Potential survival of released groupers caught deeper than 40 m based on shipboard and in-situ observations, and tag-recapture data

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POTENTIAL SURVIVAL OF RELEASED GROUPERS CAUGHT DEEPER THAN 40 M BASED ON SHIPBOARD AND IN-SITU OBSERVATIONS, AND TAG-RECAPTURE DATA

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ABSTRACT

The undersized bycatch of groupers managed under current federal minimum-size rules must have a high rate of post-release survival for the rule to be effective in maximizing yield unless there is significant avoidance of this bycatch by the fishery. Moreover, this survival rate would have to remain high over the entire range of depths fished if a single estimate of release mortality is to be used in yield models. In this study, shipboard and in situ observations were used to determine the potential post-release survival rate of groupers, chiefly red grouper (*Epinephelus morio*), caught from between 44 and 75 m on the central west Florida shelf. Potential survival rates were then further evaluated in combination with data from a tag and recapture study (3,818 releases) in the same area and time period. Potential survival rates for released red grouper and scamp (*Mycteroperca phenax*) caught shallower than 44 m were very high (86 to 100%) for up to 8 days following return. Undersized grouper (<50.8 cm) caught from both shallower and deeper than 44 m, then tagged and released, were found to survive long enough to reach legal size. For grouper caught deeper than 44 m, however, tag/recapture data and in situ observations indicate that potential survival rates are too low (<33%) for the 50.8 cm (20 inches) size rule to be effective in increasing yield.

Groupers, especially red grouper (*Epinephelus morio*), are an extremely important fisheries resource of Florida's west coast. Fully 51% of the commercial grouper harvest from the entire Gulf of Mexico since 1979 has come from central areas of the west Florida shelf via ports near Tampa Bay (Reef Fish Fishery Management Plan, 1989). The remaining landings were from near the Florida Keys and off southwestern Florida (24%), near the Florida Panhandle (19%), or from the remaining Gulf states (6%). Whereas the commercial fishery for groupers lands only two to three times the tonnage of fish as the recreational fishery, it operates over a vast area of the west Florida shelf of about 15.4×10^4 km^2.

The industry for groupers fished in federal waters of the southeastern United States is under the management jurisdiction of the Gulf of Mexico and South Atlantic Fishery Management Councils. The cornerstone of management strategy applied to groupers and snappers in both the Gulf of Mexico and South Atlantic has been the use of minimum size limits combined with quotas to achieve a favorable spawning potential ratio (SPR), and to prevent growth overfishing (Huntsman and Manooch, 1980; Waters and Huntsman, 1986; Huntsman and Waters, 1987; Goodyear and Schirripa, 1991). Because no groupers of sub-minimum size may be landed, they must be released, or otherwise discarded. Presently, a minimum size of 50.8 cm of total length (20 inches) applies in federal waters to four species: red grouper (*Epinephelus morio*), black grouper (*Mycteroperca bonaci*), gag (*M. microlepis*), and yellowfin grouper (*M. venenosa*).

Because the State of Florida adopts the federal rules for grouper, the minimum-size rule for each of the regulated grouper species is in effect over the entire range of depths where it is fished, and the rule is applied to both commercial and recreational fishermen. Under current regulations, commercial longline fishing is restricted to water deeper than 37 m (20 fm) which begins about 100 km offshore from central west Florida. However, commercial fishing in these relatively deep waters raises a problem for the management of groupers, especially red grouper, under a minimum-size rule. The adoption of this rule presupposes that sub-minimum fish caught inadvertantly (as bycatch) will be returned to the habitat and sustain only natural mortality until reaching legal size. Although adoption of a minimum-size rule is also expected to promote avoidance of undersized fish, the extent to which this is possible in a hook/line fishery where gear is not size selective is ambiguous. Thus, the most pertinent question pertaining to caught and released fish, as well as to the rule itself, is the average expected survival rates of the released fish.

Goodyear and Schirripa (1991) have argued that under a minimum-size rule fishing-induced mortality of undersized red grouper has a definite affect on yield and spawning stock biomass. They stated that "if release mortality can be ignored, . . . , then the 20-inch minimum size is clearly a benefit both for the condition of the stock and the yield it produces. However, if discard mortality cannot be avoided then delaying harvest until the fish achieve 20 inches may reduce harvest on a per recruit basis." Goodyear and Schirripa (1991) have shown that with negligible release mortality (i.e., high survival) the current minimum size is superior to a smaller size such as 40 cm (16 inches), but at high post-release mortality a smaller minimum size would increase yield. At 20% release mortality (80% survivorship), the spawning potential ratio (SPR) should exceed 0.25 at the maximum yield-per-recruit at the 50.8-cm minimum size (20 inches), although total fishing mortality might have to be restricted. At 33% release mortality (67% survival of undersized fish), SPR decreases below 0.25 at the maximum yield-per-recruit. Goodyear and Schirripa (1991) commented that significant release mortality "would seriously impair the use of minimum sizes to maintain SPR at fishing mortality rates much above 0.4."

Groupers have fully closed (physoclistous) swimbladders. As with most physoclists, groupers brought rapidly to the surface from any appreciable depth experience rapid expansion of swimbladder gases leading to ruptured swimbladders, bloating, protrusion of internal organs and eyes, and embolisms (Stearns, 1887; Moe, 1969). This led Moe (1969) to suggest that a legal minimum size for red grouper would be ineffective, because "fish brought up from depths greater than 27 m (15 fm) would seldom survive." Groupers inhabiting the depth range where red grouper close to the minimum legal size are abundant, between about 35 and 90 m, experience a 5- to 6-fold increase in the volume of swimbladder gases before reaching the surface which is more than enough to cause the conditions described above.

