Release mortality of Gulf of Mexico greater amberjack from commercial and recreational hook-and-line fisheries: Integration of fishing practices, environmental parameters, and fish physiological attributes

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2013

SEDAR59-RD08

4 December 2018

Final Technical Report for

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Final Report for Cooperative Research Program
(NA09NMF4330147) (08/01/2009 - 07/31/2013)

29 October 2013

1.0 INTRODUCTION

Greater amberjack is widely distributed throughout warm temperate and tropical waters and is an important recreational and commercial fishery in the Gulf of Mexico (Browder et al. 1978; Burch 1979; Parrack 1993a,b; Manooch and Potts 1997; Thompson et al. 1999). The recreational catch for amberjack in the Gulf of Mexico has historically exceeded commercial hand-line/longline and headboat landings on a Gulf-wide basis (Berry and Burch 1977; Manooch and Potts 1997; Cummings and McClellan 2000; SEDAR 2006). For example, in 2004 the private and charterboat catches represented 59.5% of the total catch, with the commercial handline fishery constituting a further 35%; headboat and commercial longline catches were relatively minor at 3% and 2.5%, respectively (Clarke 2006, SEDAR 2006). Landings of greater amberjack peaked in 1986-89, declined through 1995 and remained at low levels until ~2000, after which landings increased again until 2003 but have since declined, especially in the recreational sectors (SEDAR 2006). Landings from the west coast of Florida and Louisiana have dominated commercial and recreational catches of amberjack in the Gulf (SEDAR 2006).

The most recent full stock assessment (SEDAR 2006) and update (SEDAR 2011) for Gulf greater amberjack concluded that Gulf of Mexico greater amberjack are overfished and experiencing overfishing. Stock assessment of greater amberjack in the Gulf is complicated by a lack of basic biological information, including mortality rates of fish released due to increasing regulatory restrictions. Currently, release mortalities for greater amberjack in the Gulf are unknown (SEDAR 2006). Estimates of acute release mortality (i.e., fish observed floating on the surface) have be reported opportunistically as 8-9% based on extremely small sample sizes from either headboat (1 out of 11 fish) or commercial handline (1 out of 12 fish) fisheries off the Atlantic coast (SEDAR 2006). With release mortalities unknown to date, it was assumed for the purposes of the stock assessment for Gulf greater amberjack in 2006 that amberjack would have greater release mortality based on long-term mortality, and an arbitrary base estimate of 20% release mortality was incorporated into the various stock assessment models (SEDAR 2006). Since then, various other studies in the South Atlantic have reported, opportunistically, observed discard mortality in greater amberjack varying from ~0% to 92%, with all but one study involving <100 fish (SEDAR 2008). Based on a lack of information on discard mortality for greater amberjack in the South Atlantic, the South Atlantic stock assessment of greater amberjack also used an arbitrary discard mortality rate of 0.2 (SEDAR 2008), consistent with the Gulf. Release mortality estimates have the potential to influence the outcome of a stock assessment and subsequent stock trajectory (Pollock and Pine 2007).

With minimum size limits increasing for greater amberjack for the recreational fishing sector in the Gulf, there has been a concomitant increase in discard rate of sublegal-sized fish. For the recreational private boats and charterboats, the number of greater amberjack discarded relative to the total catch is already fairly substantial, for example the ratio was 0.60 in 2004 and has varied between 0.44 and 0.87 from 1994-2004 (Diaz 2005). Estimating release mortality with increasing regulatory discards due to an increase in minimum size limits will therefore be even more important in future stock assessments.

Development of accurate estimates of release mortality requires a broad understanding of how capture stresses vary as a function of fishing practices, environmental parameters, fish size, and physiology, in addition to ecological factors such as distribution (Davis 2002; Rummer 2007). Mortality of discards can be grouped into three major categories: 1) physical injury resulting from hook damage, 2) barotrauma resulting from the rapid ascent of the fish, and 3) physiological stress resulting from the energetically demanding resistance to retrieval of the fish from depth (the fight).

Physical injury may be an important factor affecting survival of discarded fish. Delayed mortality can occur from hooking wounds and infected wounds (Muoneke and Childress 1994). Differences in hooking mortality differ greatly both with the types of hooks used as well as whether bait or lures are used (Diggles and Ernst 1997). Greater amberjack hooked in the stomach or in the gill arches are likely more prone to mortality through higher rates of bleeding. However, we have observed an otherwise healthy amberjack that had been previously caught and had a healed but broken gill arch hanging out through the operculum, indicating that some fish can survive an extreme injury. Typically, fish bleed more from gut and gill hooking than jaw hooking (Bacheler and Buckel 2004). Assessment of how the fish is hooked and relative return rates of amberjack hooked in different manners will help to clarify the contribution of hooking related to the issue of chronic mortality.

Extensive literature is available on the effects of rapid decompression from depth for fish lacking a duct from the swimbladder to the esophagous or gut tract (physoclistous fish) (Rummer and Bennett 2005; Rummer 2007). Rapid expansion of the swimbladder results from decompression of the gas in the swimbladder. Since the gas doubles in volume every 33 ft (10 m) decrease in depth, fish brought up rapidly from deeper depths experience the greatest problems. Species differ in their abilities to withstand rapid decompression.

The third factor, the physiological stress resulting from retrieval of the fish from depth, is perhaps best understood by the accrual of lactic acid or lactate in the white muscle. The issue of lactic acid buildup in muscle has been studied in wide range of fish taxa (Wardle 1978; Pickering et al. 1982; Van Ginneken et al. 2004). White muscle constitutes the majority of muscle mass and provides the majority of burst power used in fighting for most teleosts, including amberjack (Rome et al. 1993; Coughlin et al. 2004). It is this burst swimming that provides the majority of resistance during fishing. Unlike aerobic red muscle, white muscle obtains most of its adenosine triphosphate (ATP) required for muscle function from the glycolytic pathway, which results in the production of lactic acid (Hochachka and Mommsen 1983; Coughlin et al. 2004). Blood lactate levels, though routinely monitored in mammals, have not been shown to reflect muscle lactate levels in teleost fishes and remain relatively stable when muscle lactate levels are high. Thus, while white muscle may contain ~30-40 mmol/ kg of muscle tissue, lactic acid concentration in the blood remains stable at extremely low levels (Wardle 1978). This disjunct between white muscle and blood lactic acid levels is due to the poor vascularization of anaerobic tissues (i.e., the white muscle), a catecholamine-regulated retention of lactate by the muscle itself preventing the dumping of lactate into the blood, the compartmental organization of fish axial musculature, and the resulting slow rate of diffusion of lactate from white muscle to the vascularized lateral aerobic red muscle (Wardle 1978; Van Ginneken et al. 2004). The accruement of lactic acid may be further exasperated by how the fish is handled on deck prior to release, as well as the temperature related metabolic demand of the fish. The most probable mechanism by which lactic acid contributes to morbidity and delayed mortality is likely through the physiological decrement in the fish's ability to swim while substantial proportions of the muscle are in tetanus (fish out of water). Such fish would also probably be more susceptible to predation once returned to the water. Glycogen concentration in muscle can be indicative of the energy reserves available for glycolysis and thus anaerobic metabolism in the white muscle (Wardle 1978). Two moles of lactic acid are produced for each mole of glucose from glycogen thus it is predicted that fish that have high levels of lactic acid in the muscle tissues will have depleted levels of glycogen (energy). Knowledge of the values of these physiological parameters may yield insight into what levels are associated with high acute and chronic mortality.

Generalized Linear Models (GLMs) are commonly applied to determine the effects of operational fishing factors (e.g., gear type, season) on release rates and release mortality. However, other external factors, such as the environment (i.e., temperature) and internal factors, such as incidence of stomach eversion, can influence release rates and mortality in fish stocks that are comparable to fishery factors (Jurado-Molina and Livingston, 2002). Incorporating environmental and physiological variables into operational models of release mortality may provide a more comprehensive view of the problem and suggest alternative management scenarios.

1.1 GOAL AND OBJECTIVES:

Our overall goal was to examine the release mortality of greater amberjack (*Seriola dumerili*) in recreational and commercial handline fisheries in the Gulf of Mexico ("Gulf") and to use an integrated approach to determine the effect of fishing practices (e.g., gear type and capture features), environmental parameters, and physiological attributes of the fish on release mortality rates. The specific objectives necessary to accomplish this goal are:

1) Determine acute and long-term release mortality rates for Gulf greater amberjack from recreational and commercial hook-and-line fisheries. Identify fishing practices contributing to release mortality.

2) Determine the primary morphological and physiological correlates of release mortality, including hooking trauma, barotrauma, and physiological indicators of relative stress, such as lactic acid morbidity.

3) Model release mortality as a function of morphological, physiological, and environmental factors.

2.0 METHODS

2.1 Study Area

Greater amberjack were captured and released in four primary areas within and adjacent to the Gulf of Mexico during 2009-2013: the northwestern Gulf (NW Gulf, primarily Louisiana), northeastern Gulf (NE Gulf), eastern central Gulf (EC Gulf), and southeastern Gulf (SE Gulf, mainly southern Florida and the Keys) (Fig. 1).

All amberjack caught and landed were measured for fork length (FL) and fate of the fish was recorded (kept or discarded/released). Basic characteristics of the fishing practices were also recorded for each fish and included: capture date, time, location, water depth (bottom depth, as well as depth when hooked-up if possible), gear type (rod hook-and-line, bandit gear), lure type (live bait, dead bait, artificial lure), and hook size and type (e.g., J-hook, circle hook).

