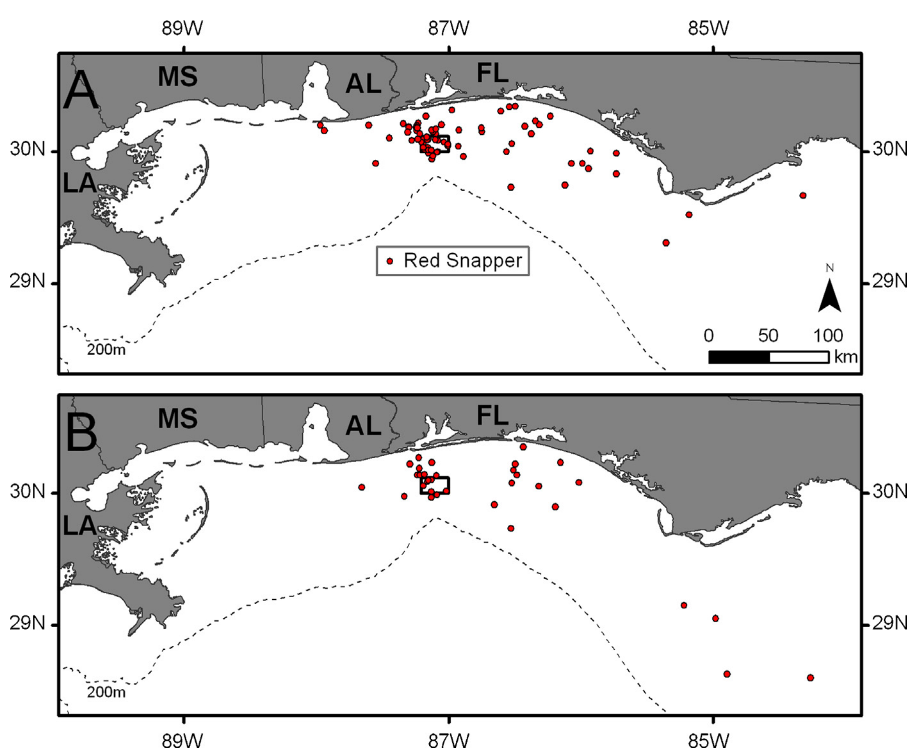


Fig. 2. Maps of northern Gulf of Mexico recapture locations reported by fishermen for red snapper (A) exposed and (B) not exposed to Hurricane Dennis. The black rectangle indicates the perimeter of the Escambia East-Large Area Artificial Reef Site where tagging reefs were located. The dashed line indicates the 200 m isobath.