Meeting the conservation goals of a management strategy calling for the release of undersized fish in a fishery that inadvertantly captures high numbers of undersized fish, due to the evident difficulty of avoiding such capture, depends on the survival of the released fish. By current yield models (Goodyear and Schirripa, 1991; Waters and Huntsman, 1986), larger minimum sizes (e.g., 50.8 cm) require very high post-release survival rates to be effective. It is therefore necessary to be able to estimate long-term, post-release survival to confirm the efficacy of a given minimum size rule. Considering the depth range over which the commercial grouper fishery operates in the eastern Gulf of Mexico, this estimate would have to be weighted to reflect different survival rates of grouper caught from, and returned to, different depths, if depth has any demonstrable effect on survival rates.

Estimating the average post-release survival of groupers caught over a range of depths is difficult due to the many conditions under which the fish are caught and released in practice. In addressing the question of long-term, post-release survival, it is appropriate first to examine potential survival of groupers following release. Potential survival is the ability of the fish to recover from the initial trauma associated with capture and release, and thus survive in good condition for a short initial period. If it could be shown, for example, that potential survival rates are too low to support a given minimum size in a fishery where release of undersized fish is much more likely to be a potential factor in conservation than avoidance of bycatch, then one should not expect a high enough survivorship under actual working conditions. Conversely, if potential survival rates are high, then high long-term survival might ensue following release of undersized fish. Substantiating long-term survival would need some ground-truth data from tag and recapture studies.

The amount of ground truth that tag and recapture data can supply is limited due to the generally low rate of tag returns—a fact which also prohibits the sole use of tag and recapture data in estimating post-release survival rates for grouper in the first place. On the other hand, an empirically supported estimate of long-term, post-release survival rates is not possible without data from tag and recapture because it is not feasible to keep fish in long-term confinement to test for survival. Thus, one possible approach is to combine observations of potential survival and data from tag and recapture, where the tag/recapture data are used as ground truth for predictions derived from short-term observations, post release.

The purpose of this paper is to examine the probable effectiveness of a minimum-size rule for groupers fished on the west Florida shelf as a function of their potential survival, post release. In doing so, we incorporate data obtained from a large tag and recapture study conducted over much of the grouper fishing grounds of the west Florida shelf between 1990 and 1994 (Fig. 1), with a series of shipboard and in situ observations of "post-release" groupers. We focus primarily on red grouper due to its abundance and commercial importance, and secondarily on gag (*Mycteroperca microlepis*) and scamp (*M. phenax*), the latter of which is regulated only under a Florida minimum size rule. Observations on these other grouper species are incorporated as appropriate. We address the following questions. What is the potential post-release survival of red grouper on the west Florida shelf? Is potential survival affected by the depth of capture? To what extent do data from tag and recapture support estimates of potential survival? Finally, is potential survival demonstrably high enough to justify a broadly applied minimum-size rule for the purpose of fishery conservation and management?

Materials and Methods

Shipboard and in situ Experimentation.—Potential survival of red grouper, gag, and scamp was determined through two approaches. In the first, grouper were caught by hook and line from an anchored vessel in about 44 m (Fig. 1). The fish were caught during May of 1991 mostly from small patch reefs having a very low relief in the vicinity of 27°35.78'N, 83°39.04'W. A simulated release was accomplished after unhooking the fish and placing it within 3 to 5 min in one of five repressurization test chambers (one fish per chamber). The chambers were then quickly repressurized to in situ pressure with natural seawater near in situ temperature. The condition of the fish was observed for 24 h, or as close to 24 h as feasible. Each grouper still alive following this observation period was tagged with a Hallprint plastic dart tag inserted immediately ventral of the spinous dorsal fin, and then released. Fish were judged survivable based on their ability to swim down.

The test chambers were of schedule 80 PVC (polyvinyl chloride) pipe of 0.92 m length and 23 cm inside diameter (i.d.), and were fitted with circular acrylic end-plates of 33 cm diameter and 3.8 cm thickness. End plates were recessed 0.95 cm and fitted with o-ring grooves to allow the PVC pipe to be shallowly inserted into the acrylic plate, forming a face seal with it. End-plates were held in place with 8 stainless-steel threaded rods of 30 mm diameter through-bolted at 8 equally-spaced holes. A 15.2-cm diameter hole in one end-plate in the center of the plate closed by a hinged aluminum door of 62 mm thickness allowed emplacement of the fish. Total chamber volume was approximately 38 L (Fig. 2).

During experimentation, each test chamber was individually pressurized with seawater using a Teel

