Evaluating Lethal and Sub-Lethal Effects of Catch-and-Release Angling in Florida's Central Gulf Coast Recreational Atlantic Tarpon (*Megalops atlanticus*) Fishery

by

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CHAPTER THREE:

PHYSIOLOGICAL DISTURBANCES OF TWO SIZE CLASSES OF TARPON (*Megalops atlanticus*) IN RESPONSE TO CATCH-AND-RELEASE ANGLING

Introduction

Fishes exhibit a physiological response when subjected to the acute stress of exhaustive exercise, such as that experienced by a fish when it is being angled. These responses are often sub-lethal metabolic and osmotic disruptions (Mazeaud *et al.* 1977) that are typically more exaggerated than in higher vertebrates (Wells *et al.* 1986, Wood 1991, Kieffer 2000). Severe, acute and chronic stressors have been shown to elevate post-release mortality in some studies (Black 1958; Wood *et al.* 1983), while other studies showed no effect of exhaustive exercise on mortality (Booth *et al.* 1994; Cooke *et al.* 2001).

Research shows that the primary and secondary physiological responses (Mazeaud 1977) and recovery of fishes after exercise may be affected by air exposure during handling (Ferguson and Tufts 1992; Cooke *et al.* 2001), the size of the fish (Childress and Somero, 1990; Somero and Childress, 1990; Ferguson *et al.* 1993; McDonald *et al.* 1998), the water temperature at the time of capture (Wilkie *et al.* 1996 and 1997), the life-history stage of the fish being caught (Tang and Boutilier, 1991; Brobbel *et al.* 1996), and its ability to swim while recovering (Milligan *et al.* 2000, Wells

et al. 2003). These studies have predominantly focused on freshwater species and salmonids that undergo stress from hatchery rearing and during spawning migrations. Limited, but recently expanding, physiological work has been performed on saltwater species such as sablefish (Davis and Parker 2004), halibut (Davis and Shreck 2005), silver trevally (Wells and Baldwin 2006), various species of tunas, marlins and sharks (Skomal 2006 and 2007), bonefish (Suski *et al.* 2007, Danylchuk *et al.* 2007, Cooke *et al.* 2008) and oxeye or Pacific tarpon (Wells *et al.* 2003, Seymour *et al.* 2003, Wells *et al.* 2007). Because of the inconsistency among physiological responses of fishes to exhaustive exercise or angling, species-specific investigations need to be made (Cooke and Suski 2005).

There are currently no published physiological data on Atlantic tarpon. Atlantic tarpon, a predominantly catch-and-release fishery in the United States, is world renowned and sought after because of its exaggerated response to angling. Their size, strength, acrobatic prowess and stamina on various tackle make tarpon an excellent model to evaluate a primitive, pelagic species' physiological response to exhaustive exercise. Large, adult tarpon in excess of 70 pounds (32 kg) are caught throughout Florida as a seasonal fishery that targets sexually mature fish in salt water environments before, during and after their spawning season. Sub-adult tarpon (sexually immature) are much smaller (ca. 5 to 30 pounds [2 to 9kg]) and are targeted in the fishery year round in backwater, estuarine, and pond environments. If smaller, sexually immature tarpon are more susceptible to mortality or sub-lethal disturbances that could limit their recruitment to the next life-history stage from catch-and-release events, it would be prudent to evaluate the responses of both size classes independently.

In addition, small tarpon are logistically easier to handle than large tarpon and may be subjected to prolonged air exposure and handling by anglers, such as for photographs. Air exposure has been shown to increase physiological recovery times from exercise (Ferguson and Tufts 1992, Davis and Parker 2004, Suski *et al.* 2004), disrupt normal behavior (Arlinghaus *et al.* 2009, Danylchuk *et al.* 2007, Suski *et al.* 2007) and influence post-release survival (Gingerich *et al.* 2007, Arlinghaus and Hallermann 2007) in freshwater and marine fishes. At the same time, tarpon can breathe air, so air exposure may have limited effects relative to gill breathers. Understanding how large and small tarpon, which represent two different life-history stages, that are targeted in Florida's recreational fishery react to catch-and-release angling can provide useful information for anglers, scientists and managers to develop methods for best handling practices that minimize physiological disturbance and maximize survival.

The objective of this study was to quantify the physiological disturbance in adult and sub-adult tarpon in response to catch-and-release angling. Four specific questions were addressed. First, were there significant physiological disturbances in adult and sub-adult tarpon after angling compared to non-stressed fish within size classes? Second, were there significant differences in the physiological disturbance between size classes after angling? Third, did angling followed by sixty seconds of air-exposure while being held horizontally or vertically out of the water prior to sampling cause a physiological response in sub-adult tarpon that was different from non-air-exposed tarpon? And finally, did angling duration, handling time or select environmental parameters significantly influence a potential disturbance in blood chemistry?

Methods

Tarpon were collected using hook-and-line methods in the Tampa Bay area (all control fish, and angled sub-adults) and Boca Grande Pass (angled adults) during 2008. Sub-adult tarpon were angled from a salt-water pond by volunteer recreational anglers and research staff (May to August). These fish were wild, juvenile tarpon from Tampa Bay that had been entrained in the pond at earlier life-history stages and grew to sizes where they could not escape. Therefore, these fish were considered representative of wild sub-adult tarpon from the local population. Adult tarpon were angled by volunteer recreational anglers and clients on guided charters. Adult angling trips took place over the course of a few days to minimize variance in the environmental data (water and air temperature, salinity, dissolved oxygen and pH) that could influence blood responses.

Control Groups. Twelve sub-adult tarpon (<20 pounds, 9kg) were transported and stocked into a 3.66m (12ft) diameter, tank at the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute Stock Enhancement Research Facility (SERF) in Port Manatee (Figure 3.1). Six adult tarpon (*ca.* 31.8 to 54.5 kg) were transported by boat and truck to the SERF facility, and then stocked into a 9.14m (30ft) diameter fiberglass tank (Figure 3.1). Water in both tanks was full strength seawater and environmental parameters were monitored daily (Table 3.1). All fish survived the stocking phase.

Tarpon were held in captivity until acclimated. Acclimation was defined as the tarpon actively and voraciously feeding in captivity. Small tarpon ate readily and voraciously. Large tarpon took up to four weeks to actively feed, but then adapted quickly to laboratory conditions. Control specimens were not fed for 24-hours prior to

phlebotomies (taking blood from a vein by puncturing it with a needle) to reduce the effect of diet in the blood chemistry.

To obtain non-stressed levels of blood from these large sportfish, adult tarpon were euthanized by delivering a lethal blow to the brain using .223 caliber blanks in a power head mounted on a pole spear. One fish per day was removed from the tank for a phlebotomy. Sub-adult tarpon were not euthanized, but rapidly hand-lined from the tank with a baited hook and bled. Previous work on oxeye tarpon (*Megalops cyprinoides*) showed that rapidly sampled control fish exhibited no statistical differences in their responses compared to cannulated tarpon that were undisturbed at the time of sampling (Wells *et al.* 1997). This method has also been used with other genera (Meka and McCormick 2005). At least one hour was allotted between sub-adult sampling events to allow the remaining fish in the tank to calm from the sampling event. These fish were dart tagged and released alive.

Angling, Handling and Air Exposure. Recorded variables for each angling event included the following: hook-up time, time landed (defined as a caught tarpon controlled by human hands at the side of a fishing vessel, pond bank, or v-tray), pre-bleed handling time, total bleed times, and total handling time. Angling duration was calculated as the length of the fight from the time of hookup until the tarpon was caught by the angler (controlled boat-side by leader, hand, or gaff) or landed in a net. For all treatments, air temperature, water temperature, salinity, dissolved oxygen and pH was recorded either at the start, during, or end of the sampling day. Environmental variables were not recorded after every angled tarpon was caught because schools of tarpon targeted by anglers typically fed all at once and hook-and-line capture events occurred in rapid succession

during these intense feeding episodes. All variables recorded, created and analyzed in this study are reported and defined in Appendix C.

Angled sub-adults were subjected to one of three handling treatments prior to bleeding: 60 seconds of air exposure while held horizontally out of water (Air-H), 60 seconds of air exposure while held vertically out of water (Air-V), and no air exposure (NoAir) (Figure 3.2). Air exposure duration was chosen as a representative time that a tarpon might be held for photographs in the recreational fishery and was included with the pre-bleed handling times for those treatment groups.

