Movement Patterns of Red Snapper (*Lutjanus campechanus*), Greater Amberjack (*Seriola dumerili*), and Gray Triggerfish (*Balistes capriscus*) in the Gulf of Mexico and the Utility of Marine Reserves as Management Tools

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ABSTRACT

In the Gulf of Mexico, reef fishes represent important commercial and recreational resources, and recently many concerns have arisen over the future of several reef fish stocks. The Reef Fish Fishery Management Plan was implemented in November 1985 to rebuild declining reef fish stocks, including red snapper (RS), greater amberjack (GAJ), and gray triggerfish (GTF).

Based on tagging studies conducted in the northern Gulf of Mexico, the movement patterns of the above three species were compared. Of the 2,932 RS and 206 GTF tagged off the Alabama coast (1995 - 1998), 427 and 42 have been recaptured, with 195 (46% of recaptures) and 28 (67% of recaptures) being recaptured at the site of release, respectively. The greatest effect on magnitude of RS and GTF movement was that of tropical cyclones; the magnitude of movement of fish not at liberty during tropical cyclones were significantly less than those at liberty during storms. Of 564 and 614 GAJ tagged off Pensacola and Panama City Beach, Florida (1989 - 1995), 178 (32%) and 118 (19%) were recaptured, with 173 (97% of recaptures) recaptured in the permit (release) area and 105 (90% of recaptures) recaptured within 30 km of the point of tagging and release, respectively.

We reason that reef species exhibiting high area fidelity may profit from the shelter of a no-take marine reserve, which may lead to an increase in spawning stock biomass (SSB). Since each of these species have pelagic larvae, which may be transported throughout the Gulf by oceanic currents, an increase in SSB in a reserve may increase the production and export of propagules. Also, tropical cyclones may facilitate the export of adult biomass from a no-take marine reserve, therefore restocking surrounding areas. However, due to interspecific differences in site fidelity, the relative effectiveness of marine reserves were evaluated on a species specific basis.

KEY WORDS: Marine reserves, movement patterns, reef fisheries

INTRODUCTION

Reef fishes represent important commercial and recreational resources in the Gulf of Mexico (Gulf), and within the past decade and a half many concerns have arisen over the future of several reef fish stocks. These concerns include declining recreational and commercial landings of many reef species and spawning stock biomass (SSB) estimates which, in some cases have fallen below threshold values (GMFMC 1989). The Reef Fish Fishery Management Plan was implemented in November 1985 (GMFMC) to rebuild declining reef fish stocks. There are numerous species managed under this plan, including the three species which are the subject of this paper.

A large problem with fishery management today is the practice of development of unique regulations for each species, without regard for environmental variability and interactions between species or a species complex (Bohnsack 1993, Lauck et al. 1998). While community-level dynamics may never be fully understood, there is little chance for effective management given this practice (Lauck et al. 1998). Also, it is not uncommon for fishing effort to shift from one species, on which regulations have been imposed, to another species, requiring future management regulations on this newly fished species (Lauck et al. 1998). Marine reserves may provide an effective management tool to overcome the weaknesses of current management practices, especially with regard to ecological complexity and the effects of shifts in fishing effort between species due to imposition of regulations (Bohnsack 1993, Lauck et al. 1998).

The utility of a marine reserve depends on the life histories and behavior of the species under management. We reason that reef species exhibiting high site and/or area fidelity may profit from the shelter of a no-take marine reserve, which may lead to a local increase in SSB. Also, we reason that tropical cyclones may facilitate the export of adult biomass from a no-take marine reserve by causing an increase in movement, therefore restocking surrounding areas. However, due to interspecific differences in area fidelity, the relative effectiveness of marine reserves must be evaluated on a species specific basis. Based on data gathered from the northern and western Gulf, movement patterns are analyzed and compared, and the utility of marine reserves to the management of these three species is discussed.