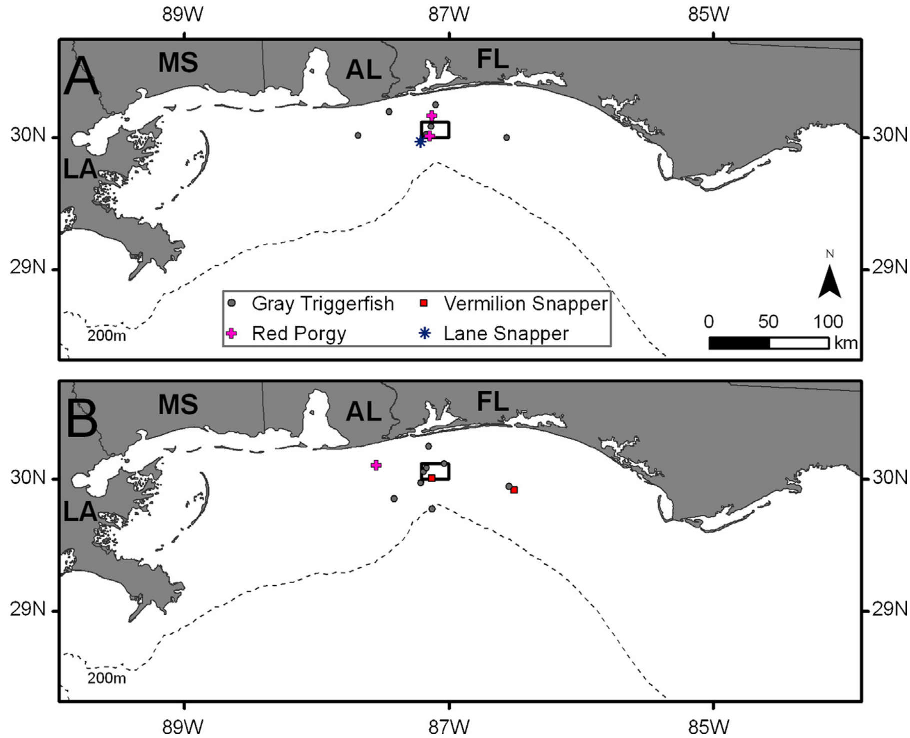


Fig. 3. Maps of northern Gulf of Mexico recapture locations reported by fishermen for reef fishes (A) exposed and (B) not exposed to Hurricane Dennis. The black rectangle indicates the perimeter of the Escambia East-Large Area Artificial Reef Site where tagging reefs were located. Legend on panel A indicates species-specific symbols. The dashed line indicates the 200 m isobath.

3.3. Movement analysis

Results from the GLIMMIX procedure indicate the probability of red snapper movement away from tagging sites was significantly affected by fish size, depth of tagging sites, time free, and hurricane exposure ($p < 0.02$; Table 4). However, only fish size significantly affected distance moved ($p = 0.036$). The same factors were significant for both the probability and distance of red snapper movement

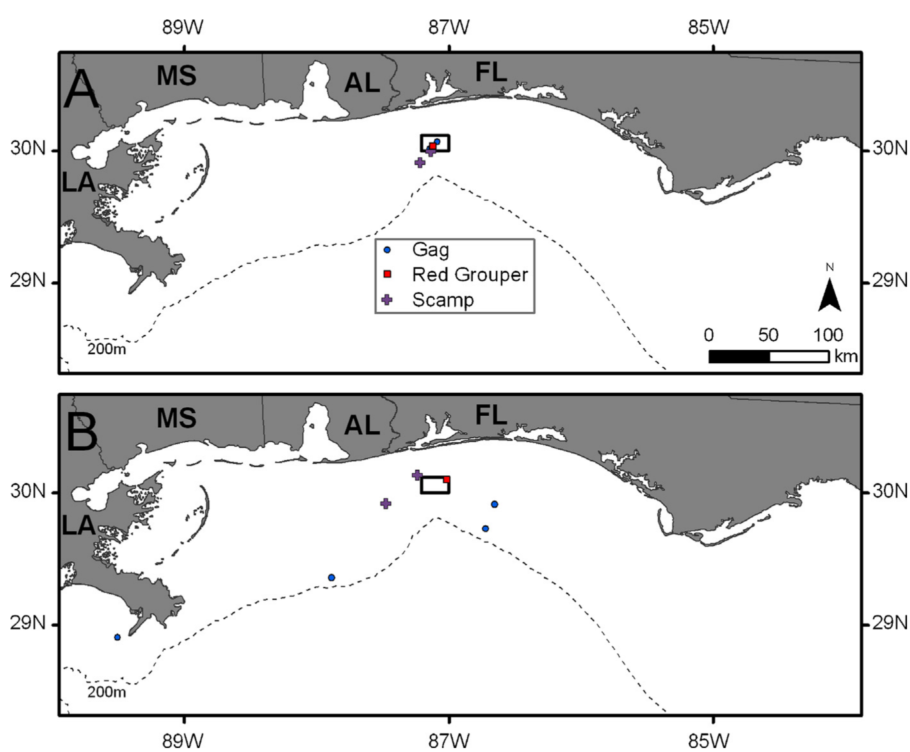


Fig. 4. Maps of northern Gulf of Mexico recapture locations reported by fishermen for groupers (A) exposed and (B) not exposed to Hurricane Dennis. The black rectangle indicates the perimeter of the Escambia East-Large Area Artificial Reef Site where tagging reefs were located Legend on panel A indicates species-specific symbols. The dashed line indicates the 200 m isobath.