Field Diagnostics and Phlebotomy. Phlebotomies were performed using caudal venipuncture while the tarpon was either inverted on a v-tray (Figure 3.3A) or held boat-side in a sling. Scales were removed and approximately 2- to 3-mL samples of blood were drawn into 4-mL BD vacutainers containing lithium heparin using 1 ½", 21-guage needles. An additional 1-mL sample was drawn into a BD vacutainer (Becton, Dickinson and Company) containing sodium fluoride potassium oxalate from each tarpon. Blood samples were placed on ice slurries until processed. Total bleed times were recorded for each tube and blood processing times were monitored. Samples were discarded if they were not spun within 60 minutes of collection. Ninety-one percent of the samples were processed in fewer than 40 minutes and 82% in less than 30 minutes. The same biologist served as the phlebotomist to reduce variation in blood sampling technique.

Blood samples were immediately processed in the field. Hematocrit (HCT) levels were measured from whole blood spun in a CritSpin microcentrifuge for two minutes and recorded as the percent red blood cell volume. Small aliquots of whole blood were placed in refrigeration for subsequent hemoglobin (Hb) analyses. Remaining whole blood

samples were spun in the Vacutainer® tubes for five minutes using a centrifuge. Plasma was pipetted from the tubes, placed into labeled cryovials, and immediately frozen and stored in a dry shipper charged with liquid nitrogen. Upon return to the laboratory, frozen plasma samples were stored in a -76 °C freezer until further processing.

Measured plasma response variables were as follows: lactate, glucose, cortisol, calcium, sodium, potassium, chloride, phosphorus and magnesium. Plasma lactate analyses were performed at the Comparative Neuromuscular Laboratory, University of California-San Diego, La Jolla, CA. Quantification of the remaining plasma parameters and Hb were performed by Antech Diagnostics Laboratory, one of the leading veterinarian analytical laboratories for the eastern United States. Accredited laboratories were used for consistency and because the analytical techniques and equipment follow current standard protocols of the field.

The angling portion of the adult field experiment was repeated because of unexpected results and logistics. Adult tarpon were difficult to handle *in situ* while lifting the tail high enough out of the water for phlebotomies and the tails were sometimes too thick for the needle to reach the vein. Such issues caused additional handling time, multiple needle sticks, and excessive bleed times that may have affected blood responses and general well being of the fish when performing phlebotomies using caudal venipuncture. In 2009, blood was drawn from branchial vessels in the gill arches while fish were in the sling (Figure 3.3B). The only difference in methodology was the location of the phlebotomy.

Lengths and girth of each tarpon were measured to the nearest mm and recorded after hematological samples were taken. Adult fish weights were estimated using the

allometric weight relationship for tarpon and converted to kilograms (Babcock 1936). Sub-adult fish were weighed to the nearest 0.1g on a scale. If no scale was available, weights were calculated using the same weight relationship as for adults. All tarpon were marked using genetic tags (adults) or plastic dart tags (sub-adults), revived if necessary, and released. The pond was monitored for subsequent sub-adult mortalities.

Statistical Analysis. Individual tarpon served as the sampling unit. Replication was achieved by sampling multiple fish. Cortisol and magnesium were natural log ($\log_e$) transformed for subsequent parametric analyses to meet assumptions of normality. Most other parameters were normally distributed (Shapiro-Wilk, $W>0.95$). Student's t-tests ($\alpha=0.05$) were used to compare means between treatment groups (angled and control), between angled size classes, and between bleed-methods (caudal venipuncture or gill). Test results were compared to results from non-parametric two-sample Wilcoxon tests in the cases where data were close to normal (Shapiro-Wilk, $W\leq0.95$). Values are presented as arithmetic means ± one standard error.

Physiological disturbances among handling treatments of sub-adult tarpon were compared with a one-way ANOVA adjusted for unequal samples sizes followed by a post-hoc Tukey test ($\alpha=0.05$). The mean lengths and weights of tarpon and environmental data were also compared for any significant differences between and among treatments ($\alpha=0.05$). The effect of size on angling duration was evaluated with a simple linear regression.

Associations and interactions among hematological responses of tarpon from each treatment (angled and control animals) to angling duration, handling time, bleed methods, body size, and various environmental variables were examined using a non-parametric

redundancy analysis (RDA) and parametric linear and multiple regressions (α=0.05). Handling times for these models were the sum of pre-bleed handling times, 60 seconds of air exposure, if applicable, and the total bleed time. All analyses were conducted using SAS version 9.2 for Windows.

The number of tarpon used for the RDA was reduced to only include tarpon for which there were a complete set of field and hematological parameters in order to statistically evaluate the relationship between fish responses and angling characteristics. Data were standardized to Z-scores and 1,000 permutations were run using the dataset. The following variables were used as explanatory variables (predictors) in the RDA model: Air Temp (°C), Water Temp (°C), dissolved oxygen (DO), salinity (SAL), pH, total length (TL), weight, angling duration (Fightr), bleed method, handling times (BoatH_secs) and handling treatments for each adult tarpon (Percussion and Angled) and sub-adult (Air-H, Air-V, NoAir, and RS-C) tarpon. Ten of the eleven blood parameters were entered as response variables into the model and are shown in green. Hemoglobin was excluded from the RDA because of the paucity of these measurements among tarpon that had complete sets of the other measured blood parameters. Distance between points in the biplot showing the first two ordination axes approximates the similarity of the tarpon's response as measured by Euclidean distances. Points represent each tarpon and are labeled with its handling treatment. For predictors, the vector lengths indicate the relative strength of the relationship with the response data. For response vectors, the magnitude is proportional to the contribution that variable makes to the patterns depicted in the multivariate space by the biplot. For both predictor and response vectors, heading indicates the direction of the underlying gradient. Angles between the response and

predictor vectors (and among predictor vectors) reflect their correlations: correlation is positive when the angle is less than 90 degrees; correlation is negative when the angle is greater than 90 degrees. Angles among responses variables are meaningless.

Results

Sample size and mean values for Atlantic tarpon sizes (length and weight), angling duration, handling times and measured environmental variables for each treatment group are presented in Table 3.1. Values for whole blood HCT and Hb, metabolites lactate and glucose, the hormone cortisol, and six electrolytes (calcium, sodium, potassium, chloride, inorganic phosphorus and magnesium) are presented for each angling treatment and non-stressed control group in Table 3.2. Table 3.3 is a compilation of the statistical comparisons of angling effects between size classes for each blood parameter. The average size of adult tarpon was significantly larger (1855 ± 21.8mm, TL; 49.2 ± 1.9 kg) than that of sub-adult tarpon (602.7 ± 14.0mm, TL; 1.6 ± 0.1kg) used in this study (t-test, df=86, $p<0.0001$, Table 3.1).

Angling Within Size Class. Angling caused a significant physiological disturbance in adult tarpon (Table 3.2). Hematocrit (HCT, t-test, p=0.0007), hemoglobin (Hb t-test, p=0.0007), plasma metabolites lactate (t-test, p=0.0004) and glucose (t-test, p=0.0007), and all plasma electrolyte concentrations (t-test, $p<0.001$) were significantly higher in angled (stressed) tarpon than mean levels of the same parameter in non-stressed adult tarpon (Control, Table 3.2). Plasma cortisol levels were not-significantly different between angled and control fish (Table 3.2, t-test: P=0.4507).

Angling caused less of a disturbance in sub-adult tarpon (Table 3.2). Post hoc analyses on sub-adult tarpon revealed no significant differences among the three angled

handling treatments with and without air exposure and the non-stressed control group for concentrations of Hb (ANOVA, p=0.536), glucose (ANOVA, p=0.636), cortisol (ANOVA, p=0.348), calcium (ANOVA, p=0.499), sodium (ANOVA, p=0.686), potassium (ANOVA, p=0.715), chloride (ANOVA, p=0.883), and inorganic phosphorus (ANOVA, p=0.447; Table 3.2). Non-angled sub-adults (RS-C) had significantly lower levels of HCT (ANOVA p=0.0041), plasma lactate (ANOVA, p=0.0001), and plasma magnesium (ANOVA p=0.0099) than angled treatments, but no differences were observed among the three angling treatments with and without air-exposure (Table 3.2).

Angling Between Size Classes. Samples from the three sub-adult handling treatments with and without air exposure were combined for scaling comparisons of angled fish since no significant differences (ANOVA, p>0.05) were observed among handling treatments for any blood parameter. Angling produced significantly higher concentrations of blood hemoglobin, plasma metabolites lactate and glucose, and most electrolyte concentrations in large tarpon than in small tarpon (Table 3.3). Only HCT and potassium showed no significant difference between size classes of angled tarpon (Table 3.3). Cortisol was significantly lower in large tarpon than in sub-adults after angling (Table 3.3).