2.2 Acute release mortality

Acute release mortality was measured immediately on landing the fish. If a fish exhibited no gill movements and no body movements then it was considered to be "dead-on-deck" and scored as a mortality. The number of amberjack suffering acute mortality was recorded based on fishing characteristics given above, as well as environmental factors such as depth of water and water temperature.

2.3 Long-term Release Mortality via Tagging

To estimate long-term release mortality, fish captured and then released were tagged with a heavy duty anchor tag (Hallprint PDAT anchor tags) using a stainless steel needle applicator through the dorsal musculature. The tag was applied so that it locked firmly between the pterygiophores below the base of the second dorsal fin (Williams 1992) (www.dnr.sc.gov/marine/pub/ seascience/tagfish.html). Approximately 5% of released fish were to be double tagged to estimate tag loss (Gulland 1963; Seber and Felton 1981; Xiao 1996; Cadigan and Brattey 2003). Each tag carried a printed label with "Reward", the fish number, return information, and the program's website.

Tags were recovered by recreational and commercial fisherman, as well as our own efforts during onboard sampling and tagging throughout the duration of the study. Each tag reported was followed up with a directed telephone call in an attempt to obtain all relevant fishing and environmental information. Data requested with each recapture of a tagged fish included the tag number, capture date, capture location (GPS coordinates if possible), capture depth, fish FL (known as measured or only estimated), fish weight when possible (known as weighed or only estimated), as well as a contact name, phone number, and address. All returned tags were rewarded by either a tagging program coffee cup or baseball cap. In addition, tags returned with tag number, recapture date, and recapture location, and optionally, depth, and length data, were entered into a random draw on a quarterly basis ($100 reward) and an annual basis ($500). These higher tag rewards were meant to increase the potential rate of tag returns and reporting (Pollock et al. 2001) without overcommitting funds for tag rewards prior to knowing the tag return rate for greater amberjack.

2.4 Release Mortality Factors: Fishing Methods and Gear

Data relating to hooking location and trauma was assessed immediately on landing the fish. Gear type (rod hook-and-line, bandit gear) was recorded for each fish, as well as information on lure type (live bait, dead bait, artificial lure), hook size, and hook type (e.g., J-hook, circle hook). Hooking parameters recorded included hook position (corner of mouth, dentary or maxilla, roof of mouth, tongue, esophagus/throat, gills, stomach or body), and hooking wounds with and without bleeding.

Fishing profiles, including depth of capture, water temperature, and rate of ascent (depth/duration of ascent following hook-up) were recorded using Sensus Ultra Data Loggers (Reefnet, Mississauga, Ontario) (Figure 2) attached to the fishing lines for a subset of fish captured. The Sensus tags record depth ± 1 cm and temperature ± 0.1 C (Figure 3). Rate of capture was assessed using the mean rate of ascent (depth/duration of ascent following hook-up). Hook-up time, fight time (time between hook-up and landing), and handling time on deck (difference between landing time and release time) were measured for individual fish that were caught while specific fishing activity was timed using a stop watch. Ascent profile and fight time were related to indices of physiological health assessed at the surface (e.g., activity levels, and blood and muscle lactate), as well as subsequent survival rate, as determined by recaptures.

Any observed predation of amberjack when released was noted, although this was not an objective of the project and should be treated as opportunistic observations.

2.5 Release Mortality Factors: Physical Barotrauma Indicators

On landing, fish were assessed for overt signs of barotrauma, including stomach protruding out of the mouth, intestine or gonads protruding from anus, turgid swimbladder (externally visible), protruding eyes ("pop-eye"), or eyes that were cloudy or showed subsurface air bubbles. General physical activity of the fish on the deck was also assessed as: 1) dead, no gill or body movements; 2) tetany, stiff as a board or no body or tail flapping, but gill movement; 3) weak (quiescent) body and tail movement; or 4) vigorous body and tail movement, still fighting. The occurrence of bubbles flowing freely from the underside of the opercula of individual fish on ascent was also noted. This was only possible to assess when surface conditions were calm.

Prior to release, a subsample of amberjack were vented using a venting tool. Only fish exhibiting turgid swimbladders were vented. General level of activity was also recorded when the fish was released back into the water as: 1) dead, no gill or body movement, floating at surface or immediately sinking with no movement; 2) alive, but floating at surface; 3) alive and able to right itself and swim slowly down; and 4) alive and able to right itself and swim vigorously down) (modified from Rudershausen et al. 2007).

2.6 Release Mortality Factors: Physiological Parameters

Blood lactate levels were measured on a subsample of amberjack in the field, and a subsample of those fish were also sampled for muscle lactate. For blood lactate, a small (<0.3 ml) blood sample was taken from the branchial artery of the first gill arch using a 1.0 ml tuberculin syringe. Blood L-lactate level was determined in the field using a lactate meter (Lactate-Pro). Attempts to measure blood glucose using a glucometer (One Touch Ultra) in the field was unsuccessful. Muscle samples for muscle lactate levels were taken using a dermal biopsy punch (Miltex® 1.0 mm) in the white muscle below the second dorsal fin, and between the lateral line and dorsum. This ensured that red muscle along the lateral line was not sampled in the biopsy. The sample was immediately frozen on dry ice in the field and then stored in a -80C ultracold freezer before being processed using a L-lactate analysis kit (Eton Biosciences). To do this, muscle tissue was homogenized using sonication and extracted with undenatured ethanol (80%) and a tissue to ethanol ratio of 1:8. Homogenate was allowed to sit for 1 hr at 4°C, to facilitate extraction of the L-lactate, followed by centrifugation at 10,000g for 5 min. Serial dilution was used to ensure samples were within the range of the L-lactate standard solution curve. Lactate measurements were quantified colorimetrically using a Bio-Tek Elx 800 UV Microplate Reader at 490 nm.

2.7 Modeling Release Mortality as a function of Fishing Practices and Barotrauma Assessment

Factors potentially related to release mortality were modeled as a function of recapture rate using General Linear Models (GLM). Base models included those associated with fishing practices (e.g., hook type), environmental variables (e.g., capture depth and water temperature) and barotrauma and physiological indicators (e.g., turgid swimbladders, lactic acid levels). General Additive Models (GAMs) were not used as input into a General Regression Analysis and Spatial Prediction (GRASP) model (Lehmann et al. 2002) because of the lack of variability in the factors contributing to recapture rates. This is deliberated on further in the results and discussion.

3.0 RESULTS

3.1 Tagging and Release

In total, 1,602 amberjack were captured, measured, assessed for acute mortality, and then tagged and released from the four major tagging areas (Figure 4A). Fish captured and released ranged from 22.6 to 141.2 cm FL. Length distributions of tagged and released greater amberjack from the west coast of Florida (EC Gulf) and the northern coast of Florida (NE Gulf) were similar (Figure 5), with fish in Louisiana (NW Gulf) more evenly distributed over all sizes; amberjack in the southeastern Gulf (south Florida and the Florida Keys) had a markedly larger length distribution, presumably due to sampling mainly the spawning aggregations of greater amberjack.

Emigration from tagging regions was observed in all groups except in fish tagged and released in Louisiana, with fish moving to Louisiana from north and central Florida, as well as from central Florida to south Florida (Figure 4B). Some fish made exceptionally long movements, such as from central Florida to Port Maria, Jamaica, and from Apalachicola to Tampico, Mexico.

3.2 Acute release mortality

A total of 4 out of 1,602 (0.25%) greater amberjack suffered acute mortality (i.e., dead on deck). Three of the four dead-on-the-deck fish were caught on “J” hooks at depths greater than 100 ft (115-210 feet), while the forth was caught on a baited “J” at 54 ft.

In total, 1,598 amberjack were released alive for this release-recapture study. Of these fish, 2 (0.12%) were observed directly to be consumed by a mako shark *(Isurus oxyrinchus)* and a barracuda (*Sphyraena barracuda*) on release. Incidentally, two other amberjack were observed to be lethally injured by barracuda near the boat before they could be brought on board. One other amberjack caught had a healed injury consistent with a barracuda attack in which most of the epiaxial musculature behind the first dorsal fin was missing. Skin had re-grown over most of the wound.

Two (0.12%) amberjack were observed to be eaten at the surface by Goliath grouper prior to being able to be removed from the water for tagging purposes. Five (0.31%) amberjack were grabbed by goliath grouper (*Ephinephelus itajara*) directly while being brought onboard for tagging but were still tagged and released as the amberjack were physically unharmed other than minor scraps on their sides. On one occasion, three Goliath grouper simultaneously chased one amberjack to the surface (from 55 ft) in an unsuccessful attempt to capture it, the Goliath grouper volitionally following the amberjack from the bottom to the surface. The occurrence of Goliath grouper interacting with greater amberjack once hooked could be noticeable because Goliath grouper are so large and because both species occur around vertical structure, such as wrecks.

3.3 Long-term Release Mortality estimated through Tagging and Recaptures

A total of 77 fish (4.82%) were double tagged to assess tag loss for released fish. As of October 2013, 12 double-tagged fish have been recaptured with 11 confirmed to still be carrying both tags. The twelfth fish may have also had both tags but this could not be confirmed because we were unable to reach the fisher again to confirm whether there had been a second tag on the fish. Tag loss could therefore be as low as 0% or possibly as high as 8.3% (1 out of 12 tagged fish). Therefore, for the purposes of our analysis, it was assumed that there was no tags lost from any of the fish released (i.e., all fish released were potentially available for recapture).

Of the 1,598 amberjack released alive after tagging, 210 have been recaptured (13.14% recapture rate overall) (Table 1). Recapture rate varied between sampling regions and was highest in Louisiana and south Florida (22-25%) compared to recapture rates in central and northern Florida (7-8%).