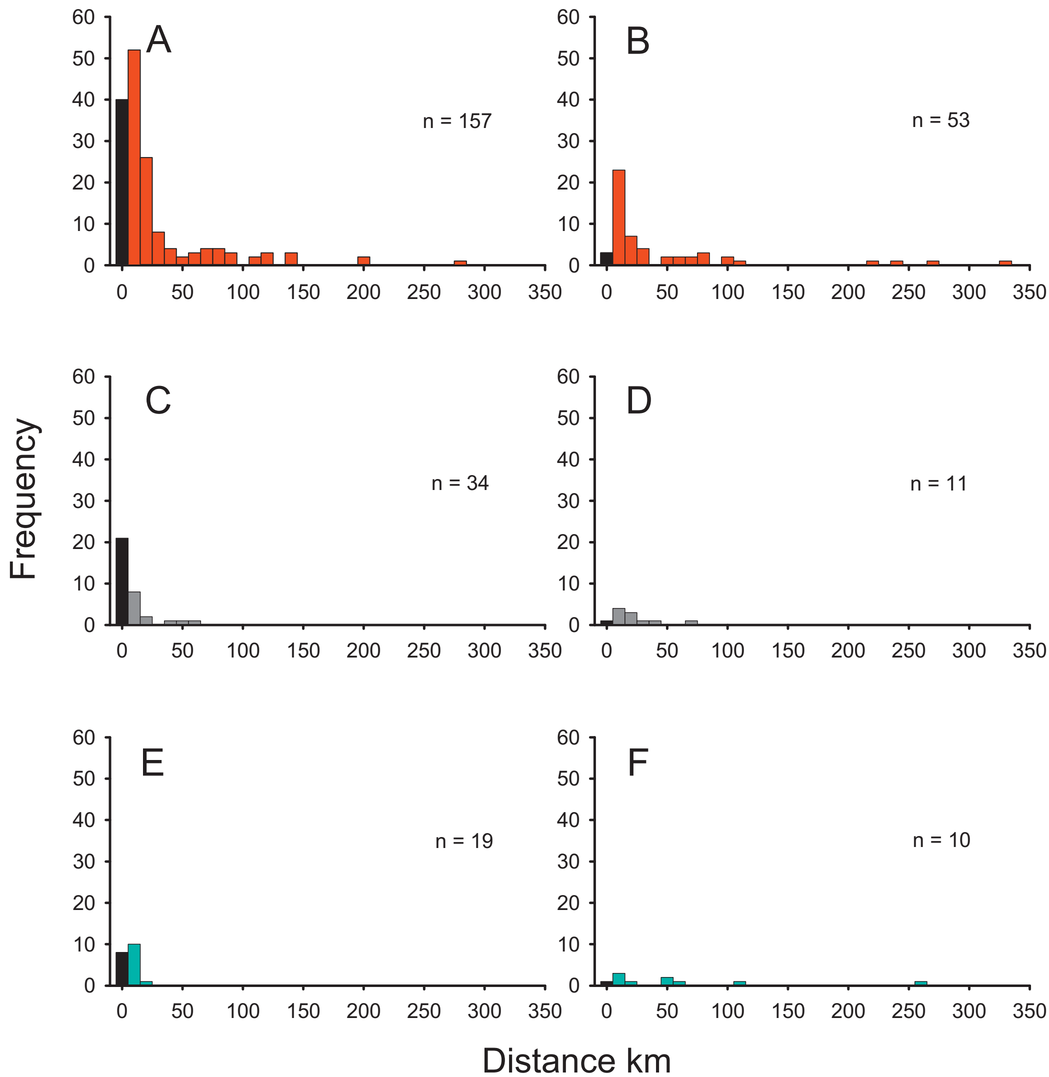


Fig. 5. Frequency distributions of estimated distance moved (km) observed for tagged fish exposed to a hurricane: (A) red snapper, (C) gray triggerfish, and (E) groupers; and frequency distributions of estimated distance moved (km) observed for tagged fish not exposed to a hurricane: (B) red snapper, (D) gray triggerfish, and (F) groupers. Recaptures made at study reefs on tagging trips are shown in black (zero movement).

when estimated movement was included for the 38 fish reported as being recaptured within the EE-LAARS but without precise recapture coordinates.

No factors significantly affected gray triggerfish movement in the base model run for that species (Table 4). However, a different result occurred when estimated movement was included for the 6 fish reported as being recaptured within the EE-LAARS but without precise recapture coordinates. In that model, hurricane exposure significantly affected the probability of movement away from tagging sites ($p = 0.035$), but no factors were significant for distance moved.