Angling Duration, Handling Time and Environmental Parameters. Adult tarpon angling durations (fight) ranged from 5 to 74 minutes and boat-side handling times (BoatH) ranged from 77 seconds to 1,370 seconds (22.8 min). In sub-adult tarpon, angling durations ranged from 0.5 minutes to 7 minutes and pond-side handling times ranged from 41 seconds to 874 seconds (14.6 min).

Bleeding large tarpon from the branchial vessels, rather than caudal vessels, significantly reduced the amount of time it took to bleed the fish and reduced the total handling time needed at the side of the boat to obtain a sample and release the fish (Table 3.4, Appendix C). Boat-side handling times were on average about three minutes shorter and bleed times were more than two times faster when tarpon were bled using the gill method. Whole blood parameters (Hb, HCT), and plasma potassium and phosphorus concentrations were the only response variables to differ between bleeding methods (Table 3.4).

A total of 64 tarpon had a complete set of field and hematological parameters and were used for the RDA. Results for the primary and secondary axes in the RDA biplot showed that 60.55% of the total variance in the observed data was accounted for by this model (adjusted r-squared = 0.633, p = 0.001; Figure 3.4). The first axis accounted for approximately 50% of that total variance. Scaled predictor vectors (red) indicated that the most influential explanatory variables on the collective blood responses of plasma lactate, glucose, calcium, chloride, phosphorus, and magnesium in angled tarpon of both size classes were angling duration (Fight), handling times (BoatH_secs), tarpon size (weight and total length) and bleed method (Figure 3.4).

Linear regression models for tarpon size and multiple regression models for individual blood parameters by angling duration and handling times supported the RDA results. Larger tarpon took significantly longer to catch (n=73, Adj. R^2 =0.404, p-value<0.001; Figure 3.5). In the case presented for plasma lactate, longer angling duration and handling time resulted in increasing lactate concentrations in adult tarpon

(Figure 3.6), and a significant interaction of angling duration and handling time on the lactate response was observed in sub-adult tarpon (Figure 3.7).

Tarpon from the three sub-adult angling treatments with and without air exposure were positively correlated in their responses and clustered together on the biplot (Figure 3.4). The only angled sub-adult tarpon that responded similarly to the angled adult tarpon experienced the longest fight time (NoAir, within dashed circle). Cortisol levels were higher in smaller angled tarpon, but did not appear to be correlated to angling duration or handling times (Figure 3.4). Potassium and HCT showed little relationship with fight time, handling time, size, or angling treatment, but were slightly associated with air and water temperatures.

Tarpon from the two control groups (Percussion and RS-C) clustered together and were separate from tarpon subjected to angling (Figure 3.4). A few RS-C tarpon, however, exhibited similar blood responses as angled sub-adults with and without air-exposure (inserted horizontal arrow, Figure 3.4). Adult control tarpon (Percussion) were correlated with lower water and air temperatures. Environmental parameters, in general, did not account for much variability in the observed blood responses of angled fish. Vectors of the environmental parameters were short in length and aligned with the secondary axis that only accounted for an additional 10% of the total variation in the observed response data (Figure 3.4).

There were some differences in water quality between the control tanks and the pond and Gulf water at the time of sampling. Sub-adult tank water had a higher salinity (ANOVA, $p=0.001$), cooler water temperatures (ANOVA, $p=0.004$), and lower pH (ANOVA, $p=0.0001$) than the pond water, but these variables were not significantly

different among the three angled sub-adult treatments (Table 3.1). No significant difference was observed for air temperatures or DO levels between the pond and tank water at the time of phlebotomies (ANOVA, $p>0.05$). Angled adult tarpon came from Gulf of Mexico water with significantly higher salinities (t-test, $p=0.0001$), pH (t-test, $p=0.0001$), and water temperatures (t-test, 0.0012) than the control tank water at the time of sampling (Table 3.1). There was no difference in DO levels between the tank and Gulf water. Air temperatures were significantly cooler (t-test, $p=0.0006$) at the time we sampled the control group (October) compared to air temperatures when we angled the adults (May and June, Table 3.1).

No short-term mortality (<6 hours) was observed with caught-and-released sub-adult tarpon. Delayed mortality of one angled tarpon was observed 43 hours post-release (1 out of 28 fish). Eight out of 27 sub-adults (30%) were recaptured throughout the 2008 sampling season.

Discussion

Acute stress in fish, such as that experienced when a fish is angled, typically elicits a stress response (Mazeaud *et al.* 1977) that is a culmination of how a tarpon functions and responds given its intrinsic and extrinsic environment. These responses can be quantified and evaluated physiologically by monitoring the changes a fish makes to adapt and cope with the stress relative to the stressor (Barton *et al.* 2002, Wikelski and Cooke 2006, Arlinghaus *et al.* 2007). This was the first study to quantify physiological disturbances in two distinct life history stages of Atlantic tarpon in response to catch-and-release angling practices associated with the sport fishery and to quantify blood chemistry from non-stressed Atlantic tarpon.

Angling caused significant increases in blood chemistry concentrations in adult tarpon and of select parameters in sub-adult tarpon relative to non-angled fish. There might have been more significant differences between control and angled treatment groups of sub-adult tarpon had only one fish per day been rapidly sampled from the control tank. The rapidly-sampled control fish that exhibited similar blood responses as the angled sub-adult tarpon (horizontal arrows on RDA biplot) were actually instances where that tarpon was the second or third fish out of the tank on a given sampling date. All tarpon in the tank reacted and became agitated when the baited hook was dropped to remove the first fish of the day. The first rapidly sampled tarpon on a given date elicited responses that placed them among the adult control tarpon (Percussion) on the biplot. Results indicated that one hour was probably not adequate time to allow the remaining tarpon in the tank to return to resting levels.

Measured whole blood responses were similar to the congener *Megalops cyprinoides* and other high energy fishes. Atlantic tarpon of both size classes showed similar mean HCT levels at rest and after angling (Table 3.2), but percentages after angling were quite variable and ranged from 28% to 58%. Wells *et al.* (1997) also found HCTs in oxeye tarpon was quite variable and ranged between 15% and 40%, and in a subsequent study, determined, mean resting HCT level to be 37.6% that increased to 51.9% after exercise (Wells *et al.* 2003). Post-exercise HCT values from this study (Table 3.2) were also similar to post-exercise HCT values of high energy pelagic fishes observed by Skomal (2006) in bluefin tuna (44%), albacore (48%) and bonito (49.9%), and slightly higher than values observed by Wells and Baldwin (2006) in silver trevally (35.6%).

Hemoglobin (Hb), the red blood cell protein that increases the carrying capacity of RBCs for oxygen (Houston 1990), while not significantly different among the sub-adult treatment groups in this study, did increase in adult tarpon after angling (Table 3.2). Sub-adult Atlantic tarpon that were a similar size to oxeye tarpon studied by Wells *et al.* (2003), had similar Hb levels to those measured in oxeyes at rest (11.69g/dL) and after exercise (14.3 g/dL). However, large Atlantic tarpon experienced higher post-exercise Hb levels than oxeyes (Table 3.2).

Changes in whole blood parameters HCT and hemoglobin often represent a fish's response to an increased oxygen demand as a result of anaerobic activity. One explanation for the increase in HCT is that the red blood cells themselves were swelling from the internal electrolyte imbalance. However, since both parameters increased after angling, Atlantic tarpon may be releasing new red blood cells from the spleen to increase blood-oxygen carrying capacity (Brill *et al.* 2008) as a response to being angled. Earlier work by Wells *et al.* (1997) determined that oxeye tarpon have higher resting Hb and HCT levels than some fishes, and a high oxygen carrying capacity. Since Atlantic tarpon values were similar to those in oxeye tarpon the same is true for them. This plays a key role in how a tarpon can rid the acid built up in its system during stress or exercise and recover from it.

Lactate, produced in response to oxygen debt and the high energy demands of anaerobic metabolism during glycolysis (Dobson and Hochachka 1987, Wood 1991), exhibited the most significant increases in response to angling and handling in both size classes of tarpon. Observed lactate levels from sub-adult Atlantic tarpon were similar to what Wells *et al.* (2007) observed in oxeye tarpon subjected to varying swimming speeds

and dissolved oxygen conditions that ranged from 0.8 to 5mmol/L. Compared to non-elopomorph fishes, adult tarpon responded similarly to other high energy fish after angling or exercise (bluefin tuna, 11.7 mmol/L; albacore tuna, 9.1mmol/L; Skomal 2006), but not as high as silver trevally after exercise (20 mmol/L, Wells and Badlwin 2006). Silver trevally's mean lactate concentrations were close to the maximum value obtained in large tarpon from this study (21.68 mmol/L). Sub-adult tarpon lactate levels were more similar in response to mako sharks (4.2 mmol/L) and wahoo (4.2 mmol/L) after angling (Skomal 2006). Lactate resting levels in bonefish were low like tarpon's (1mmol/L), but when exercised with one minute of air exposure, bonefish reached post-exercise levels of 6.0 mmol/L and 8.5 mmol/L and actually peaked two hours later at 14mmol/L under the most stressful experimental conditions of a 4 minute exercise period coupled with 3 minutes of air exposure (Suski *et al.* 2007, Cooke *et al.* 2008).