3.4 Capture Correlates of Release Mortality: Fishing Methods and Gear

Season of Release: Overall, recapture rates of greater amberjack were higher for fish released during the Summer (April to September) (16.04%) compared to fish released during the Winter (October to March) (10.01%) (χ^2 = 12.48; P=0.0004).

Depth of Capture: Depth of initial capture versus recapture of greater amberjack (Figure 6) showed that the percentage of amberjack recaptured based on 50-ft depth categories was significantly different (χ^2 = 29.7499, P = 0.001). The greatest chi-square deviations were due to the 50-100 ft and the >200 ft depth categories and removal of these depth categories from the contingency table indicated that the remaining depth categories had similar proportions of tagged fish recovered (χ^2 = 3.2266, P = 0.5206). The percent tagged by depth was greater or similar to the percent recapture for all except the deepest depth categories (>200 ft), where the percent recaptured exceeded the initial percent tagged from that depth. This indicated that greater amberjack were not suffering increased release mortality with increasing depth of capture, and that fish caught in depths exceeding 200 ft were surviving, most probably due to these fish being vented (see below).

There was no differences in the recapture rate from different depth intervals for non-vented fish (Figure 7) (χ^2=4.9621, P=0.2923). However, the percent of recaptures of vented fish increased significantly with increasing depth categories >150 ft (χ^2=7.0562, P=0.0294) (Figure 7). This indicated that a depth threshold existed whereby amberjack benefitted from venting, as was described above for amberjack caught in excess of 200 ft.

The observation that amberjack caught deep survive when vented was supported by a complementary study where five large, reproductively mature amberjack were tagged with miniature pop-up satellite tags. The fish were all tagged at depths between 150 and 350 ft, tagged, vented, and released. All five tags successfully reported (popped off and came to the surface) after a 45 day deployment period, directly indicating that these large fish suffered no mortality (i.e., were “recaptured” by their pop-up tags).

Hook Type: Overall, recapture rate was lower for amberjack caught using J-hooks compared to C-hooks (χ^2=18.148, P=0.0001) (9.68% versus 16.56%, respectively) (Figure 8) when inclusive of fish captured using both recreational and commercial hook-and-line gear. With concern over commercial vessels using bandit gear being able to fish on specific tagging sites following the spawning aggregation in the Florida Keys, we subsequently excluded commercial bandit gear from this area in the analysis to see the effect. This decreased the recapture rate of circle-hooked fish to 12.63%, which was not significantly different from the recapture rate of J-hooked fish ((χ^2=2.8206, P=0.093).

There were significant differences in recapture rates between J- and C-hooks based on various hooking positions (χ^2=57.11, df=6, P<0.0001), and subdividing the contingency table showed that hooking positions in the corner of the mouth, bottom of the mouth, top of the mouth, and gut were not different between J- and C-hooks (χ^2= 4.82, df=3, P=0.185). Most differences were due to J-hooks having a higher incidence of hooking amberjack on the body, gills, and head compared to hooking positions of C-hooks. In contrast to both circle and J-hooks, fish caught on treble hooks show a disproportionately low tag return rate, with no tagged and released fish recaptured to date (Figure 8).

Although not statistically significant, the overall trend in the recapture rate of amberjack hooked in the corner of the mouth and bottom of the mouth was higher (12.5% and 14.1%) compared to their recapture rates when hooked in the gut (3.3%) or the top of the mouth (5.5%) (χ^2=7.15, df=3, P=0.067).

Ascent Rates: Ascent rates obtained using Sensu Temperature-Depth profiles varied among fish, with fish typically fighting through at least two ascent/descent dives prior to a final ascent to the surface before being landed (Figure 9). The mean instantaneous ascent rate was $0.46 \pm 0.17\ m \cdot s^{-1}$, with a mean maximum observed ascent rate of $1.83 \pm 0.53\ m \cdot s^{-1}$. The highest observed instantaneous ascent rate was $2.66\ m \cdot s^{-1}$.

3.5 Capture Correlates of Release Mortality: Physical Barotrauma Indicators

Eversion of stomach and intestine: Of 545 fish assessed for the presence or absence of an everted stomach, only 3 had everted stomachs (0.55%). One of these fish was caught at 54 ft, 1 at 100 ft, and 1 at 315 ft. No amberjack were observed to have everted intestines (0%, n= 544 fish assessed for everted intestines).

Eye Damage: Eye damage was observed in 2 of 544 fish (0.37%). This damage resulted from being directly hooked in the eye. Separation of the cornea from the overlaying dermal layer giving the eye a crystalline appearance or popeye was not observed at all during the study.

Turgid Swimbladders: Although almost half of all amberjack had turgid swimbladders on capture (54%) (Figure 10), only rarely were they over-inflated, i.e. causing eversion of the stomach (<1% of fish). The percentage of amberjack landed with turgid swim bladders increased significantly with depth (χ^2 =27.40, P=0.0001, df = 4); ~50% for capture depths of 0 to 150 ft, then increasing with increasing depth of capture (Figure 10). However, exclusion of fish captured at depths greater than ≥ 200 ft made this relationship non-significant (χ^2 = 5.87, P = 0.1181, df =3), indicating a threshold for this relationship at water depths >200 ft. Two factors that appeared to contribute to the lack of a problem with over-inflation of the swimbladder appeared to be buttressing of the swimbladder by the ribs, which are substantial and in direct contact with the swimbladder, thus providing physical support (struts) for the swim bladder (Figure 11). Secondly, greater amberjack appear to have a self-venting mechanism for their swimbladder (below).

Self-venting Mechanism: The swimbladder of greater amberjack was observed to be in close contact with the supracleithral/post-temporal bones, with only a thin layer of tissue present in this region. Ascending greater amberjack were observed extruding bubbles from this region, with a small hole present in the area from fish seen to blow bubbles (Figure 12). From the inside of the swimbladder, single small tears of 2-5 mm diameter were observed in fish that extruded bubbles on ascent (Figure 11). Fish that extruded bubbles on ascent were also found to have an intact swimbladder that remained inflated *post-mortem*, indicating that the extruded bubbles were not due to the swimbladder rupturing during ascent.

The percentage of fish blowing bubbles on ascent increased significantly with capture depth ($\chi^2 = 192.09$, $P = 0.0001$, 4 df), with >50% of fish self-venting at depths >100 ft (Figure 13). Over 90% of amberjack self-vent when captured from depths in excess of 200 ft.

Despite having a self-venting mechanism, most amberjack caught at depths of >200 ft needed to be vented to allow the fish to re-descend (Figure 14); this is in keeping with the depth threshold observed for fish with turgid swimbladders and a high preponderance of bubble blowing. Seven amberjack that were caught at depths between 225 and 325 ft and not vented were observed on the surface for 10 minutes to see if they were able to volitionally descend from the surface. These fish were not able to descend and it was apparent that any self-venting mechanism was not sufficient to offset the expanding swimbladder in fish caught at depths >200 ft.

Activity Patterns: Body and tail flapping was assessed for 453 fish brought on to the deck. Amberjack that were captured at depths of <200 ft had no visible signs of having muscle tetany, whereas 19% of fish caught at depths >200 ft (n=48) were “stiff-as-a-board” with no apparent muscle flexion. In addition, although 84-93% of fish showed some body and tail movement at all depths of capture, the percentage of fish showing vigorous activity on the deck decreased markedly at capture depths >100 ft (Figure 15), with the concomitant increase in fish with weak or moderate activity with increasing depth of capture.

In addition, relative swimming ability was qualitatively assessed when amberjack were released as either slow swim down or vigorous swim down. Although most fish swam down vigorously overall (76-92% of 350 fish assessed), it was apparent that a higher percentage of fish captured at >200 ft swam down more slowly (~36%) upon release than fish captured at shallower depths (~14% overall) (Figure 16).

Fight Duration: On-vessel monitoring of recreationally caught fish determined that the average fight duration for greater amberjack was 118.76 ± 108.2 sec, with a median fight duration of 96 sec. Fight duration was not well correlated to depth due to variability encountered at all depths (Fig. 17). In contrast, the relationship between fight duration and size of fish was correlated, a function of larger fish being more difficult to land (Fig. 18).

Vigorous activity of amberjack on the deck decreased with increasing fight duration (Figure 19), visually indicating that fish were tiring with increasing fight times.

3.6 Capture Correlates of Release Mortality: Physiological Parameters

Lactate: Blood lactate concentration was related to fight duration, but the relationship was relatively weak (Fig. 20). Muscle lactate concentration had no relationship with fishing fight time (Fig. 21). The overall low observed levels of L-lactate may be indicative of the aerobic nature of this particular species. This was evident in the extensive and thick layer of red muscle overlaying the white musculature of greater amberjack.

Recapture rates of amberjack were not affected by sampling the fish for blood lactate (χ^2=2.045, df=1, P=0.153) but were affected by sampling the fish for muscle lactate (χ^2=12.37, df=1, P=0.0004). It may not be the sampling type that is affecting the recapture rates but the amount of time taken in doing the sampling since muscle lactate samples are taken after blood lactate samples and not all fish are sampled for both.

3.7 Modeling Release Mortality as a function of Fishing Practices and Barotrauma Assessment

General linear models were mostly non-informative in relating the recapture rate to fishing practices, or physical and physiological barotrauma indicators.

One factor that was significant was that amberjack had higher recapture rates when vented versus not vented (F=17.42; P<0.0001), indicating that even with a self-venting mechanism, fish that visually have turgid swimbladders (mostly fish captured at >150 ft) need to be vented (and survive the venting procedure).

Many external indicators related to barotrauma were encountered so infrequently that data was not sufficient to test for an effect on recapture rate, for example, everted stomachs, intestines, and gonads, or damage to the eyes. Body and tail movement were non-informative (F=0.32; P=0.569), as was the occurrence of turgid swimbladders (F=0.46; P=0.497).