4. Discussion

4.1. Fish movement

Red snapper clearly displayed movement on the largest scale among reef fishes tagged in this study. Several individuals tagged in the EE-LAARS moved >100 km to the east and southeast along the west Florida shelf. That scale of movement has been reported previously for this species (reviewed in Patterson, 2007), and is indicative of connectivity between the north central and eastern GOM being facilitated by post-settlement movement of sub-adult and adult fish. Despite significant fishing pressure targeting reef fishes on artificial and natural reefs on the shelf off Alabama and Mississippi (Minton and Heath, 1998; Shipp and Bortone, 2009), relatively few red snapper recaptures were reported west of study reefs. Patterson et al. (2001) also reported movement of red snapper tagged on artificial reefs off Alabama was predominantly to the east, with many recaptures reported from waters off Florida. Therefore, post-settlement movement may provide a recruitment subsidy to the rebuilding red snapper population along the west Florida shelf which exhibited signs of severe depletion as early as the late 19th century (reviewed in Porch, 2007). Furthermore, the scale and predominant direction of movement is consistent with the current approach of assessing GOM red snapper as separate east and west subunits, with the dividing line being the terminus of the Mississippi River, given that no connectivity between the eastern and western GOM was observed despite otherwise significant movement of tagged fish.

Less than 20% of red snapper recaptures in the current study were made at tagging reefs on subsequent tagging trips, which is consistent with low (<50% y^{-1}) red snapper site fidelity estimates reported from analysis of conventional and acoustic tagging data