Many studies indicate that lactate continues to increase post-exercise (Wells *et al.* 1986, Ferguson and Tufts 1992, Wilkie *et al.* 1996, Milligan *et al.* 2000, Davis and Shreck 2005, Meka and McCormick 2005, Suski *et al.* 2006, Frick *et al.* 2010) and that air exposure magnifies the response (Ferguson and Tufts 1992, Suski *et al.* 2004), so it is feasible that tarpon values in this study were not at their peak. In fact, blood samples obtained during a tarpon tournament (2010) provided evidence that maximum lactate levels were not obtained during recreational tarpon fishing activities. Tournament lactate levels ranged between 8.15 mmol/L and 40.96 mmol/L with a mean of 21.96 mmol/L (Guindon unpublished data). This average tournament lactate concentration was similar to the maximum value (21.68 mmol/L) obtained in the recreational fishery samples.

Extreme handling has been demonstrated to exacerbate the magnitude of the stress response in other species for lactate (Thorstad *et al.* 2003, Meka and McCormick 2005), but also for other hematological parameters, in general, when a fish responded to a stressor (Wendelaar Bonga, 1997, Barton *et al.* 2002). The tarpon with the maximum lactate level in this study experienced the longest fight time (54 minutes) coupled by the longest pre-bleed handling time (9 minutes). The adult tarpon exhibiting the second highest lactate concentration (20.33 mmol/L) was only angled for 20 minutes; however, this tarpon was towed for fifteen minutes prior to delivering it to staff for sampling. The other two angled tarpon plotted near this point had 15 and 19 minute fight times, were each towed for five minutes prior to sampling, and one of these two tarpon had the longest handling time. These three fish exhibited extreme blood responses (Figure 3.4 and 3.6, tarpon marked with vertical arrows). Towing a tarpon is not typically practiced in the recreational fishery since most fish are caught and released. But for the sake of this study, a few anglers towed their fish to the research vessel to be sampled. Some tarpon tournaments, however, require towing as part of their weigh-in procedures. Fishing tournaments, in general, typically are associated with excessive handling and stress responses in fish often resulting from holding fish alive in pens as part of the weigh-in procedures (Suski *et al.* 2004 and 2006). In the case of tarpon, the capture event, boat-side handling, distance towed and weigh-in procedures would all contribute to confounding any towing specific effects, but results here support the idea that towing is a form of excessive handling that may exacerbate observed stress responses and merits further investigation.

Hyperglycemia, the increase of plasma glucose, has been used as a stress indicator in fishes (Mazeaud et al. 1977, Wood 1991, Wendelaar Bonga 1997), and is expected with angling (exhaustive exercise). Excess handling, confinement, and air exposure have also been shown to further increase hyperglycemic responses in fish (Barton 2000, in Barton *et al.* 2002). While no differences in glucose concentrations were observed among sub-adult handling treatments, including control fish of both size classes, angling and handling caused hyperglycemia in adult tarpon. Angled adult tarpon glucose levels were similar to that observed by Wells *et al.* (2007) in fast swimming oxeye tarpon under normoxic conditions (117 mg/dL). Earlier work by Wells *et al.* (2003) on oxeye tarpon similar in size to the sub-adult Atlantic tarpon, showed that 15 minutes of exercise (angling) increased glucose concentrations in rapidly sampled control fish from 87.3 mg/dL to 93.96 mg/dL, but the increase was not significant, as was observed with sub-adult Atlantic tarpon. Again, the glucose response in adult tarpon was similar to other high energy fishes such as endothermic tunas (110 mg/dL) and skipjacks (109.3 mg/dL, Skomal 2006). In contrast, tournament sampled tarpon yielded an average glucose concentration of 176 mg/dL (Guindon unpublished data), a value higher than what was observed in exercised bonefish (162 mg/dL, Suski *et al.* 2007) and white marlin (145.1 mg/dL, Skomal 2007). Such increases in glucose do suggest a mobilization of other metabolic energy reserved to increase the individual tarpon's energy expenditure.

Angling caused a noticeable electrolyte disturbance in adult tarpon, but in general, increases in electrolytes were the least extreme compared to other measured parameters. Only small increases in sodium (19%) and chloride (12%) concentrations were observed after angling adults from the Gulf of Mexico; a common response among teleosts under

stress (Cliff and Thurman 1984, Wood 1991, Wendelaar Bonga1997). Sodium and chloride branchial exchange is important for the storage of hydrogen ions to aid recovery from an acid-base imbalance in the plasma after a stressor (Wood 1991). With the influx of sodium, there is an efflux of hydrogen ions that helps lower the pH of the tarpon's plasma. There is also a neutral exchange of chloride with bicarbonate ions (HCO_3^-) out of the fish gills (Wood 1991, Wang *et al.* 1994). Chloride and magnesium also assist in regulating the affinity between oxygen and Hb (Houston 1990). Increasing plasma chloride concentrations promotes oxygen release from the Hb to the plasma so it can travel to body tissues during anaerobic activity (Marshall 2002). Magnesium increased 67% after angling in adult tarpon, and plays a role in contractile protein activation which could aid the muscles in maintaining swimming capabilities against a buildup of lactic acid (Black 1958). Changes in magnesium or calcium may disrupt muscular contractions and neuromuscular nerve transmission and may increase due to leakage from damaged muscle cells (Cliff and Thurman 1984). In turn, a tarpon's ability to swim during the fight or after release could be detrimentally affected. Calcium can be actively taken up from the marine environment using Ca^{2+}-ATPase and used as a sodium/calcium exchanger where it plays a role in hydromineral balance (Marshall 2002, Wendelaar Bonga 1997), and increased 40% in adult tarpon after angling. Calcium has also been proposed as a means to offset cardiac damage in fish caused by acidaemia (Wells *et al.* 1986). Inorganic phosphorus, a product of glycolysis in fishes that accumulates when PCr (phosphocreatine) is depleted in white muscle (Dobson and Hochachka 1987, Hochachka 1991), increased 72% after angling in adult tarpon. This suggests that these fish were utilizing anaerobic activity as a result of the fight. The resultant acid load encountered

from the anaerobic activity requires ionic regulation to assist with recovery of the fish (Dobson and Hochachka 1987, Dubois and Dubielzig 2004), and all of these electrolytes work collectively, not independently, toward regaining acid-base balance and osmotic homeostasis (Wood 1991).

Potassium was the one salt that was similar among angled tarpon regardless of size class or handling treatment. These values were similar to values in bonefish after angling (5 mEq/L) and when angling was followed by a minute of air exposure (5.2 mEq/L; Suski *et al.* 2007). Other work done *in situ* on bonefish also showed no consistent potassium increases after angling (Cooke *et al.* 2008). Lowest potassium levels were observed in adult control fish and the RDA revealed a correlation with decreasing potassium levels and decreasing water and air temperatures. The adult control fish were sacrificed during fall (October) when air and water temperatures were significantly cooler than when adult angled fish were sampled.

In general, responses of electrolytes are very species specific and inconsistent in their responses as discussed in Suski *et al.* (2007). Overall, angled adult tarpon showed similarity to the responses observed in ectothermic tunas for potassium, sodium, chloride, and phosphorus, but calcium responded more like endothermic tunas and marlins (Skomal 2006). Several studies have shown that recovery of ionic imbalance is rapid and electrolyte levels are often back to their non-stressed values within the first 4 hours post-release (Booth *et al. 1994,* Suski *et al.* 2004 and 2006, Wells *et al.* 2003); however, this remains and unknown for Atlantic tarpon and needs to be evaluated.

We observed no evidence of significant ionic increases among sub-adult angling treatments (Air-H, Air-V, NoAir) except for magnesium. Angled sub-adults from the

pond may have experienced slight increases in ion concentrations that went undetected relative to control fish because of the salinity differences between the tank and pond. The mean salinity of water in the control tanks for sub-adults was significantly higher than the pond water, but the tank's platform was covered and free from rainfall. The pond salinity varied with rainfall. Based on its vector in the RDA biplot, salinity played a significant role in the observed blood responses of both size classes of tarpon (Figure 3.4). None-the-less, there were no observed differences among sub-adult angling treatments from the pond, so air exposure and handling of a tarpon vertically or horizontally had little bearing on electrolyte responses.