Red snapper (RS) support one of the most important commercial and recreational fisheries in the Gulf (Schirripa and Legault 1997). Despite the findings of Gold et al. (1997), indicating a single panmictic stock of RS in the Gulf, most tagging studies have indicated that snapper have high site fidelity, with most tag recoveries occurring within 10 km of the site of tagging and release (Beaumariage 1969, Beaumariage and Bullock 1976, Fable 1980, Szedlmayer and Shipp 1994). However, some movement on the order of ten to hundreds of kilometers has been reported (Beaumariage 1969, Beaumariage and

Bullock 1976, Szedlmayer and Shipp 1994, Watterson et al. 1998). More recently, Watterson et al. (1998) reported that RS showed high site fidelity above artificial reefs in the northern Gulf; however, the authors also reported movement of some fish over 100 km. They also reported that Hurricane Opal had a significant effect on snapper movement. The study described herein was a continuation of the study reported by Watterson et al. (1998).

Greater amberjack (GAJ) support important recreational and commercial fisheries in the Gulf (Burch 1979, McClellan and Cummings 1996). There have been a number of tagging studies conducted concerning the movement of GAJ. Since 1954, 5,643 GAJ have been tagged and 642 recaptured due to the efforts of the Cooperative Game Fish Tagging Program in the Atlantic Ocean, Gulf of Mexico, and Caribbean Sea, which is managed by the National Marine Fisheries Service's Southeast Fisheries Science Center (Scott et al. 1990). Scott et al. (1990) speculate that the high tag recovery rate of 11.4% is due to the abundance of amberjacks in inshore waters and the active recreational fishery. This fishery is responsible for the majority of the tagging effort. They report the longest distance traveled by a GAJ was about 2,400 km from central west Florida to Venezuela, and the record time at large for this species is just over 10 years for a fish that was tagged and recaptured off Jacksonville, Florida. Also, a tagging study was conducted by Mote Marine Lab, targeting cobia, dolphin and GAJ, from October, 1990 to July, 1992 (Burns and Neidig 1992). During this project a total of 785 GAJ were tagged and released from many locations on the Gulf and Atlantic coasts of Florida. Of these, 46 were recaptured, with only 12 showing any net movement. One of the 12 which moved did so from Florida to Texas (~850 miles) in 252 days. These results are consistent with the findings of Burch (1979), who suggests that GAJ may temporarily leave then return to the area on an annual basis.

Until recently gray triggerfish (GTF) were not prized by recreational and commercial fishermen, unlike the two previously described species. Hence, the GTF did not support an economically important directed fishery in the Gulf. Increases in regulations on other reef species and increased awareness of the excellent flesh of gray triggerfish have created a demand for this previously underutilized fishery resource.

To date, however, there have been few studies concerning movement of adult GTF. Ofori-Danson (1990) reported that GTF off the West African coast in the eastern Atlantic Ocean move from cold coastal waters as a result of seasonal upwelling (during the third quarter of the year) to join an offshore stock which is present throughout the year. In contrast, Beaumariage (1964) and Johnson and Saloman (1984) reported that Gulf GTF may be less migratory. For example, Beaumariage (1964) found that 38 of 103 GTF, which were tagged and released in the northeastern Gulf, were recaptured by investigators (36.9% recovery rate) in the approximate area of initial capture and release.

MATERIALS AND METHODS

The data sets used in this paper come from two different sources. The first source of data comes from a tagging study, which was part of a larger dissertation project concerning the population dynamics of RS (Patterson 1999). During this tagging study, GTF were opportunistically tagged during the research cruises. RS and GTF were captured at nine sites in the northcentral Gulf of Mexico off the coast of Alabama in the Hugh-Swingle General Reef Permit Area, between 20 and 30 km south-southeast of Dauphin Island, Alabama between March 22, 1995 and July 20,1998 (Figure 1). The sites, which were artificial reef structures, were arranged in a 3 × 3 grid; three reefs were in each of three depth strata: 20, 26, and 35 m. Fish were taken by hook and line, measured for length and tagged abdominally with an individualized Floy® internal anchor tag. Recaptures by researchers were recorded and the fish were re-released, while recaptures by fishermen were reported via the phone number provided on each tag.