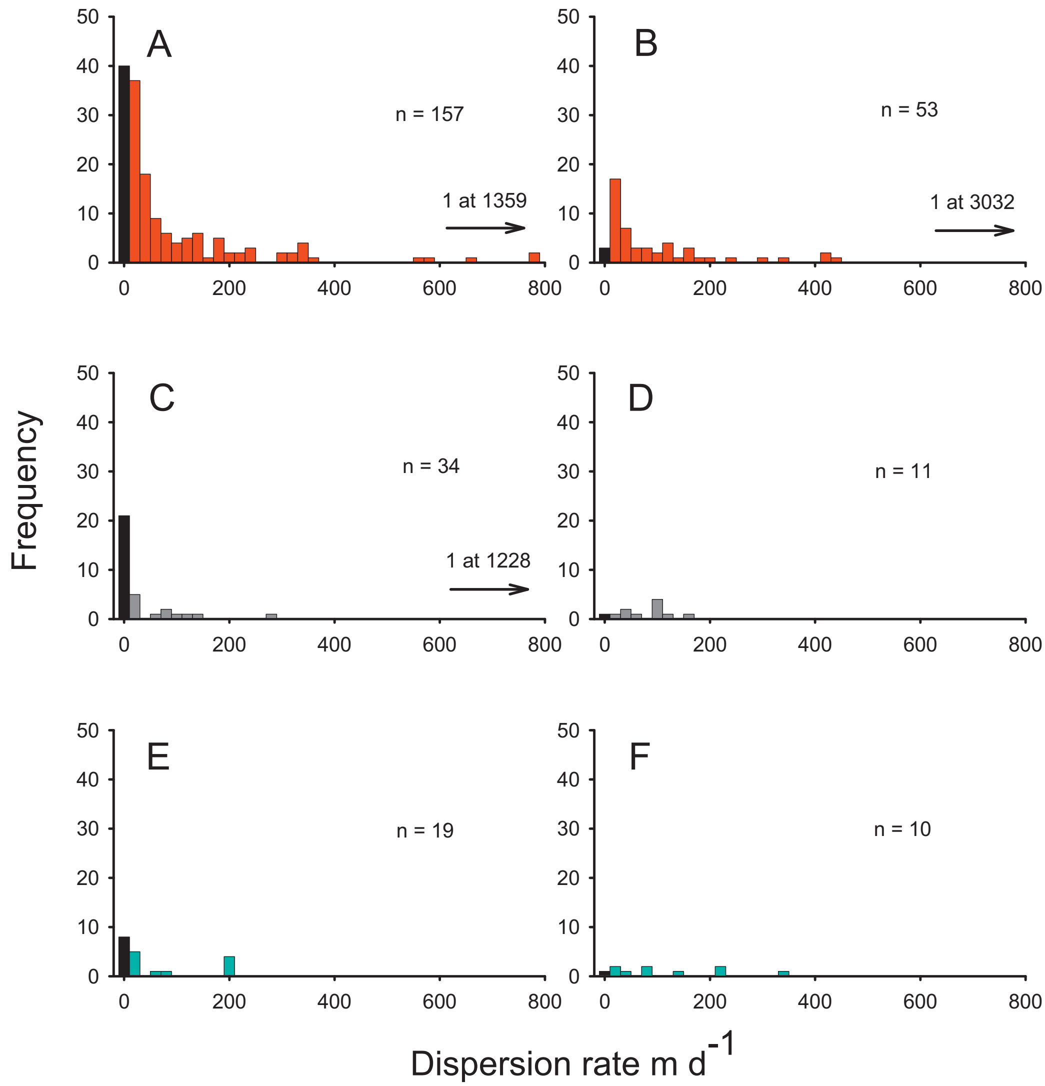


Fig. 6. Frequency distributions of estimated dispersion rates (m d^{-1}) observed for tagged fish exposed to a hurricane: (A) red snapper, (C) gray triggerfish, and (E) groupers; and frequency distributions of estimated dispersion rates (m d^{-1}) observed for tagged fish not exposed to a hurricane: (B) red snapper, (D) gray triggerfish, and (F) groupers. Recaptures made at study reefs on tagging trips are shown in black (zero movement).

(Patterson and Cowan, 2003; Strelcheck et al., 2007; Szedlmayer, 1997; Szedlmayer and Schroepfer, 2005). Topping and Szedlmayer (2011) acoustically tracked adult red snapper at a series of artificial reefs off Alabama in the north central GOM for up to 968 d and concluded that red snapper displayed high site fidelity to their study reefs. While their results may seem inconsistent with the large scale movement reported here and from several other conventional tagging studies (reviewed in Patterson, 2007), a sizeable (20–40%) percentage of red snapper recaptures among conventional tagging studies, including this one, have been what Diamond et al. (2007) referred to as "stayers" (versus "movers"). A key advantage of acoustic telemetry is the ability to estimate daily activity or foraging behavior in stayers, but we are aware of no acoustic arrays in the GOM capable of tracking fish movement over the area of red snapper movement (~40,000 km^2) observed in the current study. While the ability to track fish with acoustic tags is limited to the area of detection, conventional tagging enables estimation of larger scale movement, such as reported here for red snapper and other reef fishes (Patterson and Cowan, 2003; Patterson et al., 2001). Clearly, conventional tagging has its own set of limitations, such as tag loss, imprecise recapture location reporting, or low reporting rates, but those limitations tend to cause under – not over-estimation of movement.

Watterson et al. (1998) and Patterson et al. (2001) reported that Hurricane Opal, which made landfall just east of Pensacola, Florida on October 4, 1995, significantly affected movement of red snapper tagged at artificial reef sites in the northern GOM off Alabama. In fact, all the large scale (>100 km) movement of red snapper in their study was of fish at liberty during Hurricane Opal. In the current study, however, more tagged fish ($n = 10$) not potentially affected by Hurricane Dennis moved >100 km than fish ($n = 7$) at liberty during that storm, which is counter to the inference that large scale movement in red snapper only occurs due to hurricanes (Diamond et al., 2007; Gallaway et al., 2009; Gold and Salliant, 2007). It is unclear why the difference in non-storm movement exists between this study and earlier results. Drawing comparisons between tagging studies may also be limited by the many factors that could influence movement that were not tested, such as differences in study locations (e.g., AL versus western FL), habitat type (e.g., mud versus sand), prey availability, or hurricane factors (e.g., duration, direction, or intensity). However, it has been suggested that the expansive shell rubble habitat found 75–200 km to the west of our

Table 4
Results of delta-lognormal models (Type III) testing the effect of factors on red snapper ($n = 173$) and gray triggerfish ($n = 47$) movement in the northern Gulf of Mexico. Binomial submodels tested the effect of factors on the probability of movement, while lognormal submodels tested the effect of factors on distance moved for fish recaptured away from tagging sites.