Cortisol was the only parameter that did not show a significant increase with angling and was lower in adults than in sub-adults. This was an unexpected result since cortisol release is a primary stress response in animals (Mazeaud *et al.* 1977, Wendelaar Bonga 1997, Mommsen *et al.* 1999), and given that all other parameters significantly increased after angling adult tarpon. Potential explanations for the cortisol results are varied. The ability to respond to stressors develops at early life history stages (Brobbel *et al.* 1996, Barton *et al.* 2002, Ricklefs and Wikelski 2002) and Wendelaar Bonga (1997) stated that early life history stages are more sensitive to cortisol than later stages (adults). The observed differences between the two size classes of tarpon may be attributed to the sub-adults being a naïve population relative to adult tarpon of Boca Grande Pass that have been previously exposed to boat noise, angling pressure, repeated capture, and predator abundance in their environment which are all known fish stressors (Barton *et al.* 2002, Arlinghaus *et al.* 2007). Bursts of exercise experienced during angling events may be no different than bursts of activity required to avoid predation or capture prey;

therefore, angling a tarpon may not elicit a different physiological response that these other behaviors. These types of comparisons of catch-and-release angling to other routine behaviors is lacking in the literature (Cooke and Schramm 2007).

There are a number of wildlife examples where animals can exhibit phenotypic plasticity or endocrine control (Ricklefs and Wikelski 2002, Wikelski and Cooke 2006). Cortisol, a hormone, is under endocrine control so a tarpon may be able to suppress its release. There are advantages to doing so. Fish have been shown to reduce the cortisol response during the reproductive period which can already be physiologically stressful to the animal (Wendelaar Bonga 1997), and the adult tarpon were sampled during peak spawning season. Other studies have shown that the absence of cortisol production allowed faster acid base recovery, repletion of muscle glycogen, and lactate depletions to pre-exercise levels (Milligan *et al.* 2000, Eros and Milligan 1996) and reduced the total recovery time when sustained swimming followed exercise (Milligan *et al.* 2000). Oxeye tarpon allowed to swim freely after release with access to the air (for breathing) physiologically recovered some of its blood parameters in less than an hour, but cortisol was not measured (Wells *et al.* 2003). It could simply be that the cortisol response was delayed (Gamperl *et al.* 1994, Suski *et al.* 2006, Kieffer 2000), or as a potential worst case scenario, that sampled adult tarpon were under chronic stress where plasma cortisol can fall back to the resting levels, even though the fish may still be responding to the stressor of being angled (Vijayan and Leatherland, 1990). This remains an area of future work.

Scaling Effects of Angling. There were significant scaling effects on the physiological disturbances of angled tarpon that were more extreme in large tarpon than

in small tarpon. This agrees with results from other wildlife (Bennett *et al.* 1985) and fishery studies (Somero and Childress 1990, Ferguson *et al.* 1993, Wang *et al.* 1994, Brobbel *et al.* 1996) that evaluated the scaling effects of body mass on stress responses using blood chemistry. Work by Childress and Somero (1990) found length to be more relevant in the observed scaling patterns of muscle enzymes, not mass or weight, but for tarpon, length and weight contributed to the total explained variation in the observed blood responses (Figure 3.1).

Angling, Handling Time, Air Exposure and the Environment. Results from this work indicated that minimizing angling and handling times in tarpon can reduce the overall physiological disturbance. There was intra-species variation in physiological responses to stressors in tarpon. Angling duration and total handling time (boat-side or pond-side) were treated as stressors on tarpon of two size classes in the RDA model. Based on vector magnitudes, total handling time (BoatH_secs) was less influential on the tarpon blood responses than angling duration (Fight) or bleed method. Had all tarpon been bled at the gill arches, handling and bleed times would have been further reduced potentially lessening the effect of sampling and handling time on the observed responses. Implementing the use of more field-portable diagnostic tools (Cooke *et al.* 2008) could potentially reduce handling and processing times even further. Bleeding large tarpon from the branchial vessels in a gill arch should be used for further physiology studies on large tarpon.

Air exposure has been shown to exacerbate fish stress responses and cause gill lamellae to collapse and gill filaments to adhere to one another which compromises the surface area available for gas exchange (Ferguson and Tufts 1992, Graham 1997). Tarpon

are air breathers, which may explain the lack of an effect of air exposure on physiologic response. Other studies showed prolonged air exposure altered swimming behavior after release (Danylchuck *et al.* 2007, Gingerich *et al.* 2007). Some of the air exposed sub-adult tarpon lost equilibrium when bleed times were prolonged. In such cases, the tarpon were turned upright and held in the pond until they regained equilibrium and swam away. One fish that experienced an extreme total handling time of 17 minutes, because of difficulty in bleeding, suffered from severe equilibrium loss on release and died in the pond 43 hours post-release. No other angled sub-adults experienced delayed mortality and short-term survival within the first 6 hours post-release was high (100%). Three other sub-adult mortalities occurred from the control group which experienced no angling, but did experience tank confinement at release, which may have added to post-release stress and subsequent mortality that occurred after 72 hours post-release. These estimates may be conservative relative to tarpon in the wild since shark predation was excluded in the pond environment.

In general, angling with minimal air exposure, such as might be required if taking a photograph on a fishing trip, did not appear detrimental to tarpon recovery and survival under routine angling conditions. In fact, eight of the 37 sub-adult tarpon from this study were recaptured and indicated that tarpon can recover from the stress of catch-and-release angling. Three of the recaptured tarpon were from the control group, three were exposed to air while being supported horizontally and two were tarpon exposed to air while being handled vertically. One vertically-handled, air-exposed fish was actually recaptured five times throughout the summer.

Water temperature has been shown to play a role in the stress response of fish, being more extreme in temperatures greater than 20 degrees Celsius (Wydoski 1976, Gustaveson 1991, Kieffer *et al.* 1994, Wilkie *et al.* 1997, Meka and McCormick 2005), but most of these studies were on coldwater species and tarpon is a tropical species. Average summer water temperatures (pond and Gulf) when angled tarpon were sampled ranged between 29 and 30°C. However, fish from control groups experienced significantly cooler temperatures at their time of sampling. This was partly because the outdoor tanks were shaded, but for the adult control group there was also a seasonal effect since these fish were sacrificed in the fall. Satellite pop-up archival tags (PAT) have recorded tarpon swimming in water temperatures ranging from 16-34°C with preferred water temperatures of 28-30 °C in the summer and 24-26°C in the spring and fall (Luo *et al.* 2008). Water temperatures at the time of sampling fell within the preferred ranges for the species based on Luo *et al.* (2008). Despite this seasonal difference and correlation with low water temperatures, the RDA showed that collectively temperature effects and effects of other environmental parameters were minimal, especially in comparison to angling effects (Figure 3.7).

Several other factors not measured in this study may account for the unexplained variability in the data. The list includes many intrinsic factors beyond the control of an angler such as gender, age, previous exposure to the stressor or multiple captures, and condition (Arlinghaus *et al.* 2007). Preexisting conditions of disease or chronic stress (Sumpter *et al.* 1986), nutritional state (Barton *et al.* 2002), prey availability and predator abundance in the tarpon's environment (Wikelsi and Cooke 2006) and individual fitness variability (Cooke *et al.* 2002,) can each affect fish physiology and were unknowns in

this study. Physical injuries obtained during angling such as hook injuries, bleeding or cardiac response were not qualified or monitored in this study and can also affect a fish's physiological state (Cooke *et al.* 2001, Meka and Margraf 2007). None of these factors are independent from each other, but have cumulative effects on a fish's physiological (lethal and sub-lethal) response (Wood *et al.* 1983, Cooke *et al*. 2002, Arlinghaus *et al.* 2007).