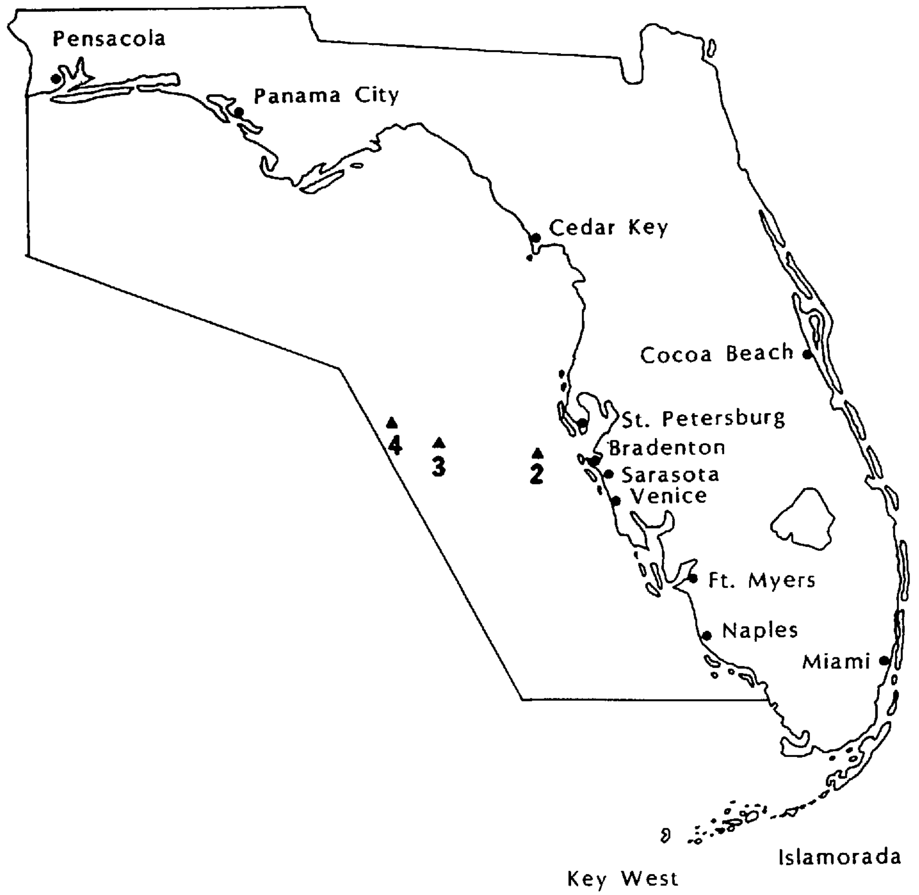

Figure 1. Study area over the west Florida shelf. Filled triangles indicate the sites at which the shipboard and in situ observations were carried out. Tag and recapture data were obtained from over the entire area of the west Florida shelf enclosed by the box. Station 2: 27°36.5′N, 83°38.1′W (44 m), Station 3: 27°41.8′N, 84°10.6′W (54 m), Station 4: 27°57.8′N, 84°24.9′W (75 m).

(Teel #3P-616E) submersible well pump capable of pumping seawater up from a depth of over 30 m at over 2,000 L per hour, and at more than 13.6 atm pressure. Each test chamber was individually supplied with water. Internal chamber pressure was controlled with an adjustable pressure-relief valve. Flow rate for each chamber was periodically adjusted by eye to maintain a steady stream. Based on calibrations in the laboratory of the flow rate by eye, the rate during these experiments averaged between about 0.5 and 2.0 liters·min^{-1}. Generally higher average rates were maintained for the larger specimens.

Fish were allowed to acclimate to conditions inside the chamber for between 1 and 4 h before routine observation. Acclimation was judged to have occurred when the fish became either negatively or neutrally buoyant, and had acquired an upright, or nearly upright, orientation. The fish were observed for three minutes every 2 to 3 h over a period of between 20 and 26 h, but as near to 24 h as practical. For these experiments, an observation period near 24 h was judged a priori to provide adequate time to observe acute lethal effects, as well as time for an indication of longer-term detrimental effects. Following observation, the fish were removed from the chambers, measured, and then released. The condition of the fish at release and whether or not it swam down was recorded.

For the in situ approach, grouper were again caught by hook and line from patch reefs lying at 44, 54, and 75 m during two research cruises of 12 and 9 days duration in late May/early June and mid-September, respectively, of 1992. The coordinates of these sites were 27°36.5′N, 83°38.1′W at 44 m, 27°41.8′N, 84°10.6′W at 54 m, and 27°57.8′N, 84°24.9′W at 75 m. Simulation of the return of a fish

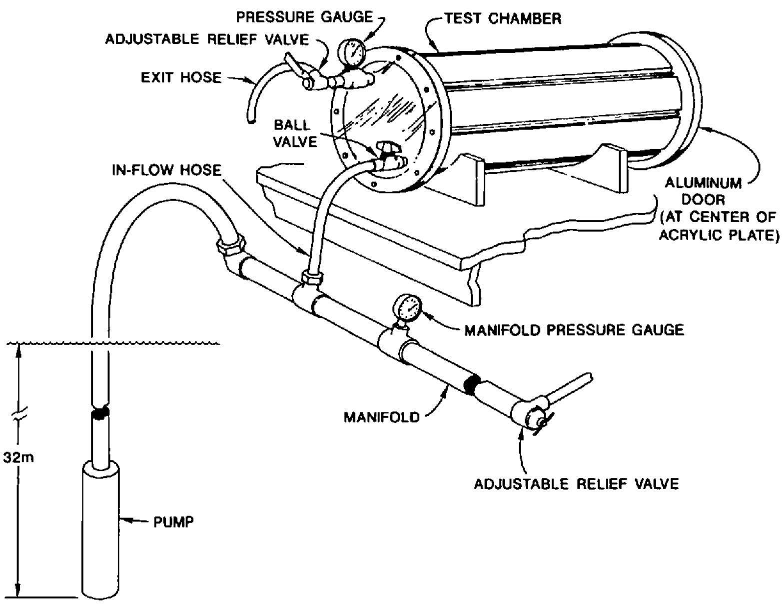

Figure 2. Quasi-schematic diagram of the experimental apparatus and one test chamber. During the experiment, seawater was pumped from approximately 32 m depth through the manifold and into the chamber at a high flow rate. Chamber and manifold pressure was controlled using pressure-relief values set at desired pressures, thus allowing nearly isobaric, flow-through circulation.

to its capture depth was accomplished after unhooking it, and quickly (within 5 min) placing it in a wire-mesh cage, then lowering the cage to the bottom from a catwalk suspended from the ship's U-frame.