Model	Effect	D.F.	χ^2	*F* value	Pr > *F*
Red snapper					
Binomial submodel	Fish size	1; 165	9.94	9.94	0.011*
	Reef type	2; 165	0.68	0.34	0.721
	Depth	1; 165	9.94	9.94	0.002*
	Time free	1; 165	45.32	45.32	<0.001*
	Hurricane	1; 165	42.46	42.46	<0.001*
Lognormal submodel	Fish size	1; 122	4.51	4.51	0.036*
	Reef type	2; 122	1.96	0.98	0.378
	Depth	1; 122	1.18	1.18	0.280
	Time free	1; 122	0.89	0.89	0.349
	Hurricane	1; 122	0.13	0.13	0.719
Gray triggerfish					
Binomial submodel	Fish size	1; 32	2.58	2.58	0.118
	Reef type	1; 32	0.17	0.17	0.680
	Depth	1; 32	2.27	2.27	0.142
	Time free	1; 32	3.34	3.34	0.077
	Hurricane	1; 32	1.93	1.93	0.174
Lognormal submodel	Fish size	1; 10	0.11	0.11	0.752
	Reef type	2; 10	1.38	0.69	0.525
	Depth	1; 10	0.44	0.44	0.521
	Time free	1; 10	0.21	0.21	0.655
	Hurricane	1; 10	0.03	0.03	0.861

* Significance at $\alpha = 0.05$.

study reefs is the most significant red snapper nursery habitat in the north central GOM (Patterson et al., 2005; Wells et al., 2008). Density-dependent emigration of fish from an expanding red snapper population may have resulted in more extensive movement than was observed previously in the absence of hurricanes (SEDAR, 2013).

Small sample sizes of recaptures for several other reef fish species tagged in this study prevented quantitative analysis of movement. However, among those for which modest sample sizes existed, gray triggerfish displayed the most limited movement, while grouper movement was intermediate to that of red snapper and gray triggerfish. Results of the few previous studies of gray triggerfish movement indicate they display limited post-settlement movement and high fidelity to natural and artificial reefs (Beaumariage, 1969; Ingram and Patterson, 2001; Johnson and Saloman, 1984). Specifically, Ingram (2001) estimated gray triggerfish site fidelity to be 63–87% y^{-1} for fish tagged at artificial reefs off Alabama, and recaptured fish moved distances similar to those reported here. Ingram (2001) also reported that hurricanes significantly affected gray triggerfish movement. Hurricane Dennis affected the probability of gray triggerfish movement in the current study when additional EE-LAARS movement estimates were included, but no factors significantly affected the distance gray triggerfish moved. Mean distance moved by fish exposed to Hurricane Dennis was three times greater than that of fish not exposed to the storm. However, high variance and low sample size resulted in a non-significant result for the effect of the hurricane on the distance moved by gray triggerfish.

Grouper are known to display high short term (weeks to months) site fidelity to northern GOM artificial and natural reefs (Lindberg et al., 2006); however, tagged individuals also have displayed significant movement (>100 km) (Heinisch and Fable, 1999; Lindberg et al., 2006; McGovern et al., 2005). Similar patterns of dispersion were apparent for gag in this study, with several recaptures near or at release sites but a few individuals moving significant distances. Additionally, other GOM shallow water groupers (e.g., red grouper *Epinephelus morio*, scamp *Mycteroperca phenax*) have been shown to display similar dichotomous movement behavior (Wilson and Burns, 1996). However, due to a small number of tagged red grouper and scamp, and consequently a low number of reported recaptures, the movement pattern was not apparent for those two species. Most recaptures of red grouper and scamp were at or near tagging sites with no significant movement observed apart from a tagged scamp that moved 41 km to the west of its release site. Overall, grouper recaptures at study sites paired with the significant number of fisherman recaptures within 50 km of the tagging area indicates that groupers perhaps have lower site fidelity than gray triggerfish, but do not move nearly as much as red snapper. It is also well established that GOM shallow water grouper species exhibit ontogenetic shifts in movement to offshore habitats and spawning aggregation sites (Beaumariage, 1969; Coleman et al., 2011; Lindberg et al., 2006; McGovern et al., 2005; Wilson and Burns, 1996). Given that groupers tagged in this study were relatively small, young fish, it is possible that mid-shelf artificial reefs such as those in the EE-LAARS serve as intermediate habitat along this inshore to offshore transition.