Understanding the physiological effects of catch-and-release angling is useful information to scientists and managers charged with maintaining the sustainability of the Atlantic tarpon fishery, especially if results can help determine ways to minimize stress and maximize survival when there is extensive fishing pressure (Young *et al.* 2006). The current work compared pre- to immediate post-exercise values of these blood parameters, but studies show that physiological disturbances can continue for hours post-release. No measurements of physiological activity post-exercise or throughout the time it takes Atlantic tarpon (large and small) to metabolically recover from angling events were obtained. Recovery entails a clearance of lactate from the tissues (muscle and blood), a resynthesis of muscle energy stores and a correction of osmotic and ionic imbalances in the fish (Wedemeyer *et al.* 1990). The energy requirement for recovery may reduce a fish's immediate ability to avoid predators at the time of release, and can have more long-term effects on feeding or reproductive activity (Wendelaar Bonga 1997). Adult tarpon are targeted with intense pressure during the peak of their reproductive cycle and future studies should evaluate the effects of catch-and-release fishing on reproduction. The potential for suppressed reproductive activity or diminished success is a tertiary stress effect that has potential population level implications. More work is also needed to

determine if there is an effect of multiple captures as a potential chronic stressor in tarpon. Finally, no lethal thresholds for tarpon relative to excess metabolites or acid-base and ionic imbalances from anaerobic activity were established in this study. Quantifying the physiological response up to these thresholds is necessary in order to apply the results here and potentially have predictive indices for post-release mortality and to set appropriate catch-and-release science-based guidelines that benefit the resource and fishery.

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Table 3.1: A summary of tarpon sizes and field variables related to angling events for each treatment group. Total number (N) and means of total lengths (TL) in millimeters, weights (Wt) in kilograms (kg), angling duration (in minutes), handling times (which includes bleed time) in seconds (secs), air temperatures and water temperatures in degrees Celsius (°C), salinity in parts per thousand (ppt), dissolved oxygen (DO) of the water in parts per million (ppm) and pH for each treatment group and size class of tarpon. Groups of adult tarpon were either angled or control fish. Sub-adult tarpon were subjected to one of three handling treatments: angling followed by 60 seconds of horizontal air exposure (Air-H), angling followed by 60 seconds of vertical dangling air exposure (Air-V), and angling followed by no air exposure (NoAir). The other treatment was the rapidly-sampled (RS) control group. Standard errors are presented in parentheses. Average size and environmental parameters were compared for each size class. An asterisk (*) denotes a statistically significant difference of means between angled and control groups of adult tarpon compared with a Student's t-test ($\alpha = 0.05$). Sub-adult handling treatments were tested with a one-way ANOVA ($\alpha = 0.05$). Dissimilar superscripted letters after a given concentration indicate statistically significant differences among handling treatments of sub-adult tarpon as determined post hoc with a Tukey Test. No letters next to the values would indicate no statistical differences among the four sub-adult handling treatments.

Size Class	Treatment	N	TL (mm)	Wt (kg)	Angling (min)	Handling (secs)
Adult	Angled	45	1872 ± 22.58*	50.95 ± 2.02*	22.36 ± 2.37	472.29 ± 45.15
	Control	6	1732 ± 58.12	35.73 ± 3.15	0	411.00 ± 62.98
Sub-adult	Air-H	9	563 ± 18.89[a]	1.26 ± 0.10[a]	2.11 ± 0.26	277.33 ± 52.70
	Air-V	9	581 ± 28.05[a]	1.56 ± 0.25[a]	1.72 ± 0.30	425.44 ± 47.59
	No Air	10	567 ± 16.78[a]	1.33 ± 0.12[a]	3.40 ± 0.49	295.10 ± 74.81
	RS Control	9	703 ± 20.70[b]	2.42 ± 0.22[b]	0.11 ± 0.07	258.56 ± 44.12

Table 3.1: Continued.

Size Class	Treatment	N	Air Temp (°C)	Water Temp (°C)	Salinity (ppt)	DO (ppm)	pH
Adult	Angled	45	30.5 ± 0.38*	29.11 ± 0.11*	38.08 ± 0.06*	6.11 ± 0.07	8.29 ± 0.02*
	Control	6	26.7 ± 0.80	24.34 ± 0.74	35.88 ± 0.18	6.62 ± 0.29	7.97 ± 0.05
Sub-adult	Air-H	9	30.6 ± 0.58	28.92 ± 0.63[a]	28.16 ± 1.22[a]	5.97 ± 0.96	8.29 ± 0.09[a]
	Air-V	9	31.3 ± 0.91	29.24 ± 0.60[a]	26.72 ± 1.4[a]	6.40 ± 0.57	8.30 ± 0.08[a]
	No Air	10	31.5 ± 1.04	30.18 ± 0.36[a]	29.53 ± 0.79[a]	6.33 ± 1.00	8.37 ± 0.05[a]
	RS Control	9	29.4 ± 0.94	27.27 ± 0.14[b]	36.45 ± 0.08[b]	6.26 ± 0.05	7.98 ± 0.02[b]

Table 3.2: A quantitative summary of eleven hematological parameters measured in adult and sub-adult Atlantic tarpon at rest and after angling. Blood composition from angled sub-adult tarpon were summarized by different three handling treatments, angling followed by 60 seconds of horizontal air exposure (Air-Horizontal), angling followed by 60 seconds of vertical dangling air exposure (Air-Vertical), and angling followed by no air exposure. The following response variables were measured from each tarpon: hematocrit (HCT, %), hemoglobin (Hb, (g/dL)), metabolites lactate (mmol/L) and glucose (mg/dL), the hormone cortisol (µg/dL), and select electrolytes calcium (mg/dL), sodium (mEq/L), potassium (mEq/L), chloride (mEq/L), phosphorus (mg/dL), magnesium (mEq/L). Non-stressed groups of adult and sub-adult tarpon are labeled as control and rapidly sampled control (RS-C), respectively. The mean concentration ± one standard error and sample size (n) are presented for each handling treatment and parameter. An asterisk (*) denotes a statistically significant difference of means between angled and control groups of adult tarpon compared with a Student's t-test ($\alpha = 0.05$). Mean concentrations among sub-adult handling treatments were tested with a one-way ANOVA ($\alpha = 0.05$). Dissimilar superscripted letters after a given concentration indicate statistically significant differences among handling treatments of sub-adult tarpon as determined post hoc with a Tukey Test. No letters next to the values would indicate no statistically significant differences among the four sub-adult handling treatments.

Table 3.2: Continued.

	Hematology		Metabolites		Hormone
Treatment	HCT	Hb	Lactate	Glucose	Cortisol
Adult					
Angled	46.9 ± 0.85*(41)	19.4 ± 0.36(29)*	10.5 ± 0.75(35)*	114.3 ± 4.02(38)*	0.8 ± 0.09(43)
Control	31.8 ± 2.99(6)	11.2 ± 1.73(4)	0.3 ± 0.20(6)	64.7 ± 5.43(6)	0.5 ± 0.16(6)
Sub-Adult					
Air-Horizontal	45.6 ± 1.15(9)[a]	15.9 ± 1.40(6)	3.5 ± 0.17(8)[a]	61.3 ± 2.94(9)	4.4 ± 1.34(9)
Air-Vertical	45.7 ± 1.83(9)[a]	17.3 ± 0.81(8)	3.7 ± 0.33(7)[a]	67.8 ± 5.88(9)	4.1 ± 1.09(9)
No Air	45.1 ± 1.22(10)[a]	17.5 ± 1.07(7)	4.4 ± 0.64(10)[a]	60.4 ± 4.44(10)	5.7 ± 1.27(10)
Control (RS-C)	38.8 ± 1.48(9)[b]	15.8 ± 0.87(7)	1.1 ± 0.20(8)[b]	64.2 ± 3.73(9)	3.5 ± .087(9)

Table 3.2: Continued.

	Electrolytes					
Treatment	Calcium	Sodium	Potassium	Chloride	Phosphorus	Magnesium
Adult						
Angled	15.9 ± 0.39(36)*	192.8 ± 1.99(27)*	5.4 ± 0.13(38)*	167.4 ± 2.53(37)*	10.0 ± 0.36(38)*	5.0 ± 0.29(38)*
Control	11.4 ± 0.41(6)	162.0 ± 1.95(6)	3.7 ± 0.14(6)	149.0 ± 2.22(6)	5.8 ± 0.16(6)	3.0 ± 0.32(6)
Sub-Adult						
Air-Horizontal	11.7 ± 0.36(9)	162.7 ± 3.09(9)	5.0 ± 0.16(9)	139.2 ± 4.38(9)	7.7 ± 0.41(9)	3.0 ± 0.11(9)[a]
Air-Vertical	11.7 ± 0.31(8)	164.3 ± 2.76(9)	5.2 ± 0.21(8)	142.4 ± 3.72(9)	7.3 ± 0.45(9)	3.5 ± 0.46(9)[a,b]
No Air	12.3 ± 0.34(10)	163.8 ± 3.97(10)	5.2 ± 0.20(10)	140.0 ± 5.67(10)	7.2 ± 0.63(10)	4.0 ± 0.48(10)[b]
Control (RS-C)	11.9 ± 0.23(9)	167.8 ± 1.85(9)	5.1 ± 0.17(9)	143.6 ± 2.50(9)	6.6 ± 0.20(9)	2.6 ± 0.08(9)[a,c]

Table 3.3: A size class comparison of the mean responses of eleven blood parameters to angling. The three sub-adult angling treatments were combined to represent angled, small tarpon since there were no significant differences detected among treatments. The following response variables were measured from each tarpon: hematocrit (HCT, %), hemoglobin (Hb, (g/dL)), metabolites lactate (mmol/L) and glucose (mg/dL), the hormone cortisol (µg/dL), and select electrolytes calcium (mg/dL), sodium (mEq/L), potassium (mEq/L), chloride (mEq/L), phosphorus (mg/dL), and magnesium (mEq/L). Ranked scores were used to compare the hematology concentrations using non-parametric Wilcoxon two-sample tests ($\alpha = 0.05$). The two non-significant tests are in bold. Only angled fish were used in these comparisons.