Recapture rate was also not related to physical or physiological barotrauma factors present on release, including the amount of time amberjack were on the line fighting (F=0.01; P=0.911). This was also reflected in the lack of a relationship between recapture rate and either blood lactate concentration (F=0.94; P=0.335) or muscle lactate concentration (F=2.42; P=0.121). With both of these latter relationships, the trend was towards lower probability of recapture with increasing lactic acid concentrations, although not significant. It was difficult to get blood and muscle lactic acid concentrations in the high end and the narrow range of concentrations may have impeded this analysis.

One factor that was weakly linked to recapture rate was the interaction between capture depth and tagging month (F=6.09; P=0.0004), due to the deeper depths that amberjack were captured (and released) during the months that they aggregate (March-May) (Figure 22). However, this relationship was very weak (R^2<0.10) and it was positive, i.e., higher probability of recapture with deeper capture depth. It was also not related to surface temperature at capture because recapture rate was not related to surftemp at capture and release ($F=1.23$, $P=0.295$). In general, this was the opposite relationship that one would expect for physoclistic reef fishes. However, the self-venting mechanism of greater amberjack, in combination with survival after venting, combined to give high survival of released fish.

4.0 DISCUSSION

The greater amberjack stock in the Gulf of Mexico is considered to be overfished and for overfishing to still be occurring, and with increasing regulations there is the concern that there will be a concomitant increase in discarded (released) fish due to minimum size regulations, bag limitations, and closed seasons. This scenario has been observed in other major reef fish stocks, such as gag, red grouper, and red snapper, where the release mortality of the species exceeds the harvest. However, although greater amberjack are managed as a “reef fish”, they do not have all of the typical characteristics of reef fishes that create management concerns when the stock is heavily regulated by bag, minimum length, and seasonal closures. The single most important release factor for most reef fish is the depth of capture, since increasing depth is correlated with increased mortality due to barotrauma. This is because most reef fishes have a closed swimbladder (physoclistous condition) and gas within their swimbladders expands on ascent, causing morphological and physiological problems for the fish. Greater amberjack is also considered to have a closed swimbladder, similar to most other reef fishes (including the groupers and the snappers). However, during this study, greater amberjack were discovered to have a “self-venting” mechanism unheard of in other physoclistous reef fishes. This self-venting mechanism consists of a membranous pathway from their swimbladder to the base of their operculum, and is only freely open when the fish is actively venting. Amberjack brought up from deeper depths (usually greater than 100 ft) are observed to have bubbles flowing out from under their opercula on ascent, and on the deck it is possible to hear the excess gas escaping from the opercular region. These same fish have intact (i.e., inflated) swimbladders on necropsy, clearly indicating that their swimbladders have not ruptured during ascent. Since our study begin, a study in Australia has also found the same type of self-venting mechanism in a related species, the Samson fish (*Seriola hippos*) (Rowland 2009). Although not directly comparable because Rowland (2009) did not using venting as a release method, he also found that Samson Fish had much less problem with barotrauma than other fishes, and that they display no post release mortality due to neuroendocrine responses. For a subset of fish, Rowland did observe 3-15% rupture of swimbladders of Samson Fish at depths between 110 m and 195 m (not necessarily mortality).

Venting does appear to assist greater amberjack when captured from deeper depths, usually deeper than 150 ft. Amberjack would be difficult to assist in their descent after capture using descending devices that lip-grip the fish because they are very powerful swimmers, even if for just bursts at the surface. We have used the Shelton Descender successfully with amberjack since the device physically “re-hooks” the fish until it is released at depth. However, amberjack may be a good candidate for venting because their swimbladder is tough and is buttressed by its ribs. This provides support for the swimbladder during the venting process.

Overall, greater amberjack survive capture and release seemingly much easier than most other reef fishes. This may be because they are really semi-pelagic, and although they aggregate around structure, similar to reef fish, they also use the water column from the surface to great depths in a matter of minutes. They have rapid ascent rates even when caught during fishing and use they use the entire water column when fighting. Typical signs of barotrauma occurred very infrequently in greater amberjack, including a low incidence of acute mortality, and low stomach, intestine, and gonad inversion rates. In addition, we did not observe one case of popeye in a greater amberjack, or any separation of the cornea from the overlaying dermal layer giving the eye a crystalline appearance. This was of interest because like many fish possessing a pseudobranch, choroid rete and the Root effect in the blood hemoglobin, it is likely that oxygen levels are maintained near saturation in the tissues of the eye and should thus be subject to rapid decompression (due to ascent) and baurotrama. However, pathologies of the eye due to rapid decompression of greater amberjack were not observed throughout the study. This is in stark contrast to red snapper (*Lutjanus campechanus*) where pathology of the eye was a primary correlate with hooking mortality for a recent study on red snapper by Diamond and Campbell (2009).

Physiologically, the low observed levels of L-lactate may be indicative of the aerobic nature of this particular species. This is evident in the extensive and thick layer of red muscle overlaying the white musculature. In addition, the lack of relationship between blood and muscle lactate levels likely arises from the relatively poor circulation in mitochondria-poor white muscle, where anaerobic processes such as glycolosis provide ATP. Analysis of blood glucose is on-going but suggests concentrations are extremely low, in the range of 3-4.4 mg/dl. This is an order of magnitude lower than has been previously observed for some species of fish.

These observations indicated a high acute survival rate for greater amberjack for some handline fisheries, and initially depth of capture and decompression does not appear to be a major factor in release or discard mortality. There are several possible explanations as to why acute barotrauma may not be high in amberjack. First, greater amberjack cannot be brought up as quickly to the surface as other fish, such gag grouper or red snapper, because they energetically resist being brought up (hence their attribute of being great fighting fish). This may give the fish time to re-absorb oxygen from the swimbladder into the blood stream. Second, the membrane of the swimbladder is very thick in amberjack and is internally baffled (pers. obs.), and would provide greater structural support. Finally, the occurrence of the self-venting mechanism is the main contributor to off-gassing of the excess gases expanding in the swimbladder.

5.0 ACKNOWLEDGEMENTS

As with any tagging study, we were dependent on both commercial and recreational fishers returning tags and we are especially grateful to all of those that returned tags with information that could be used in this study. We thank the Louisiana Department of Fisheries and Wildlife for offering logistical assistance on tagging trips to Louisiana. Thanks also to Captain Myron Fischer (Cut-Off, LA; presently of the Louisianna Department of Wildlife and Fisheries), Captain Mark Hubbard (Madeira Beach, FL), Captain Ron Meyers (Little Torch Key, FL), and Captain Clay Bailey (Apalachicola, FL) for sharing their expertise in fishing for greater amberjack. Thanks go to the Gainesville Offshore Fishing Club for participating in tagging amberjack. This study required substantial field and laboratory support and we greatly appreciated the assistance of Geoff Smith, Doug Colle, Woody Miley, John Hargrove, Felipe Carvalho, and Chelsey Campbell.

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Table 1. The total number of greater amberjack (*Seriola dumerili*) tagged by sampling region and the percentage that were recaptured (n = 210).

	Sampling Region			
	South Florida	Central Florida	North Florida	Louisiana
# Tagged	261	550	501	286
# Recaptured	65	44	37	64
% Recaptured	24.90	8.00	7.38	22.38

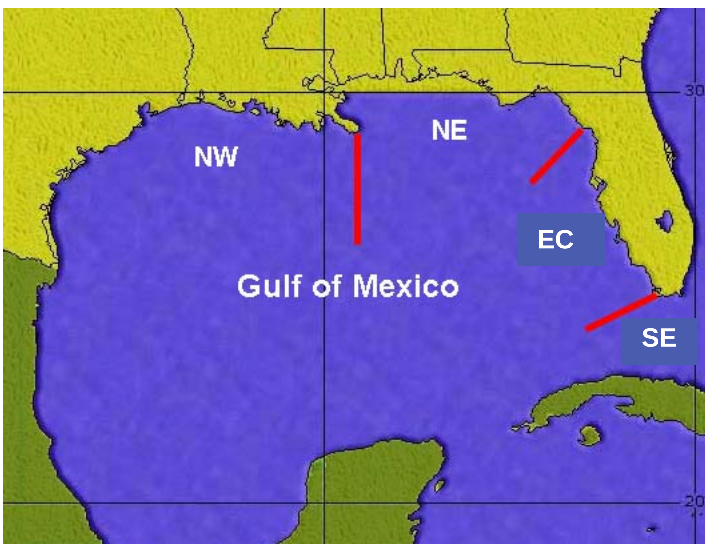

Figure 1. General sampling areas for tagging, and potential tag recoveries, for greater amberjack, including off the coast of Louisiana in the northwestern Gulf of Mexico (NW), in the northeastern Gulf (NE), eastern central Gulf (EC), and southeastern Gulf (SE, mainly south Florida and the Keys).

Figure 2. Sensus Ultra Archival tags were attached to the fishing lines to record capture depth, ascent profiles, and water temperature, which were used as correlates to release survival in tagged greater amberjack.