After being set on the bottom, the cages were periodically inspected using a remotely-operated-vehicle (ROV). This ROV was a Superphantom IV, manned by experienced operators from the National Undersea Research Center (NURC) at Wilmington, N.C. The ROV was equipped with a video recording system which allowed recordings to be made of each dive, and a Trackpoint-II system which gave the position of the ROV relative to the vessel. The ROV was operated on a tether by a team of three experienced operators. The deployment of the ROV occurred at irregular intervals which were determined mostly by sea conditions and the success rate of grouper captures.

The wire-mesh cages were 61-cm cubes made of panels of marine-coated wire mesh held together with hog rings. The cages were weighted with 4 to 6 bricks (10 kg ea.) fastened to the bottom panel with plastic wire ties. The cages had no opening or exit after assembly. The cages were lowered to the bottom on braided polypropylene (yellow) line which remained buoyed at the surface. Each buoy and cage were numbered together. After setting, each cage received an "initial inspection" to determine the condition of the fish shortly after being returned. The period between the deployment of the cage and the initial inspection varied among sites, and among fishing spots within a site.

At inspections it was determined whether the fish was alive or dead. If alive, its apparent condition was noted (good or poor). At each inspection, the ROV was positioned very close to, or even against, the cage so the fish was clearly viewed for several minutes. If there was doubt as to the condition of the fish, the ROV was repositioned to observe movements such as gill ventilation. When necessary, the cage was "bumped" to cause the fish to move to ascertain its apparent condition. Two original video recordings of the fish were made at each inspection in VHS and 8-mm formats. The VHS recording was retained by the first author. The 8-mm recording was retained by the NURC @ Wilmington for archiving, and is publically accessible. Cages were recovered as quickly as possible after inspection for fish that had died; the expired fish were cursorily inspected. For a condition other than dead, a cage remained in place until it was necessary to recover the cage to abandon that site for the remainder of the cruise.

Tag and Recapture.—The tag and recapture study is the outgrowth of a tag and release fishing tournament initiated by the Southern Offshore Fishing Association (S.O.F.A.) and the Fishermans' Environmental Fund of Madeira Beach, Florida, and Mote Marine Laboratory (MML) of Sarasota, Florida.

Table 1. Results of shipboard observations of red grouper (*E. morio*) caught from 44 m and repressurized in shipboard chambers. Legal minimum size is 50.8 cm; potential survival is at least 15/21, = 71.4%, for all red grouper. Length is fork length.

N	Mean/Median length (cm)	Length range	Mean/Median observation (h)	Observation range (h)
15*	43/42	38–47	24/24.5	20–25
3†	42/42	38–56	16/20	3–26
3‡	44/48	29–53	2/2.3	2–3

* Swam down after release from chamber.
† Did not swim down after release from chamber.
‡ Died in chamber.

The first tournament was held in October 1990 and following it, Mote Marine Laboratory became the repository of data for an expanded Reef Fish Tagging Program. During the two annual tournaments, groupers were identified, tagged, and released by trained "observers" placed aboard the vessels for that specific purpose. In the interim between tournaments, and since the last tournament in 1991, tagging has been carried out voluntarily by recreational charter boat and commercial vessel captains in the regular pursuit of fishing activities. To acquire as much assistance as possible, the tagging program was publicized via official Mote Marine Laboratory press releases, presentations to local fishing clubs, and during Mote Marine Laboratory Open Houses.

Tagged and released grouper were caught by hook and line. At release, a single-barbed Hallprint plastic dart tag was inserted at an angle under the anterior portion of the spinous dorsal fin. Each tag was numbered and was printed with an 800 telephone number and with the mailing address of MML. Data taken for each tagged fish included the tag number, species name, date, location within 9 km (5 n.mi.), water depth (ft), fork length (in), type of gear and bait used, comment on the condition of the fish, and whether the abdomen was aspirated. Data on returned tags usually included all of the following data—the tag number, species name, date, coordinates (to one minute), water depth (ft), fork length (in), type of gear and bait used, and comment on the condition of the fish. Tagging data were recovered through the mail and direct telephone interviews with persons calling the 800 number during regular working hours. After hours, an answering machine was used.

Tag return data were sorted by species and depth of original capture which allowed determination of tag return rates by species and depth of capture. Distances traveled during freedom were computed by straight line measurements between release and recapture sites. Coordinates reported for tagged and recaptured red grouper, scamp, and gag were used to calculate the directions and distances traveled. Vectors of direction and distance traveled were plotted on a polar diagram to look for any obvious trends in movements related to season or fish size. Only fish traveling more than 9 km (5 n.mi.) were plotted because this was the radius of positional uncertainly accepted for the intitial release. Each of the 16 possible size by season plots were constructed for red grouper, but data were insufficient to do this for the other two species.

Results

Potential Survival from Shipboard Experimentation.—Twenty-one red grouper between 28 and 66 cm of FL were caught by hook and line from between 43 and 44 m, and tested for potential survival in the repressurization chambers (Table 1). All grouper caught showed signs of rapid decompression, which included bloated abdomens, everted stomachs, and in three instances, popped (protruded) eyes. All but four grouper had been hooked in the mouth, with the remaining hooked in the stomach or gut. Bleeding occurred during removal of the hook from some fish. Also, frothy bleeding was observed around the eyes of one grouper with protruded eyes.

Three of the 21 grouper so tested died within 4 h of repressurization and a fourth was judged moribund after 3 h of lying on its side (Table 1). One of the three that died appeared to be doing fine, but while still buoyant during initial repressurization this small fish (29 cm) was injured as it was sucked against the outflow port. Two of the 17 groupers surviving the experiment were unable to swim down rapidly after release and drifted from view within a few minutes. These fish showed no more obvious stress during the test period than the fish that swam down. The remaining 15 grouper were scored as survivable primarily on their ability to swim down rapidly and vigorously after release.