	Adult		Sub-Adult		Wilcoxon
Response Variable	Mean	S.E.	Mean	S.E.	Pr > |Z|
HCT	**46.9**	**0.85**	**45.4**	**0.79**	**0.0863**
Hb	19.4	0.36	17.0	0.61	0.0008
Lactate	10.5	0.75	3.5	0.28	<0.0001
Glucose	114.3	4.02	3.9	2.6	<0.0001
Cortisol	0.8	0.09	63.1	0.87	<0.0001
Calcium	15.9	0.39	11.9	0.2	<0.0001
Sodium	192.8	1.99	163.6	1.88	<0.0001
Potassium	**5.4**	**0.13**	**5.2**	**0.11**	**0.3334**
Chloride	167.4	2.53	140.5	2.65	<0.0001
Phosphorus	10.0	0.36	7.4	0.29	<0.0001
Magnesium	5.0	0.29	3.5	0.23	<0.0001

Table 3.4: Comparisons of blood chemistries, body size, angling duration and various handling times (PBH, TBT, BoatH, THT) from adult tarpon bled using caudal venipuncture (CV) and gill methods. Bleeding large tarpon from branchial vessels in the gill arch is a significantly quicker method for obtaining samples to measure immediate effects of angling (post-exercise). Arithmetic means on raw data are presented for cortisol and magnesium but statistical tests were performed natural log ($\log_e$) transformed data to meet assumptions of normality. Significant values (α=0.05) are in bold face. Variable abbreviations and descriptions are detailed in Appendix C.

	CV			Gill			Student T-test			Wilcoxon	
	N	Mean	± SE	N	Mean	± SE	T	df	P	Statistic	Pr>|Z|
HCT (%)	14	44.25	1.16	27	48.26	1.06	-2.37	39	**0.0230**	297.5	**0.0003**
Hb (g/LdL)	7	18	0.53	22	19.8	0.4	-2.32	27	**0.0283**	89.5	**0.0008**
Lactate (mmol/L)	10	12.54	1.54	25	9.72	0.82	1.75	33	0.0890		
Glucose (mg/dL)	12	110.2	6.13	26	116.2	5.19	-0.7	36	0.4909		
Calcium (mg/dL)	10	15.77	0.93	26	16	0.41	-0.26	34	0.7943		
Sodium (mEq/L)	12	197.6	5	25	190.5	1.62	1.34	35	0.2015		
Potassium (mEq/L)	13	5.99	0.25	25	5.09	0.12	3.73	36	**0.0007**		
Chloride (mEq/L)	12	170.3	7.3	25	166	1.5	0.59	35	0.5682		
Phosphorus (mg/dL)	12	11.33	0.54	26	9.32	0.42	2.81	36	**0.0008**		
Magnesium (mEq/L)*	12	5.89	0.78	26	4.58	0.2	1.73	36	0.1054*		
Cortisol (µg/dL)*	16	0.71	0.1	27	0.78	0.13	0.47	41	0.6389*		
TL (mm)	18	1881.7	32.9	27	1864.9	31	0.36	43	0.7197		
Weight (kg)	18	50.46	3.01	27	51.28	2.7	-0.2	43	0.8450		
Angling Duration (min)	18	28.8	4.7	27	18.04	2.06	2.09	43	**0.0236**		
PBH (min)	18	4.51	0.6	27	4.15	0.63	0.39	43	0.7012		
TBT (sec)	18	363.6	51.3	27	144.4	40.13	3.39	43	**0.0015**		
TBTgn (sec)	18	295.8	49.95	27	72.77	20.58	4.13	42	**0.0004**		
TBTgy (sec)	18	403.8	59.56	27	173.2	46.04	2.88	34	**0.0068**		
BoatH (secs)	18	586.5	68.15	27	396.1	56.3	2.15	43	**0.0373**		
BoatHgn (sec)	18	555.2	55.03	27	359.2	56.7	2.37	43	**0.0225**		
BoatHgy (sec)	11	706.9	76.4	25	431.7	58.4	2.7	34	**0.0106**		
THT (min)	18	39.24	5.15	27	25	2.17	2.55	43	**0.0179**		

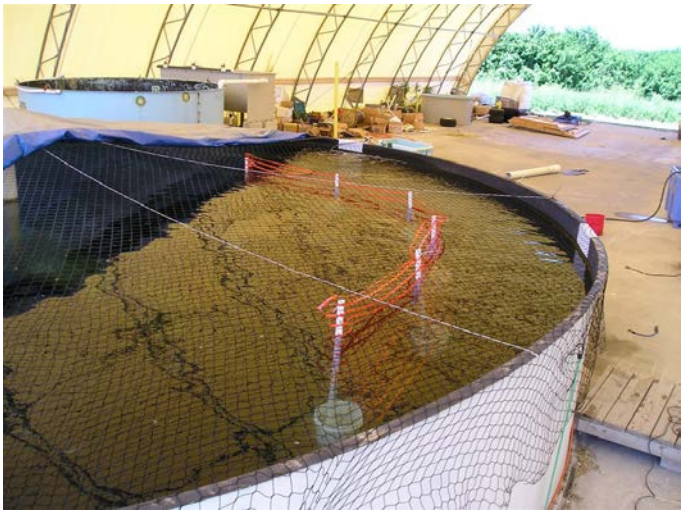
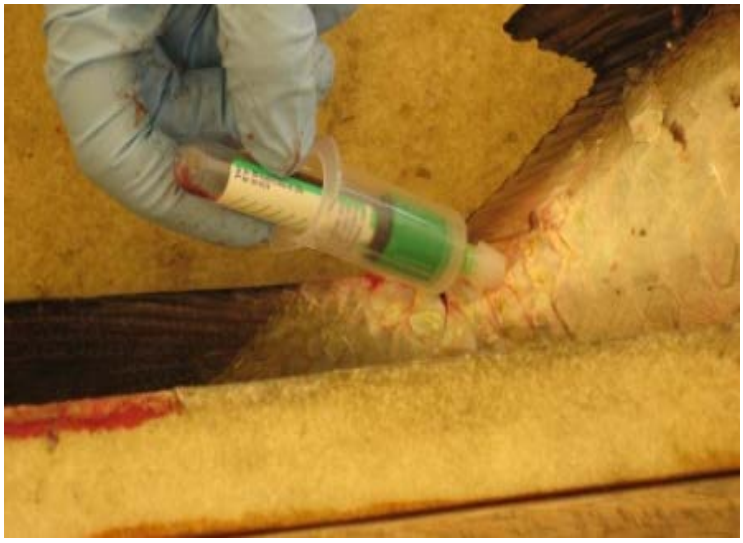


Figure 3.1: Holding tanks for sub-adult (rear) and adult tarpon (front) control groups.

Figure 3.2: Depictions of two handling treatments for sub-adult tarpon. (A) angling followed by 60 seconds of air exposure while being held horizontally out of the water (Air-H), and (B) angling followed by 60 seconds of air exposure while being held vertically out of the water (Air-V). Images used with permission from the FWC-FWRI.

A.



B.

Figure 3.3: Drawing blood using caudal venipuncture methods in a sub-adult tarpon (A) and drawing blood from the branchial vessel in a gill arch from an adult tarpon (B). Images used with permission from the FWC-FWRI (A) and BobTheriault (B).