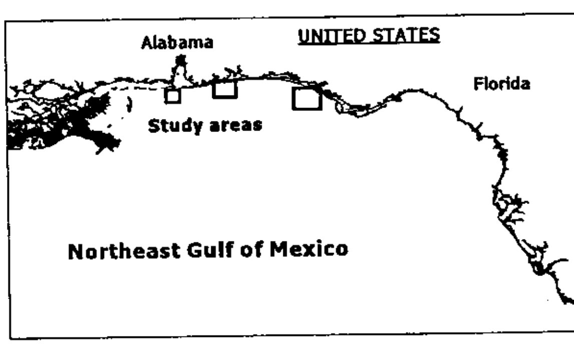

Figure 1. Study areas in the northeast Gulf of Mexico

Recreational fishermen from Pensacola and Panama City Beach, Florida provided the second source of data, which concerned GAJ tagging and movement. The fishermen used individualized dart tags, with which they dorsally tagged GAJ over artificial reefs off the coast of Pensacola and Panama City Beach, Florida from 1989 to 1995 (Figure 1). As each GAJ was tagged the total length of each fish was taken, and the release site and date were recorded. When recaptures were made, a phone number provided on each tag enabled the location of recapture and size of the GAJ to be reported.

A number of statistical procedures were used to describe and compare movement patterns of RS, GAJ, and GTF. The distance traveled from the point of tagging and release, if any, and the days at large of all recaptured fish were recorded. Polar graphs of distances moved from the point of tagging and release were developed for each species for visual analysis of movement patterns. Unbiased estimates of mean distances moved and mean velocities (distance moved/days at large) were computed for each species using the delta method due to the abundance of zero values in the data (Pennington 1983). Rayleigh's test for randomness in direction of movement was employed to determine if there was significant directional movement in each of the three species (Batschele 1981). Parametric and non-parametric analyses of variance were employed to characterize the effects of tropical cyclones, fish size, time at large, etc., on the movement patterns of each species at an $\alpha = 0.05$. Finally, graphs of cumulative frequency distributions of each species recaptured within three years of tagging versus the distance moved from the point of tagging and release were developed to analyze the frequency of recaptures within certain radii of distances moved.

RESULTS

Mean total length (± SE) of RS tagged in this study was 335.1 mm (± 1.34). Of the 2,932 RS tagged, 80% were shorter than the legal size limit of 380 mm TL; 427 were recaptured. Of the 427 RS recaptured, 195 were recaptured at their site of release and 232 were recaptured at some other location. The largest distance moved was 344 km for a RS that was at large for 400 days. The maximum time at large for a recaptured RS in this study was 1,142 days for a RS that moved 55 km to the southwest of where it was released off the Alabama coast. The mean time at large for recaptured RS was 313 days.

Statistical analysis performed by Patterson (1999) found days at large after tagging and release ($p < 0.001$), exposure to hurricanes ($p < 0.001$), residuals of the relationship between days at large and TL at recapture ($p = 0.001$), and transportation prior to release ($p = 0.033$) were significant effects in a model with the ranked distance of RS movement as the dependent variable. Similar effects were found on the ranked velocity of RS movement using the same model, without days at large as a covariate. RS that were at large during Hurricane Opal, which moved over the tagging stations on October 4, 1995, or Hurricane Georges, which moved over the tagging stations on September 27, 1998, moved greater distances and had greater velocities of movement than did RS that were not at large during hurricanes. Unbiased estimates of the mean distance (± SE) that RS moved away from the point of tagging and release and mean velocities (± SE) calculated using the delta method are as follows: overall mean distance, 12.78 km (± 0.13); overall mean velocity, 47 m/day (± 29); mean distance moved during tropical cyclones, 48.98 km (± 3.72); mean velocity during tropical cyclones, 136 m/day (± 11); mean distance moved not during tropical cyclones, 5.93 km (± 0.11); mean velocity not during tropical cyclones, 36 m/day (± 0.9). Also, Rayleigh's test for randomness in direction of movement indicted directional movement of RS during hurricanes ($p < 0.001$) and random movement in RS not a large during hurricanes ($p > 0.25$). The resultant vector of RS at large during tropical cyclones was 37.4 km at 8.0° (0° = due east). Polar graphs of RS movement patterns during and not during tropical cyclones can be seen in Figure 2.