Test periods for most of these grouper were at least 24 h; two grouper were tested for 20.4 and 20.7 h. Survivables included fish that had been hooked by the mouth as well as by the gut, and fish with protruded eyes (Table 1). Thus, the potential survival of red groupers caught near 44 m depth was around 71.4% (15/21), a release mortality of 28.6%. Counting all the fish that did not actually die during the test, and removing the injured fish from consideration, raises potential survival to 85% (17/20), yielding an initial release mortality of only 15%.

Potential Survival from in situ Observations.—Forty-six groupers in combination of red grouper, gag, and scamp were caught by hook and line, and returned in cages to depths of 44, 54, and 75 m, during two summer cruises of 1992. Sizes tested ranged from 24 to 74 cm FL (N = 26) for red grouper, 30 to 58 cm (N = 17) for scamp, and 79 to 84 cm (N = 3) for gag. Length of the observation period varied among the sites and between cruises. The observation period for red grouper caught at 44 m was between 68 and 92 h on the first cruise and between 157 and 194 h (8 d) on the second. This median observation period at 44 m was 157 h (6.5 d). Only two of the 23 red grouper tested at 44 m died within these observation periods giving a potential survival rate of 91% versus the (best case) 85% obtained during the shipboard experiments. For red grouper caught at 54 m, there was only one observation lasting 106 h, following which the fish had extensive internal hemorrhaging, was clearly moribund upon recovery, and probably would have died within a few hours. Both red grouper caught at 75 m died within 67 h of return (Table 2). Thus, the potential survival for the last two depth sites (54 and 75 m) was zero.

The three scamp caught at 44 m were observed from between 83 and 185 h. None died within these periods (100% potential survival). Of the two scamp caught at 54 m, one was observed for 45 and the other for 73 h. The one observed for 73 h died (50% potential survival). The 12 scamp caught at 75 m were observed for a maximum of 140 h (5.8 d). All but four observations were truncated because the fish died, giving a median observation period of only 68 h. Of the four survivors, one was moribund at the time of cage recovery (25 h). The potential survival at 75 m was therefore 25% (3/12). Only three gag were caught, one at 54 m and two at 75 m. None survived more than 147 h. The two caught at 75 m died within 52 h after return (Table 2).

In summary, the potential survival for red grouper was 91% at 44 m, but zero at the two deeper sites (54 and 75 m). Combining the shipboard and in situ observations for red grouper caught at 44 m, the potential survival rate was at least 86% (14% initial release mortality). The potential survival for all grouper species caught at 44 m and observed in situ was 92.5% (25/27) (Table 2). The potential survival for scamp was 100% at 44 m, 50% at 54 m and 25% at 75 m. The potential survival of gag was zero at 54 and 75 m.

Tag and Recapture.—Between October 1990 and April 1994, 2,772 red grouper, 184 scamp, and 862 gag were tagged and released at sites between the northeastern Gulf of Mexico, to south of Naples, Florida (Fig. 3). Of these, 505 tagged fish have been recovered. Total return rates are 14.5% (403) for red grouper, 12.0% (22) for scamp, and 9.3% (80) for gag. Forty-eight fish were captured multiple (2–6) times from among 28 different sites: 44 were red grouper, 3 gag, and 1 scamp (Table 3).

There were 353 red grouper caught and released between 42 and 80 m, i.e., within the depth range of grouper caught for the experiments on potential survival.

Table 2. Results from the in-situ ROV study of grouper caught from and returned to 44, 55, and 75 m

Species	Fork length (cm)	Depth (m)	Min. survival time (h)	Max. survival time (h)	Hours of observation	Alive when cage pulled?
E. morio	27.9	44	92	>92	92	Yes
	35.6	44	92	>92	92	Yes
	30.5	44	92	>92	92	Yes
	24.1	44	92	>92	92	Yes
	25.4	44	91.5	>91.5	91.5	Yes
	33.0	44	90	>90	90	Yes
	35.6	44	82.5	>82.5	82.5	Yes
	35.6	44	82	>82	82	Yes
	45.7	44	82	>82	82	Yes
	45.7	44	73	>73	73	Yes
	54.6	44	36	<68	68	Yes
	33.0	44	194	>194	194	Yes
	33.0	44	193	>193	193	Yes
	38.1	44	193	>193	193	Yes
	38.1	44	193	>193	193	Yes
	50.8	44	161	>161	161	Not recovered
	48.3	44	157	<192	192	No
	48.3	44	192	>192	192	No
	33.0	44	189	>189	189	Yes
	50.8	44	187	>187	187	Yes
	30.5	44	157	>157	157	Yes
	45.7	44	173	>157	157	Yes
	25.4	44	173	>157	157	Yes
	73.7	55	106	>106	106	Yes, but moribund
	38.1	75	<69	<69	69	No
	73.7	75	<67	<67	67	No
M. microlepis	83.8	55	136	<147	147	No
	83.8	75	29	<51.5	51.5	No
	78.7	75	24	<46	46	No
M. phenax	31.8	44	83.5	>83.5	83.5	Yes
	55.9	54	47	<73	73	No
	30.5	54	45	>45	45	Yes
	54.6	75	*	<17	17	No
	41.9	75	42	>44	44	Yes†
	52.1	75	4.5	<32	32	No
	38.1	75	20	<37.5	37.5	No
	50.8	75	75	<140	140	No
	45.7	75	41	<75	75	No
	50.8	75	70	<70	70	No
	45.7	75	71	>71	71	No
	53.3	75	68	>68	68	Yes
	58.4	75	<68	<68	68	No
	40.6	75	*	25	25	Yes, but moribund
	48.3	75	24	<48	48	No
	30.5	44	158	>158	158	Not recovered
	33.0	44	185	>185	185	Yes
E. drummondhayi	38.1	44	193	>193	193	Yes
E. adscensionis	40.6	55	129	>129	129	Not recovered
	35.6	55	130	>130	130	Yes

* Fish dead at first ROV inspection.
† Cage fouled anchor rode and had to be pulled early.