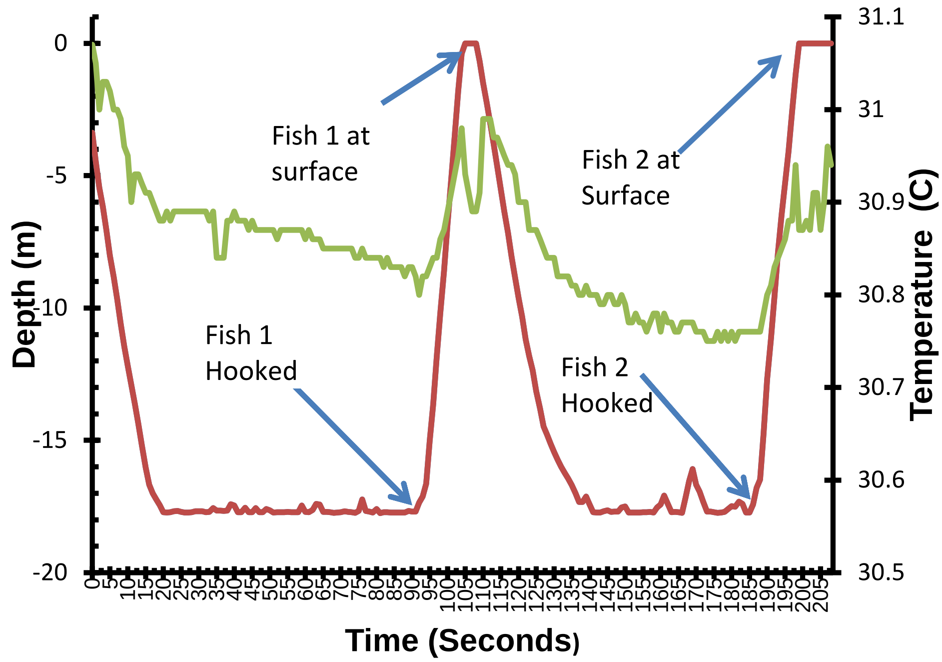

Figure 3. The ascent profile of two greater amberjack captured and brought to the surface along with the associated ambient summer water temperature in the Gulf of Mexico.

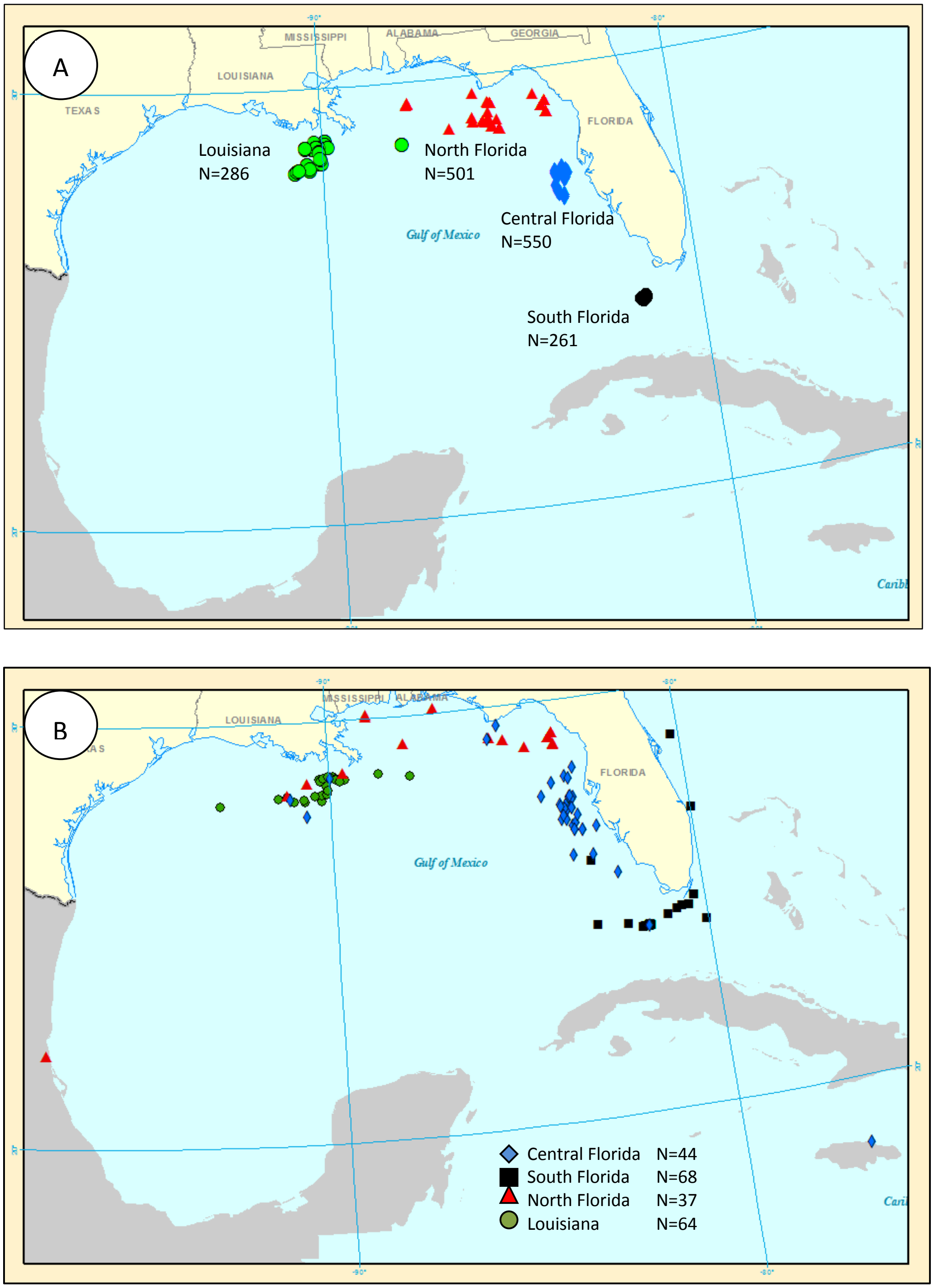

Figure 4. A) Tagging locations of greater amberjack captured and released alive; and B) recapture locations of greater amberjack. Not all recaptured fish were returned with location coordinates and therefore are not plotted. Note the recaptures in Jamaica and Mexico.

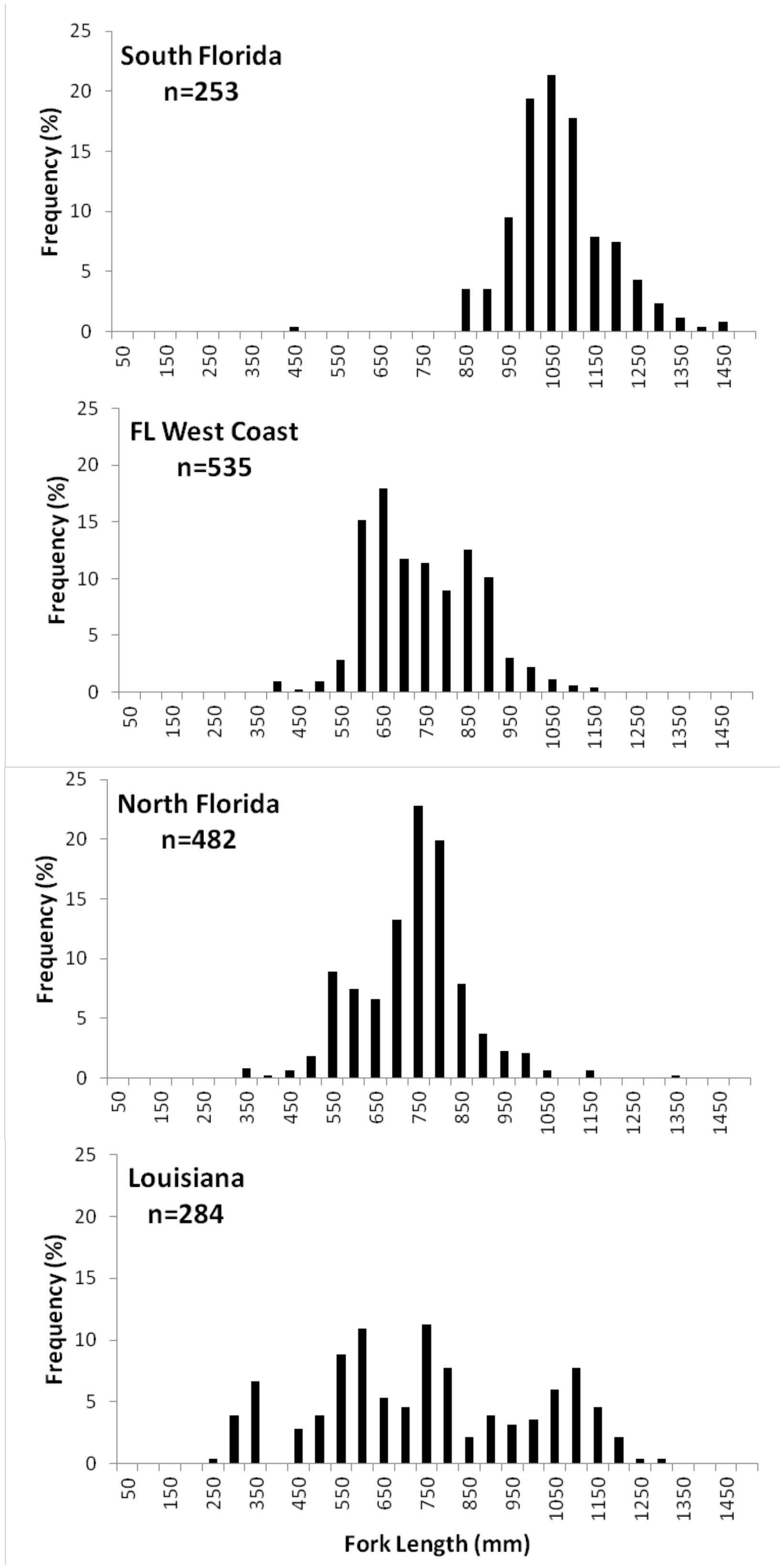

Figure 5. Length frequency distribution for greater amberjack tagged and released from four primary tagging areas.