4.2. Implications for management

Results from this study have several implications for reef fish management in the northern GOM, as well as for the broader use of artificial reefs in reef fish fisheries. Foremost, movement results indicate that mobile reef fish, such as red snapper, would be unlikely to remain resident at unreported artificial reef sites. Among the reef fishes for which we have the most movement data, red snapper, gag, and gray triggerfish are all estimated to be severely overfished in the northern GOM (SEDAR, 2006, 2011, 2013). Not coincidentally, these fishes also are among the most heavily targeted species in the northern GOM reef fish fishery. Therefore, even small scale (<5 km) movement away from unreported reef sites likely exposed fish to high regional fishing mortality among publically known natural or artificial reefs. We did not witness any fishing occurring at tagging reefs or at other unreported reefs in the EE-LAARS during remotely operated vehicle based video sampling (Dance et al., 2011), nor were any tag recaptures reported with GPS coordinates that matched those of study reefs. However, given the amount of known natural and artificial reef habitat in the region it is unlikely that unreported reef sites could go undetected by fishers indefinitely. Therefore, the long term efficacy of unreported reef sites serving as no-harvest refuges would be doubtful even for fish such as gray triggerfish that display limited post-settlement movement.

Reef fish movement estimates reported here also have implications for consideration of MPAs as fishery management tools in the northern GOM. Coleman et al. (2011) reported that large (>700 mm TL) red snapper and gag demonstrated site fidelity to offshore grouper spawning aggregation sites in the northeastern GOM. They inferred that MPA creation or expansion would likely protect spawning stock biomass for both those species. However, it is apparent from this study and others that young red snapper and gag are capable of moving extensive distances. For gag, protection by MPAs across life stages would require corridors of protected habitats across the shelf from estuarine nursery areas to shelf edge spawning aggregation sites. For red snapper, however, the issue is even more complex given they do not aggregate to spawn, and movement within a given depth stratum can be extensive.

The state of Florida's artificial reef strategic plan (FWC, 2003) calls for the design and placement of artificial reefs within zoned management areas for the enhancement of reef fish stocks. Results from this study indicate that deploying unpublished artificial reefs near known natural or artificial reef habitat is unlikely to create no-harvest refuges toward achieving this enhancement goal.

Furthermore, modern sonar and GPS technologies would likely facilitate discovery of unreported artificial reefs over time. However, deploying unpublished artificial reefs within the boundaries of a no-take MPAs, presuming areas were planned and sited effectively, could potentially benefit the recovery or maintenance of reef fish biomass (Crowder et al., 2000; Pitcher et al., 2002; Coleman et al., 2004a; Claudet et al., 2006). A network of MPAs exists in the GOM, but individual protected areas are limited in spatial extent (<1000 km^2), only exclude certain fishing gears, or are only seasonally closed to fishing (Coleman et al., 2004a). Some managers have expressed general skepticism about the utility of creating MPAs as a fisheries management tool in the region (Shipp, 2003), while movement patterns of many exploited species suggest the dimensions of future MPAs would have to be much larger than current MPAs to have a significant impact on the spawning stock biomass of overfished stocks (Walters, 2000; Walters et al., 2007). Clearly, the potential benefits of MPAs go beyond fisheries management (Lester et al., 2009), but much of the discussion of developing a network of MPAs in federal waters of the GOM has centered on fisheries conservation, access to fisheries, or both.

Acknowledgments

The authors express their gratitude to the Florida Fish and Wildlife Conservation Commission for funding (Grants FWC-04032, -05027, and -06120 to WFP), specifically J. Dodrill and K. Mille for their support. Study sponsors played no role in study design, in data collection, analysis, and interpretation, in report writing, or in the decision to publish this work.

We thank Capt. J. Thierry for participation aboard the *F/V Dorado* and Seth Wilson aboard the *F/V Rip Tide*. We thank N. Morris, K. Shepard, and C. Lounder for invaluable field support. We thank Bill Kline for GIS assistance. We thank the volunteer anglers who participated on tagging trips, as well as the many fishermen who reported tag recoveries. We would also like to recognize the Florida Fish and Wildlife Research Institute for allowing manuscript preparation to be completed at its facility in St. Petersburg, Florida.

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