The rest were caught shallower than 42 m. The cumulative tag return rate for this fraction deeper than 42 m was 8.8%, but no red grouper caught from deeper than 62 m and released have been returned. These deep-caught fish (>42–43 m; >62 m) were at liberty for between 9 and 770 days, and a few had grown to legal

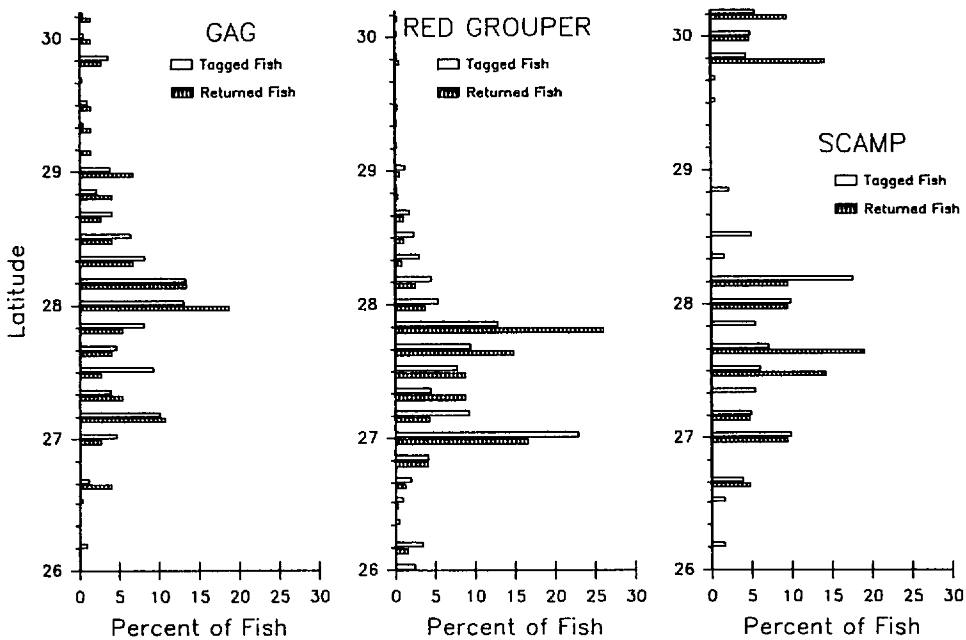

Figure 3. Frequency histogram by latitude showing where grouper were tagged and released between October 1990 and June 1993 on the west Florida shelf. Latitude of lower Tampa Bay is about 27°40′N.

harvestable size since release (Table 4). One of the returned red grouper, at 381 days of freedom, was one of the fish scored as survivable and released during our shipboard repressurization studies in May of 1991. There were 45 gag caught and released between 44 and 101 m. Of these, three (7%) have been returned. However, none of the returned fish was initially caught below 75 m. There were 58 scamp caught and released between 45 and 76 m, with a cummulative return rate of 12.1%. In contrast to red grouper, of which none caught deeper than 62 m has been returned, all but one of these recaptured scamp were first caught between 64 and 73 m. These returned deep-caught scamp were at freedom for between 177 and 740 days.

Approximately ¼ to ⅓ of released red grouper and gag (27.7 and 25.4%, resp.) moved more than 9 km (i.e., beyond the radius of positional uncertainty) from the reported release site, but among scamp the figure is 52.6%. The direction of these movements (i.e., offshore, inshore, or along shore) did not appear, based

Table 3. Number of tagged and recaptured fish listed with multiple recaptures (2–6×) indicated. Totals include multiple recaptured fish. Multiple recaptures were from among 28 separate sites.

Times recaptured (no.)	Red grouper	Gag	Scamp
1	300	74	20
2	26	3	1
3	4	0	0
4	2	0	0
5	2	0	0
6	1	0	0
Total recaptures	403	80	22

Table 4. Status of grouper as undersized or legal size (50.8 cm) between times of capture and recapture for tags returned with length data

Capture Recapture	Undersize Undersize	Legal Legal	Undersize Legal*	Total
Fish recaptured				
Red grouper	275	25	60	360
Gag	42	7	12	61
Scamp	11	6	1	18
Percent of total recaptures				
Red grouper	76.4	6.9	16.7	100
Gag	68.9	11.5	19.7	100
Scamp	61.1	33.3	5.6	100

* Of the tagged undersized fish that were recaptured at legal size, no gag, 11 red grouper and 1 scamp were originally captured at depths greater than 43 m (140 ft), but less than 62 m (201 ft). The 11 red grouper ranged from 0–11 km traveled and 39–770 days of freedom. The single scamp was recaptured at the same location after 740 days of freedom.