The mean fork length (± SE) of GTF tagged was estimated to be 346.7 mm (± 4.0). Of the 206 gray triggerfish tagged, 50 recaptures were made of 42 fish, with 28 (67% of recaptures) recaptured at the site of release. The mean time at large for GTF in this study was 190 days. The longest time at large for a GTF in this study was 949 days for a fish that moved 4.1 km. The greatest distance move by a GTF in this study was 8.6 km for a fish that was at large for 54 days during which Hurricane Opal passed over the tagging stations.

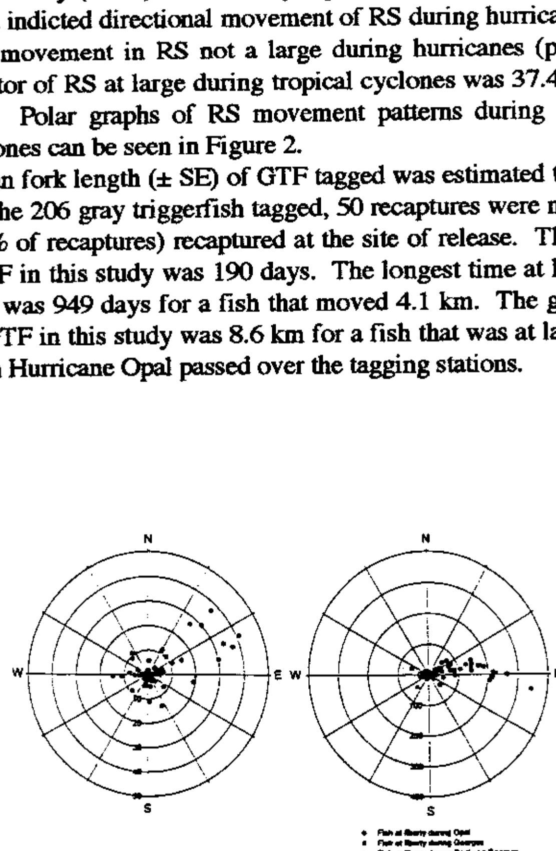

Figure 2. Movement patterns of red snapper not during (left graph: n = 284; 163 fish recaptured at release site) and during (right graph: n = 143; 24 fish recaptured at release site) tropical cyclones. Scale in km.

The greatest effect on magnitude of movement of GTF was that of Hurricane Opal, which passed over the tagging stations on October 4, 1995 (Figure 3). A Kruskal-Wallis One Way Analysis of Variance on Ranks indicated that the differences in the median values among the treatment groups (i.e., magnitude of movement of gray triggerfish tagged and recaptured before Opal, tagged before and recaptured after Opal, and tagged and recaptured after Opal) are statistically significant ($p < 0.001$). Dunn's Method, a multiple comparison procedure, showed that the magnitude of movement of gray triggerfish tagged and recaptured before Opal were not significantly different from that of fish tagged and recaptured after Opal ($\alpha = 0.05$). However, the magnitude of movement of fish tagged before and recaptured after Opal was significantly different from that of fish tagged and recaptured before Opal and tagged and recaptured after Opal ($\alpha = 0.05$). Unbiased estimates of the mean distances (± SE) and mean velocities (± SE) moved by GTF calculated using the delta method are as follows: overall mean distance, 1.64 km (± 0.40); overall mean velocity, 13 m/day (± 5); mean distance moved during tropical cyclones, 7.45 (± 0.65); mean velocity during tropical cyclones, 82 m/day (± 10); mean distance moved not during tropical cyclones, 0.72 km (± 0.20); mean velocity not during tropical cyclones, 4 m/day (± 1). The Rayleigh test for randomness indicated that direction of movement of GTF not at large during Hurricane Opal is random in nature ($p > 0.25$) and directional during Hurricane Opal ($p < 0.05$) with a resultant vector of 3.86 km at 166° (0° = due east).