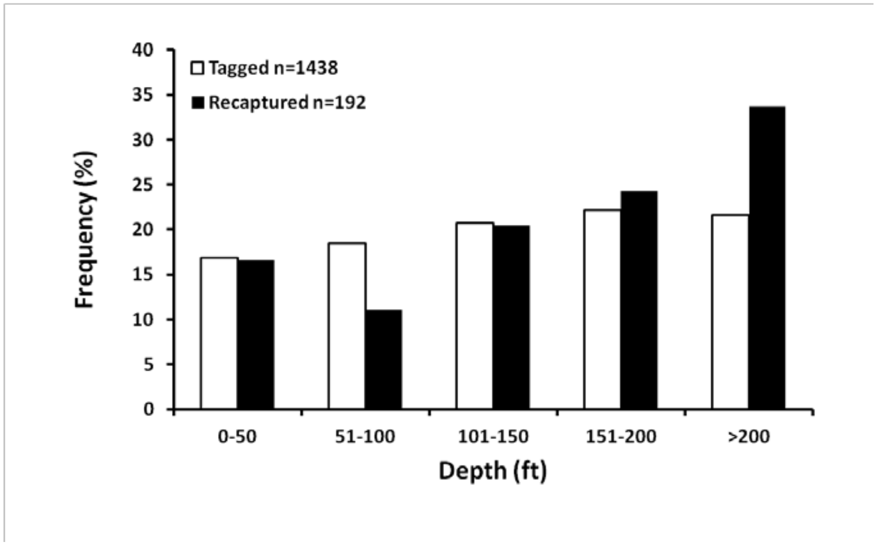

Figure 6. Frequency of tagged and released (white bars) and recaptured (solid bars) greater amberjack based on depth of initial capture.

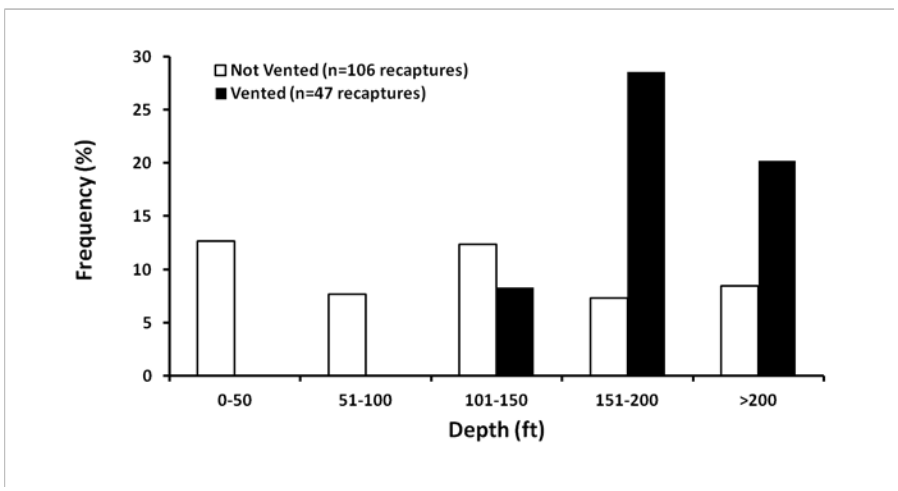

Figure 7. Frequency of released and recaptured amberjack that were not vented versus vented based on depth of initial capture.

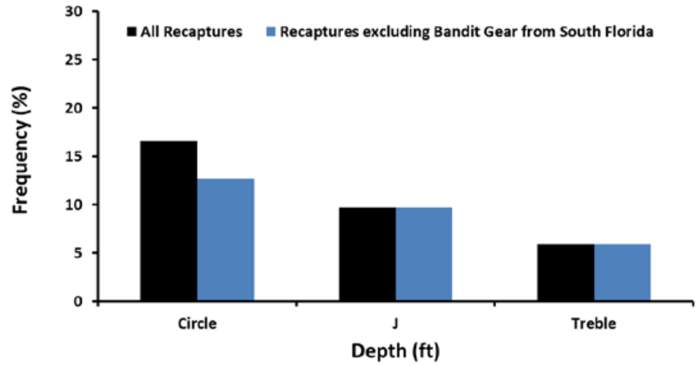

Figure 8. Recapture rate of greater amberjack as a function of hook type used in initial capture when all recaptures were used versus exclusion of commercial bandit-gear in South Florida fishing immediately after the spawning aggregation closure.

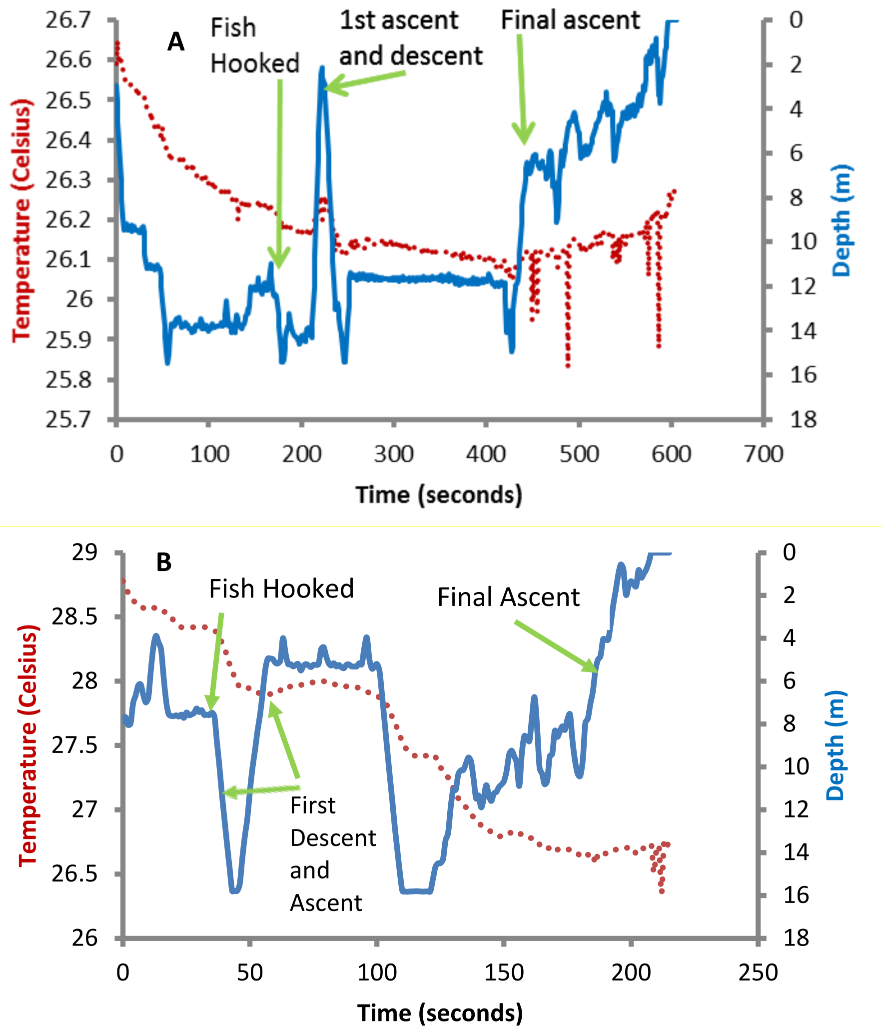

Figure 9. The dive/ascent profiles of a A) 1021 mm FL and B)730 mm FL greater amberjack captured and brought to the surface, along with the associated ambient water temperature in the Gulf of Mexico (measured using a Sensus Ultra temperature-depth recorder). Acquisition rate of data was an average of 4 samples per 1 sec interval.

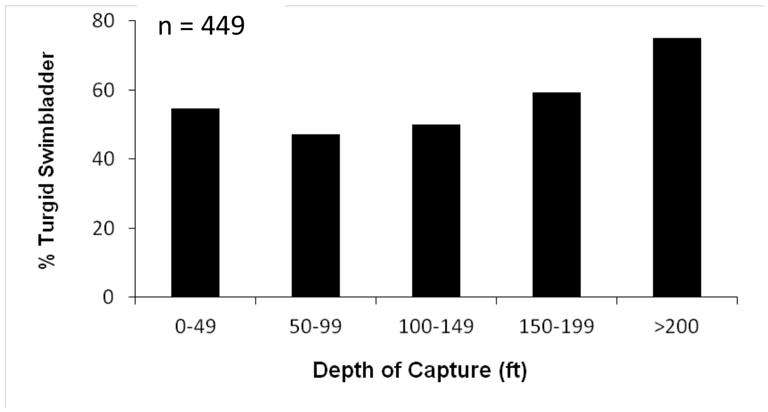

Figure 10. The percentage of greater amberjack landed with turgid swimbladders by depth of capture.