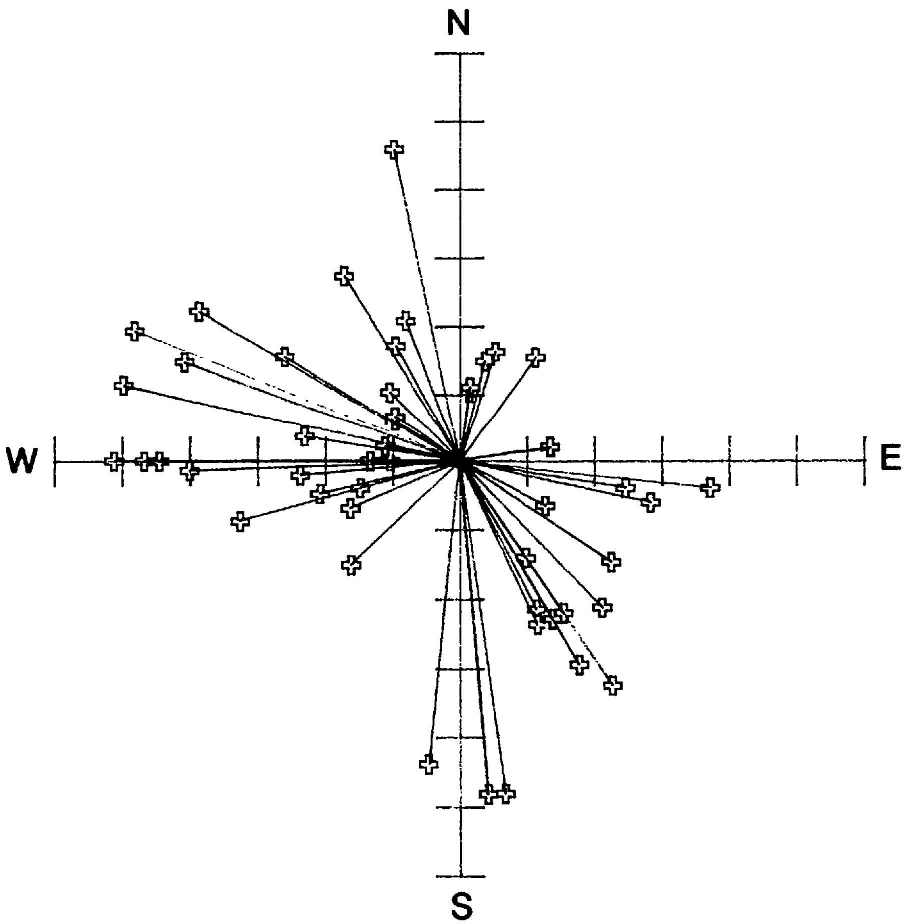

Figure 4. Polar diagram showing the net directions of travel for red grouper travelling more than 25 km from site of release. There is no significant mean direction by the Rayleigh's test ($P > 0.20$, N = 59). Grid lines are scaled at 20 km each.

on present data, to be related to season or to fish length. Distance traveled was uncorrelated with fish length ($P > 0.10$, $N = 78$, Spearman rank correlation). The travel directions of 59 red grouper that moved 25 km or more did not converge to a statistically significant mean direction (Rayleigh's test, $P > 0.20$). However, significant bipolar movements toward the northwest and southeast from release points (Fig. 4) would not be revealed with the Rayleigh's test, nor any other test of which we are aware.

Discussion

Nothing in our findings conflicts with the current management strategy for red grouper based on a minimum size limit of 50.8 cm (20 in) for fish caught from as deep as 44 m even though estimates of potential survival are barely high enough for this large of a minimum size to achieve increased yield. The potential survival rate of groupers caught near 44 m remained near 91% for as many as eight days following return of the fish to in situ conditions, giving a post-release mortality in the in situ study of only about 9%. Combining the data from the shipboard and in situ studies, the post-release mortality figure is 16%, slightly below that identified by Goodyear and Schirripa (1991) as the highest initial mortality that permits an effective 50.8-cm minimum size regulation for red grouper. Conversely, the potential survival was no more than 25% (75% post-release mortality) for any groupers caught at 75 m (zero for red grouper), placing potential survival far below the minimum necessary to increase yield by the release of undersized red grouper according to the models of Goodyear and Schirripa (1991).

These data represent the maximum potential survival rate attainable under ideal and benign conditions. In the shipboard study, the fish scored as survivable were held for between 17 and 26 h before release (except in two cases where it was 3 and 5 h) while recovering from the trauma and exertion of being caught. Most could swim down vigorously after release because they had rested, and because the residual gas expelled internally by the ruptured swimbladder had diffused. Similarly, in the in situ (ROV) study, the returned fish were treated gently, did not have to swim down on their own (lowered in a cage), and were protected from predation inside the cages as they recuperated. But although these data on potential survival are derived from relatively short observation periods, the data from tag and recapture clearly demonstrate that fish caught near these depths, and returned, can survive long enough to reach the legal minimum size (Table 4). Remarkably, one of the fish scored as survivable and released from our shipboard repressurization experiments was recaptured after attaining the minimum legal size, thereby adding credibility to the concept of potential survival as an estimator.

The combined data sets still produce only a circumstantial case for long-term survival, and no precise estimate of this rate for groupers caught shallower than about 42–44 m is yet possible. However, the 48 multiple recaptures were of grouper initially caught shallower than 43 m from among 28 independent sites; in some cases, these recaptures were separated by many days. Moreover, these are only the minimum number of multiple recaptures since the shedding rate for Hallprint tags is unknown for these species. Coupled with the high potential survival rate of grouper held in cages in situ at 44 m, the data indicate that long-term survival rates for grouper returned to shallow depths could be very high. In addition, our findings support very old (Stearns, 1887), as well as recent (C. Neidig, Mote Marine Lab, pers. comm.), anecdotal reports that grouper, particularly red grouper, caught shallower than about 36 m survive captivity for many months in good condition.