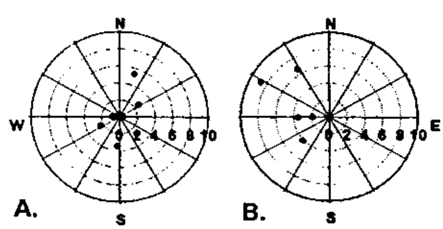

Figure 3. Movement patterns of gray triggerfish not during (A: n = 32; 25 fish recaptured at release site) and during (B: n = 5; no fish recaptured at release site) tropical cyclones. Scale in km.

The GAJ tagged in artificial reef permit areas off Pensacola and Panama City Beach, Florida (1989 - 1995) were done so opportunistically by recreational fishermen. The majority of the GAJ tagged were fish which were under the legal size limit (28 inches = 711 mm) and had to be released. There were very few GAJ tagged that were larger than the legal limit. Five hundred sixty-four GAJ were tagged by recreational fishermen in the reef permit area south of Pensacola, Florida. Thirty-two percent (178) of those GAJ tagged were recaptured. Of these recaptures, 97% (173) were recaptured within the reef permit (release) area.

An additional 614 GAJ were tagged by recreational fishermen in the reef permit area southwest of Panama City Beach, Florida. These recreational fishermen provided very detailed coordinates of tagging and recapture sites of GAJ allowing a more in depth analysis of GAJ movement (Figure 4). Nineteen percent (118) of those GAJ tagged off Panama City Beach were recaptured. Of these recaptures, the greatest time at large was 1,210 days for a GAJ that moved 92.3 km. The greatest distance moved was 403.6 km from off Panama City Beach, Florida to off Fouchain, Louisiana for a GAJ that was at large for 396 days. The mean time at large for the GAJ tagged off Panama City Beach was 200 days. There was no significant directional movement or effect of tropical cyclones on the movement of GAJ off Panama City Beach found during statistical analysis. The only large tropical cyclone that occurred during this study was Hurricane Andrew, and this storm passed well south of the tagging area. However, the GAJ which moved the greatest distance was at large during this storm. Days at large after tagging and release ($p < 0.0001$) was a significant effect in a model, with the ranked distance of GAJ movement as the dependent variable. As days at large increased so did the value of the ranked distance. Unbiased estimates of the mean distance moved (±SE) and mean velocity (±SE) of GAJ off Panama City Beach calculated using the delta method was 10.8 km (± 8.9) and 1.07 km/day (± 0.88), respectively.

DISCUSSION

Before we compare movement patterns of these three species and begin the discussion of the utility of marine reserves, we first discuss the validity of these tagging studies. To be valid these studies have to meet certain assumptions. First, we address the assumption of no effect of tagging on mortality for each species. Estimates of acute mortality rate caused by tagging were calculated for both RS and GTF using a scale of relative condition of the fish at release. Assuming only fish released in good condition survived, acute mortality rates for RS and GTF due to tagging were estimated to be 15% and 2%, respectively. No direct estimate of acute mortality rate due to tagging of GAJ was calculated during this study. However, during the tagging study conducted by Burns and Neidig (1992) condition of GAJ after tagging and release was recorded with 4.3%

in a condition other than excellent or good. As seen by the above estimates of acute mortality, these studies basically met the assumption of no effect of tagging on mortality with the possible exception of RS.