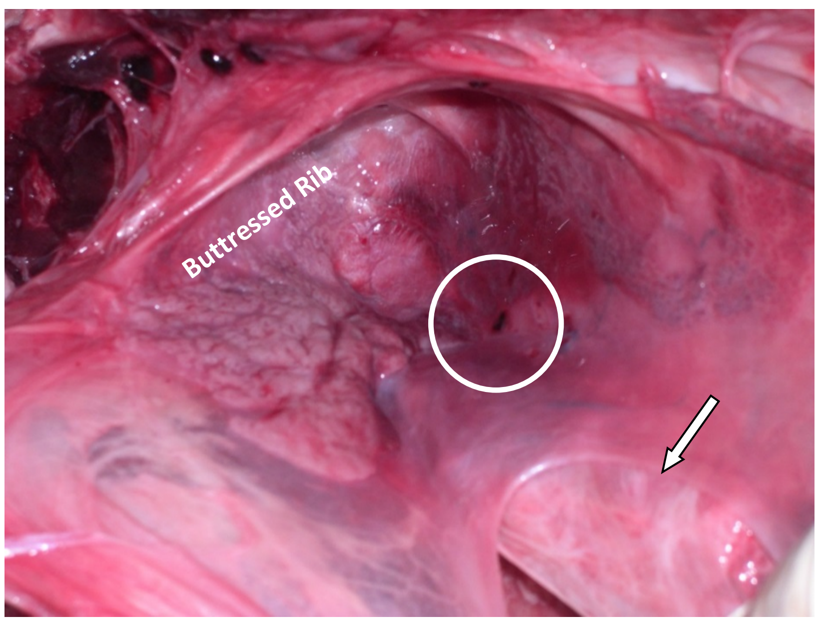

Figure 11. Inside view of the anterio-dorsal portion of a swimbladder from a greater amberjack that self-vented on ascent. A tear in tissue in anterior portion of the swimbladder at the supracleithral bone as viewed from inside the bladder (enclosed by the circle). This is the source of gas bubbles coming out of the operculum of fish being brought to the surface. The relaxed edge of the sphincter muscle of the ovale is indicated by the white arrow. In physoclistic fish, this sphincter is typically contracted in a neutrally buoyant animal to prevent oxygen from being resorbed into the bloodstream from the gas bladder. One of the strong buttressing ribs of the thoracic region is labelled. Photo by D. Parkyn.

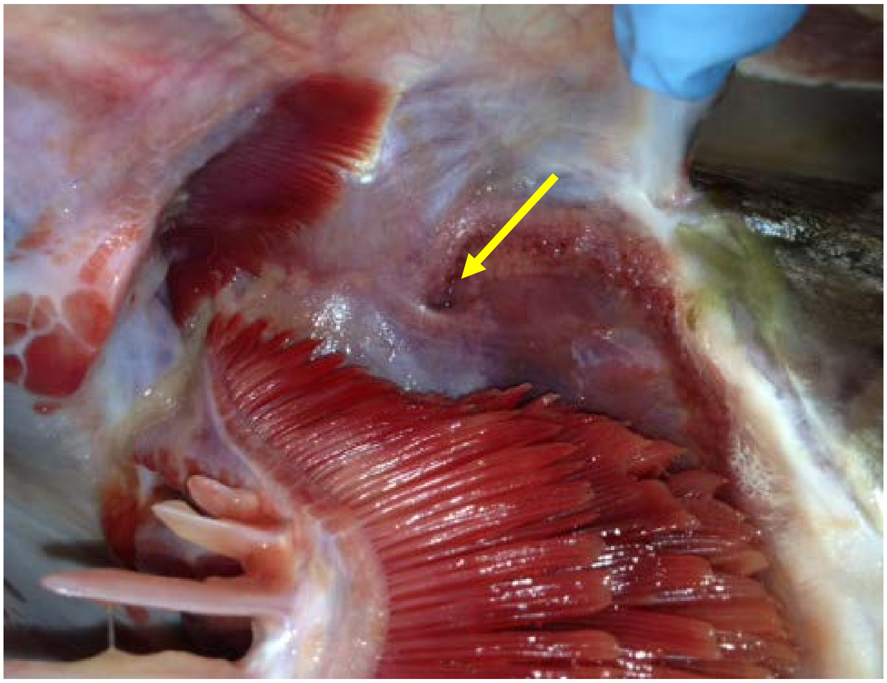

Figure 12. View of the external opening under the operculum where air exits when greater amberjack ascend from deep water. Photo by D. Murie.

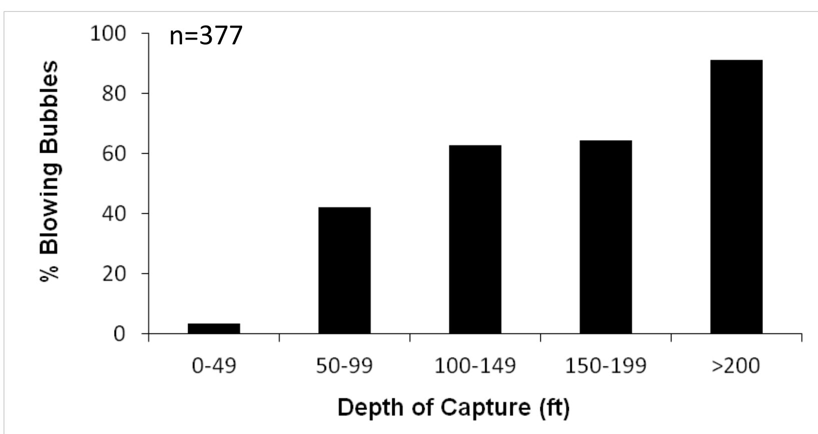

Figure 13. Percentage of greater amberjack self-venting by "blowing bubbles" as a function of capture depth.

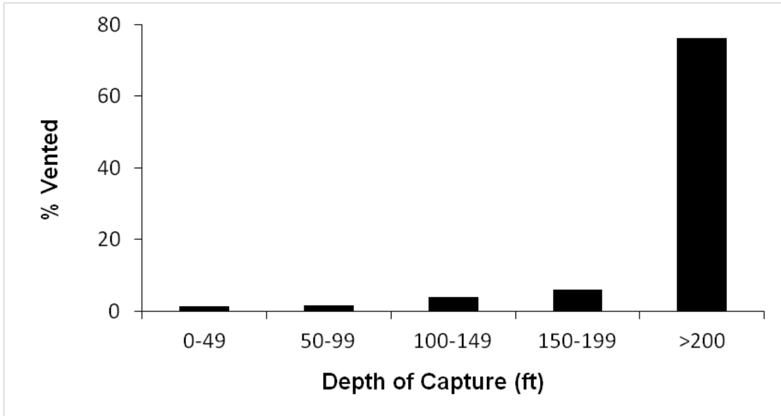

Figure 14. Percentage of greater amberjack manually vented as a function of depth of capture.

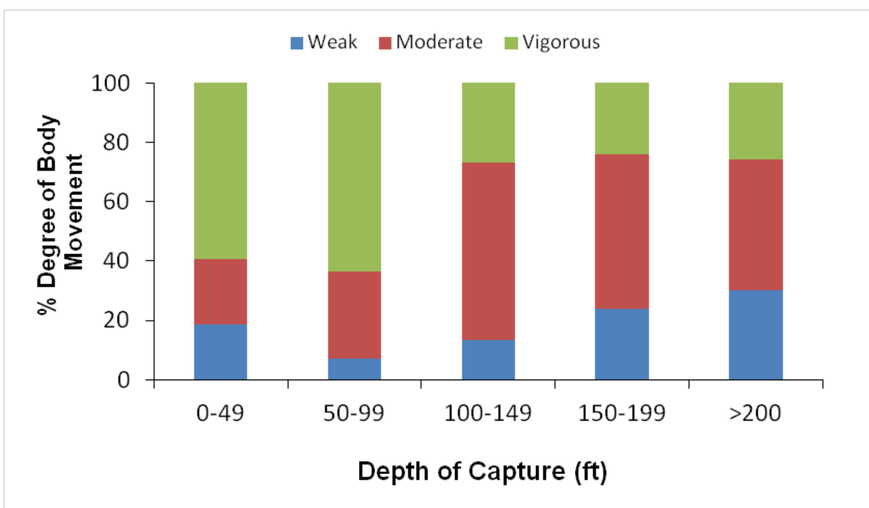

Figure15. Relative degree of body movement (flexion) as a function of depth of capture.

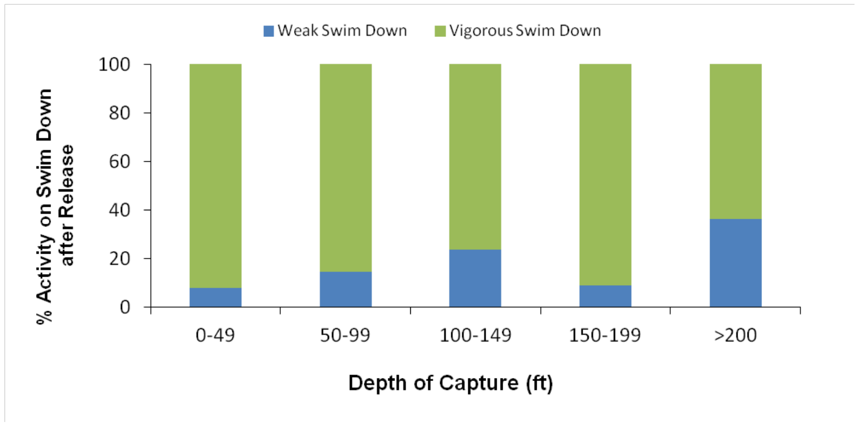

Figure 16. Relative swimming activity on release for greater amberjack as a function of depth of capture.

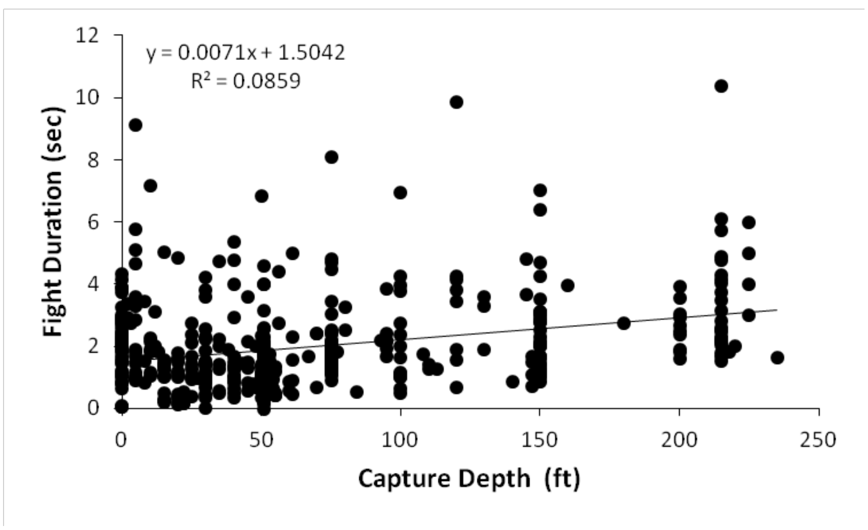

Figure 17. Relationship between fight duration and depth of capture for greater amberjack (n=459).