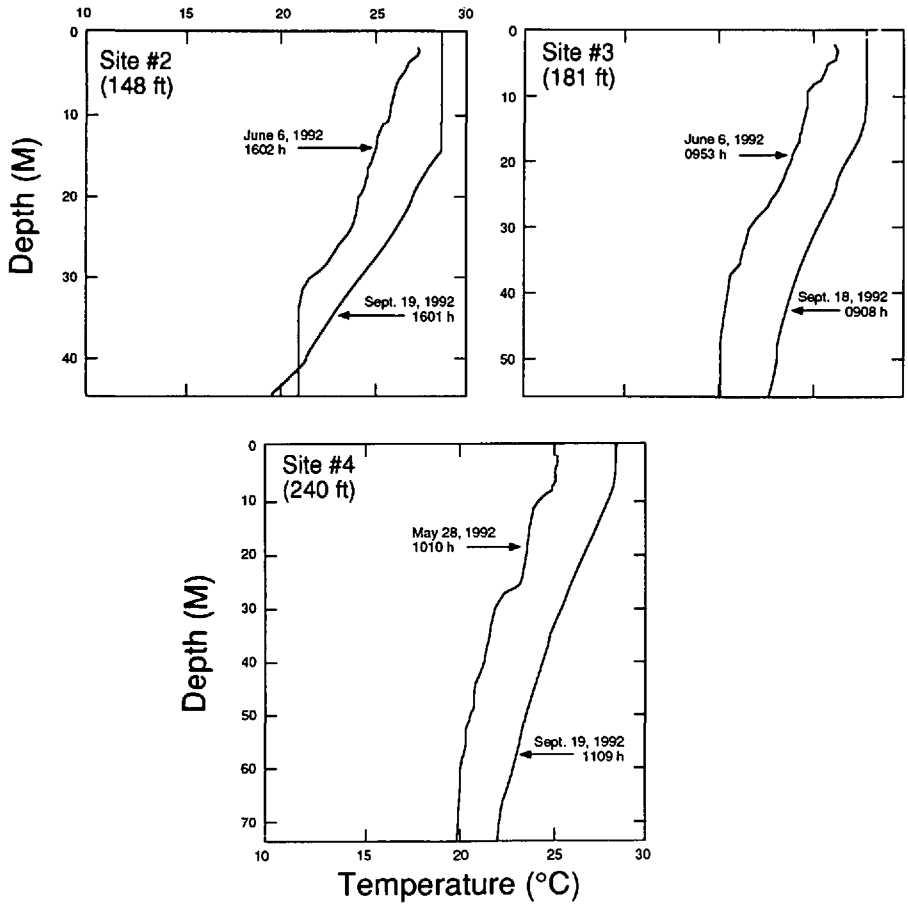

Figure 5. XBT profiles taken at the sites of the in situ observations on each of two cruises: A) ca. 44 m; B) ca. 54 m; C) ca. 75 m. Differences between the surface and bottom temperatures are between 5 and 8°C for all sites.

The long-term survival rate for groupers caught deeper than 62 m is probably too low to meet the goals of a minimum-size rule where release, rather than avoidance of capture, is the primary resultant action of the rule, assuming that the observed dramatic drop in potential survival is due mainly to depth of capture. We believe this is a reasonable assumption in view of the following and in view of similar findings for other species of reef fishes (Gitschlag and Renaud, 1994).

Fish caught from and returned to 75 m in the in situ study did not experience temperature differentials between the bottom and surface much greater than those experienced by the fish caught at 44 m (Fig. 5). The temperature differential was only about 5°C or less at all sites in May/June and between 5 and 8°C in September (Fig. 5). Thus, the difference in potential survival of fish caught at 44 versus 75 m is not due to differential thermal stresses.

Currents may have, but probably did not, influence the in situ results. The cruise to the 75-m site during May/June of 1992 occurred near the time of full moon (i.e., during spring tide). Bottom currents observed through the ROV were very strong. They had abated somewhat by the time the 44-m site was visited several days later (moon phase nearing quadrature). Fish deployed in cages at 75 m were therefore exposed to bottom currents strong enough to carry coarse-grained sediment, whereas those deployed at 44 m were exposed to weaker currents. (Following actual release, a fish would probably return to its patch reef or "hole" and be sheltered from currents carrying abrasive sediments altogether.) All of the fish returned to 75 m during this May/June cruise died within 3 days. In September, 1992 the 75-m site was visited closer to neap tide. Currents at this time were closer in strength to those occurring at the 44-m site. Nevertheless, the potential survival rate for just the September experiment alone was still dramatically lower than that observed for grouper caught at the 44-m site. Thus, any influence on survival due to experimental conditions appears to be small relative to the observed trend.

Neither of the two red grouper caught at 75 m in September, when bottom currents were mildest, survived even 3 days after return. None of the 31 red grouper, nor any of the 21 gag, tagged from deeper than 62 m (201 ft) in the MML study has been returned to MML. Potential survival of scamp caught at 75 m was near 25%, and if only the results of the September cruise are used, the rate is similar at 33%. Compared to red grouper caught from this depth, scamp show a higher rate of potential survival. These results are paralleled in the tag and recapture data where 6 of 28 (21.4%) of the scamp tagged from below 62 m have been recaptured. Nevertheless, given this low potential survival, it is unlikely that the long-term survival rate for scamp would be high enough to impose an effective minimum-size rule for this species. Even though scamp evidently survive the significant decompression from below 62 m much more frequently than red grouper, the trauma of capture seems to contribute to a high initial post-release mortality.

One final interesting point arising from a review of these two data sets for deep-caught scamp is the evident efficiency of the fishery for grouper on the offshore patch reefs from which these fish were taken. Considering a minimum initial post-release mortality of between 67 and 70% for scamp caught below 62 m, only 9 or 10 of the 28 fish tagged and released would be expected to survive more than a few days. Of these, no fewer than 6 (60%) were recaptured within 768 days. One fish moved 74, and the another 255, km from the tagging site. Although it is not our purpose to attempt an estimate of the size of the fishable scamp population in deep water off central west Florida, this extraordinarily high recapture rate from such a vast area suggests a very heavily exploited population for its size.

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