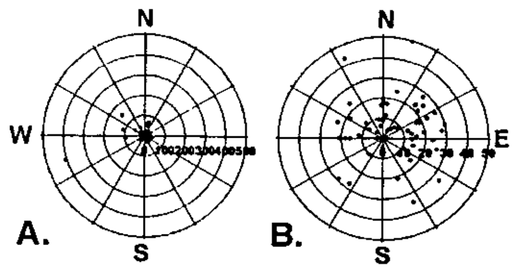

Figure 4. Movement patterns of greater amberjack tagged off Panama City Beach, Florida. A: Scale to 500 km. B: Scale to 50 km

Next, we address the assumption that all the tagged fish were recognized, which depends largely on tag retention. Using logistic regression, retention rates of the external portion of internal anchor tags were estimated for both GTF and RS. Retention rates (± 95% C.I.) were estimated to be 93% (88 - 96%) and 92% (82 - 97%) for fish at large for six months, 77% (68 - 86%) and 86% (66-95%) for fish at large for one year, and 18% (7-40%) and 38% (0.1-99%) for fish at large for two years, for RS and GTF, respectively. As for GAJ, no direct estimation of tag loss was made. However, Dunning et al. (1987) conducted a double tagging study on striped bass, *Morone saxatilis*, and estimated that retention rates of internal anchor tags was 98% after two years, while the retention rate of t-bar anchor tags placed dorsally on the striped bass, similar to those used to dorsally tag GAJ, was only 42% after one year. Tag loss, or the failure to recognize a tagged fish, can have significant impact on results. Due to tag loss in this study, it is possible that we are underestimating movement in each species, especially RS and GAJ, which tend to move greater distances the longer these species are at large.

Finally, the assumption of equal catchability is addressed. The first part of this assumption made is that tagged and untagged fish have the same probability of being captured. This implies that tagging a fish did not alter its behavior. No tests of this part of the assumption were conducted for any of the species in this paper, but 30 tagged RS were held for six months in the laboratory by Szedlmayer and Shipp (1994), and no changes in behavior were recorded. The second part of this assumption concerns seasonal trends in catch rates. Catch rates for both RS and GTF were higher in the fall than other seasons, which can be explained by seasonal stratification of the water column. In the late spring and summer, stratification of the water column leads to depleted bottom dissolved oxygen. Patterson (1999) found that catch per tagging station was significantly correlated with bottom dissolved oxygen, and when wind mixing broke down stratification in the fall, catch per tagging station increased. Similar trends were also found with GTF. For GAJ, Thompson et al. (1999) reported monthly changes in size and availability of GAJ, which may be due to seasonal migrations of larger fish. These seasonal patterns of catch rates could bias estimates of equal catchability low for larger fish.

One of the most important uses of a marine reserve is as a refuge from fishing pressure for some or all of the species in the area. By releasing such fishing pressure, a population may then become structured by natural mortality instead of fishing mortality (Bohnsack 1992). Thus, reserves may increase the density, average size, and SSB of species in the reserve, even large predatory species like carangids and lutjanids (e.g., Russ and Alcala 1996, Polunin and Roberts 1993, Roberts 1995). Because larger individuals tend to have higher reproductive output, a population now structured by natural mortality with more larger and older individuals in a marine reserve may have a much higher reproductive output (Bohnsack 1992). Hence, marine reserves could possibly enhance fisheries by acting as centers of dispersal of propagules and adults into the areas surrounding the reserve.

However, the utility of a marine reserve would depend on the ecology of each species in question. In this discussion we characterize the utility of a marine reserve with area fidelity using unbiased estimates of mean distance and velocity moved, coupled with analysis of the cumulative frequency of recaptures versus the distance from the point of tagging and release to point of recapture. Also, we mention the relative effective size of a reserve for each species in the context of area fidelity and reproductive patterns.

GTF were estimated to have extremely high area fidelity. This can be seen in the estimates of mean distance moved and velocity (i.e., 1.64 km and 13 m/day, respectively). Also, as illustrated by the cumulative frequency graph (Figure 5) 100 % of all GTF were recaptured within nine kilometers of the point of tagging and release. Even though there was a significant effect from exposure of GTF to Hurricane Opal and a pulse of GTF movement to the west-northwest was observed, area fidelity remained high. GTF are very territorial, have an early age at maturity, build nests during the spawning season, and have larvae and juvenile life history stages that are pelagic through the first year of life (Harper and McClellan 1997). Therefore, we reason that territorial species like GTF may benefit from small no-take marine reserves; SSB may increase in the face of no fishing pressure, since highly fidelic species exposed to fishing pressure may more vulnerable to overexploitation (Bohnsack 1989).