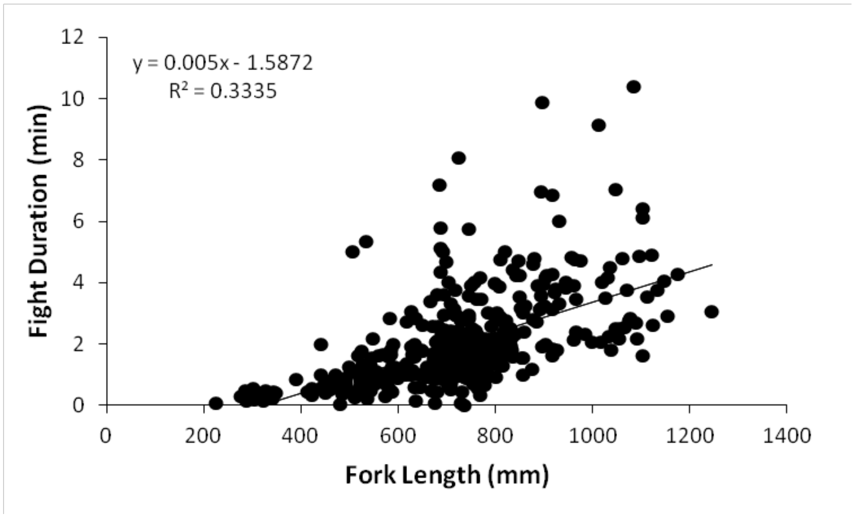

Figure 18. Relationship between fight duration and length of greater amberjack captured (n=450).

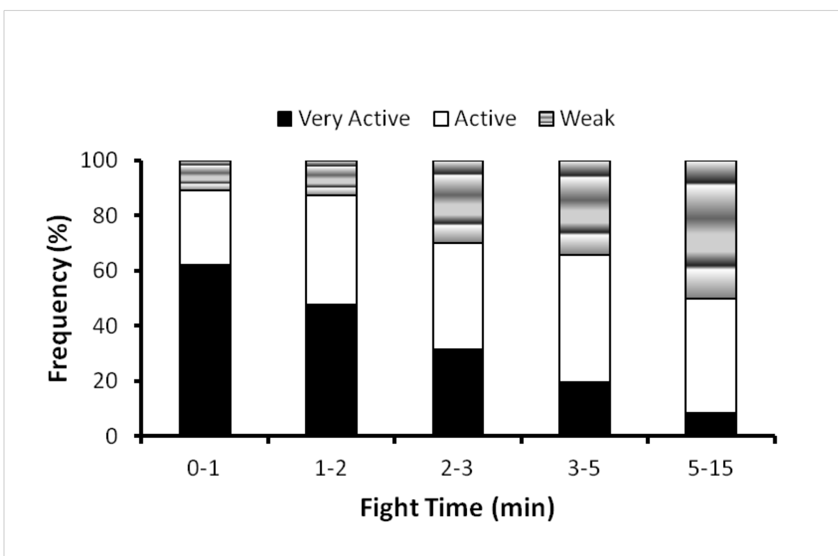

Figure 19. Activity of greater amberjack on the deck as a function of fight time. Very active fish had continuous tail and body flapping, active fish only initially flapped, and weak fish had very feeble movements.

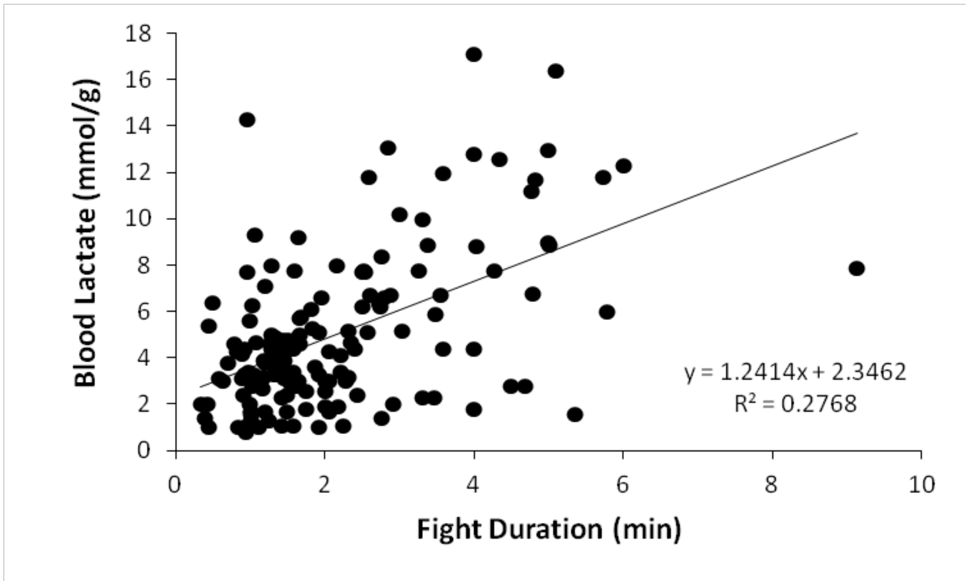

Figure 20. Relationship between blood L-lactate concentration as a function of fight duration for greater amberjack. Lactate concentration was measured <u>in situ</u> using a Lactate-Pro meter.

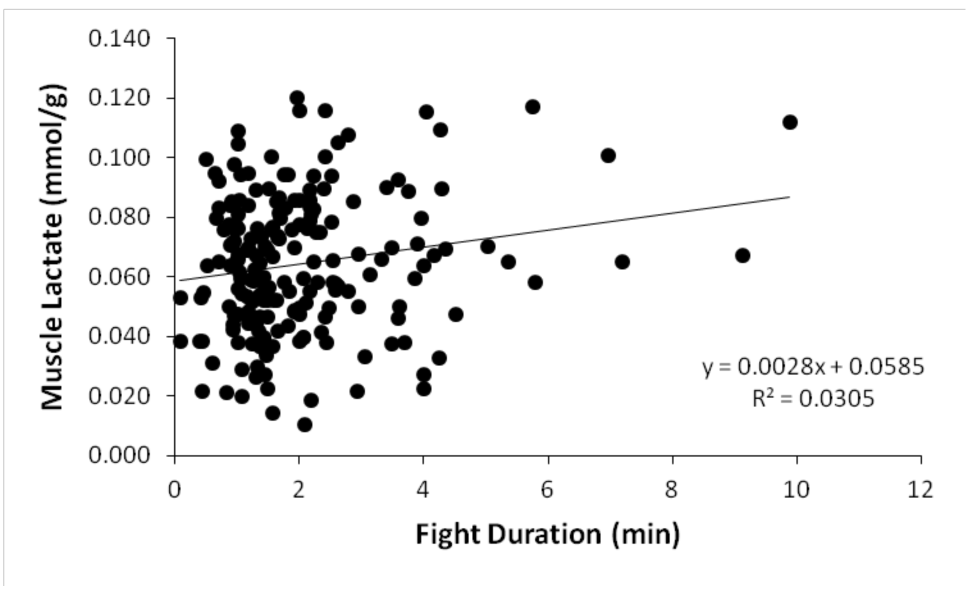

Figure 21. Relationship between muscle L-lactate concentration as a function of fight duration for greater amberjack (n=204).

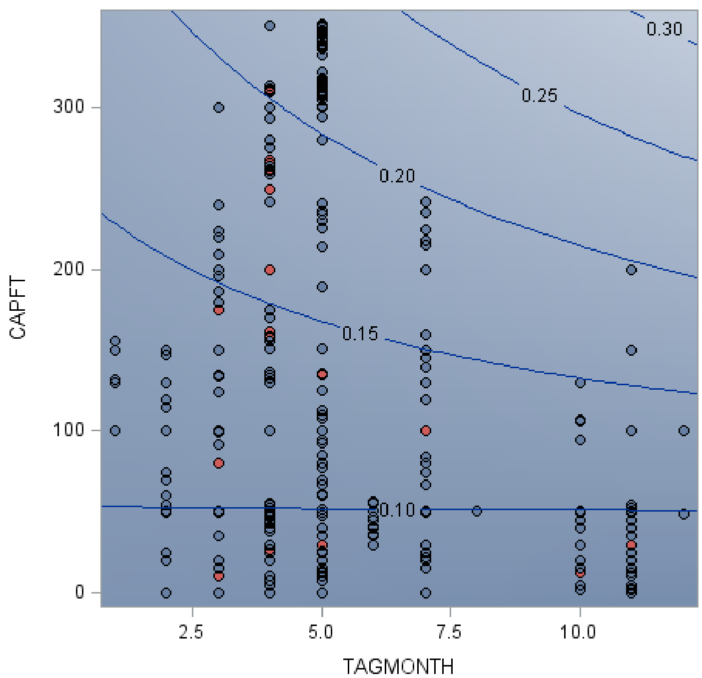

Figure 22. Contour plot of recapture probability as a function of capture depth (ft) and tagging month for greater amberjack in the Gulf of Mexico.