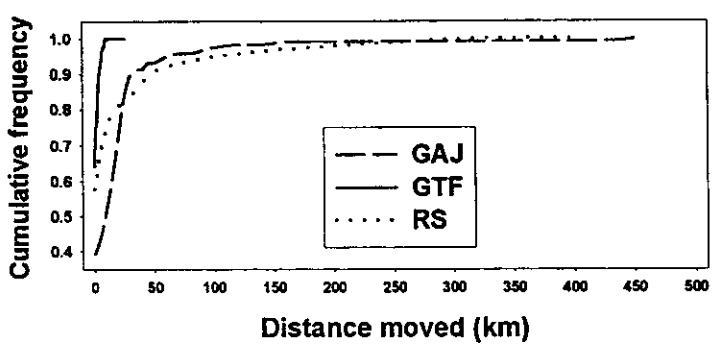

Figure 5. Cumulative frequencies of fishes recaptured versus distance from the point of tagging to the point of recapture

Eighty percent of the RS tagged in this study had total lengths less than the legal size limit of 380 mm at the time of the study. Therefore, the portion of the population that is analyzed by this study consists of relatively small fish. Patterson (1999) reports greater distances moved by RS in this study than in previous studies. However, of these small RS, 58% were recaptured at the site of release and 80% were recaptured within 20 km of the site of tagging during this study (Figure 5). Therefore, we reason that red snapper exhibit moderate area fidelity, relative to the high area fidelity of GTF, with the probability moving out of an area increasing over time. Hence, at the very least these undersized RS may benefit from escape of release mortality. Also, due to the fact that RS mature later than do GTF, do not reach their peak fecundity until around 15 years of age, and tend to move greater distances over time, RS may require a marine reserve covering a much larger area than GTF.

Surprisingly, the relatively small GAJ (< 711 mm TL) tagged off Florida were found to have a higher area fidelity than red snapper. Off Pensacola, 97%

of GAJ tagged were recaptured within the reef permit (release) area. Off Panama City Beach, there were less recaptures at the site of release than RS (39% < 58%). However, 90% of GAJ recaptures were made within 30 km of the point of tagging, while 90% of RS recaptures were made within 50 km (Figure 5). While mean velocity of GAJ is much greater than RS and GTF (i.e., 1.07 km/day, 47 m/day, and 13 m/day, respectively), the mean distance moved by GAJ is less than that of RS (i.e., 10.8 km < 12.8 km). This implies that young GAJ move around a great deal but may do so in a relatively small area. Therefore, like RS, GAJ exhibit moderate area fidelity, with the probability moving out of an area increasing over time. This last relationship may be partially explained by the findings of Thompson et al. (1999), which suggested that larger GAJ may undergo seasonal migration. However, the size at which GAJ begin to migrate is unknown (Burch 1979). Again, like RS, the relatively smaller GAJ in this study may benefit from escape of release mortality. Also, due to the facts that GAJ mature and reach peak fecundity earlier and appear to have higher area fidelity, GAJ may benefit from a relatively smaller marine reserve than RS.

We conclude that marine reserves can benefit the species addressed in this paper. However, caution needs to be used when forming marine reserves in the future. All of the fish in these studies were tagged over the shallow shelf of the northern Gulf of Mexico. RS and GTF, exhibited greater distances and velocities moved during tropical cyclones. It is reasonable to assume that RS and GTF inhabiting a marine reserve placed in a similar area would also show an increase in movement. Therefore, there may be a reduction in the effectiveness of a marine reserve placed in relatively shallow areas susceptible to perturbation by tropical cyclones with an increase in export of adult biomass to surrounding areas. Hence, due to the high frequency of tropical cyclones in the northern Gulf, offshore placement of a marine reserve may be more advantageous to these species.

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