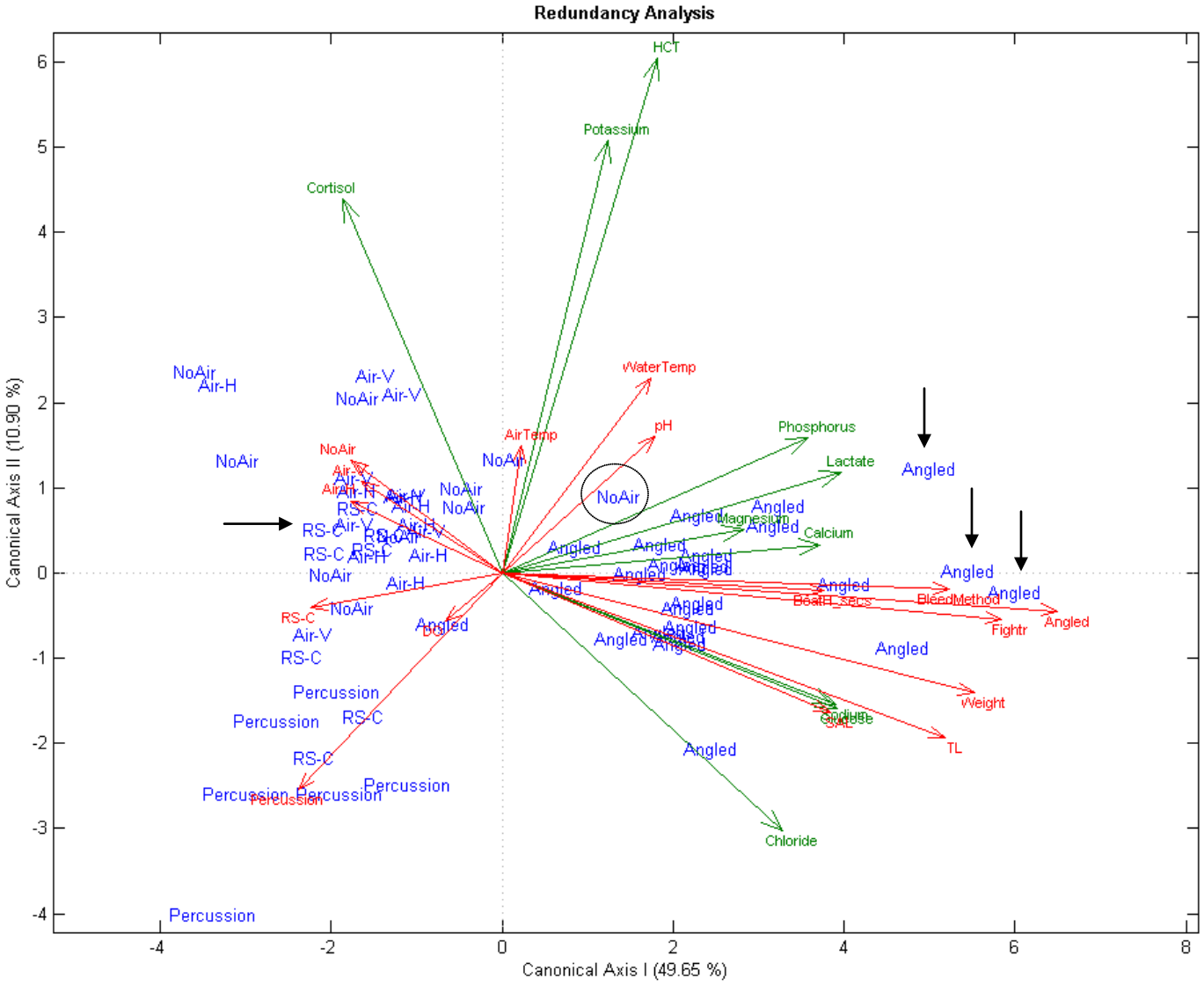

Redundancy Analysis
Canonical Axis I (49.65 %)
Canonical Axis II (10.90 %)
HCT
Potassium
Cortisol
WaterTemp
pH
AirTemp
Phosphorus
Lactate
Magnesium
Calcium
Chloride
Weight
TL
Fightr
NoAir
Air-V
Air-H
RS-C
Percussion
Angled

Figure 3.4: Results of a multivariate non-parametric redundancy analysis examining the variance of tarpon blood responses for all handling treatments. Each labeled point (blue) represents one tarpon (n=64). The spatial distance between points represents the similarity of the tarpon's response (closer is more similar). Adult handling treatments were labeled as Angled or Percussion (control animals). Sub-adult handling treatments were labeled as Air-H (angled followed by 60 seconds of air exposure while being held horizontally out of the water), Air-V (angled followed by 60 seconds of air exposure while being held vertically out of the water), No Air (angled followed by no air exposure), or RS-C for the rapidly sampled control group. Hematological (response variables, green), and predictor variables pertaining to the angling events (in red) were used in the model. For predictors (red), the vector lengths indicate the relative strength of the relationship with the response data. The longer vectors are more influential on the tarpon's blood response. Predictor variables include Air Temp (°C), Water Temp (°C), dissolved oxygen (DO), salinity (SAL), pH, total length (TL), weight, angling duration (Fightr), bleed method, and handling times (BoatH_secs). Handling times used in the model combined the amount of time the fish was handled at the side of the boat or by the bank of the pond before it was bled plus the amount of time it took to bleed the tarpon. For response vectors (green), the magnitude is proportional to the contribution that blood parameter makes to the patterns depicted in the multivariate space by the biplot. Result are given for the primary and secondary axes which accounted for 60.55% of the total variance in the observed data (adjusted r-squared = 0.633, $p = 0.001$).

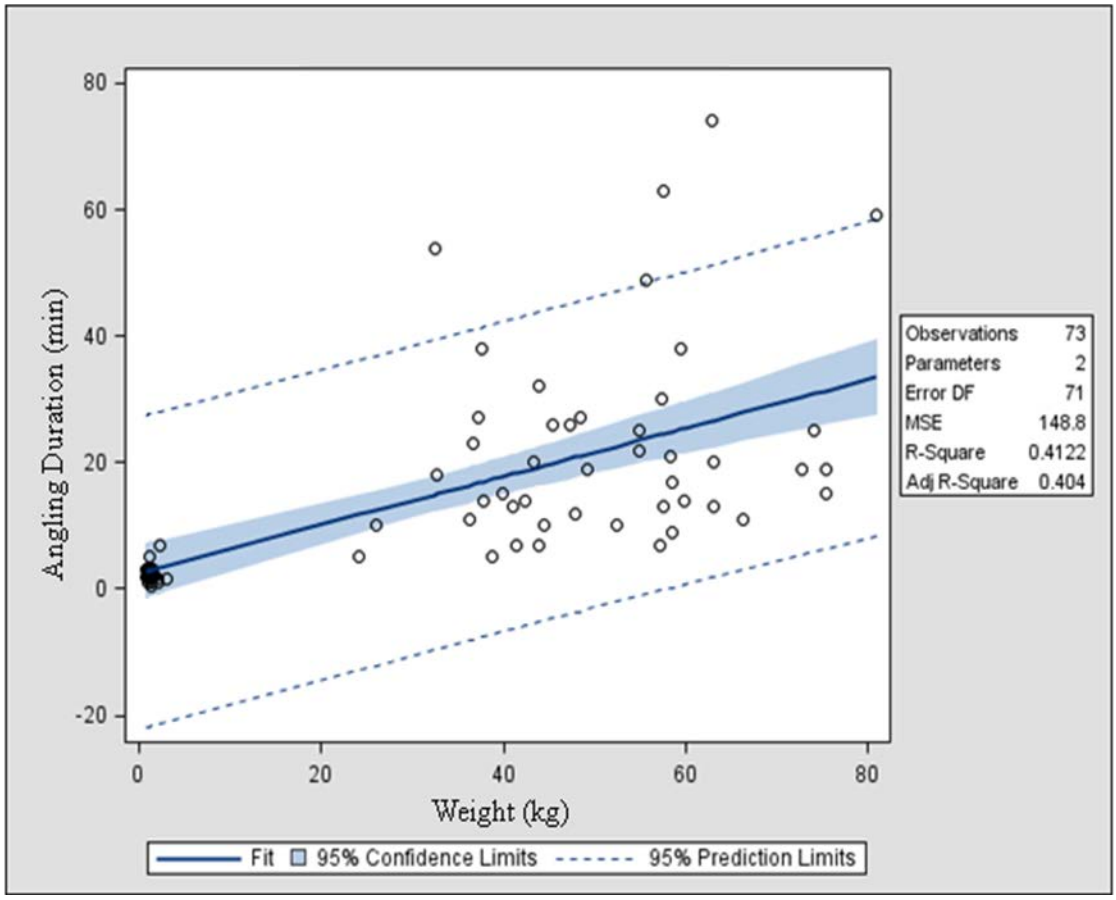


Figure 3.5: Larger tarpon take significantly longer to land in the recreational fishery. Depicted is the weight (in kilograms) by angling duration (in minutes) regression for combined size classes of angled tarpon: $Y = 2.4847 + 0.38305$ (Weight); $p<0.001$.

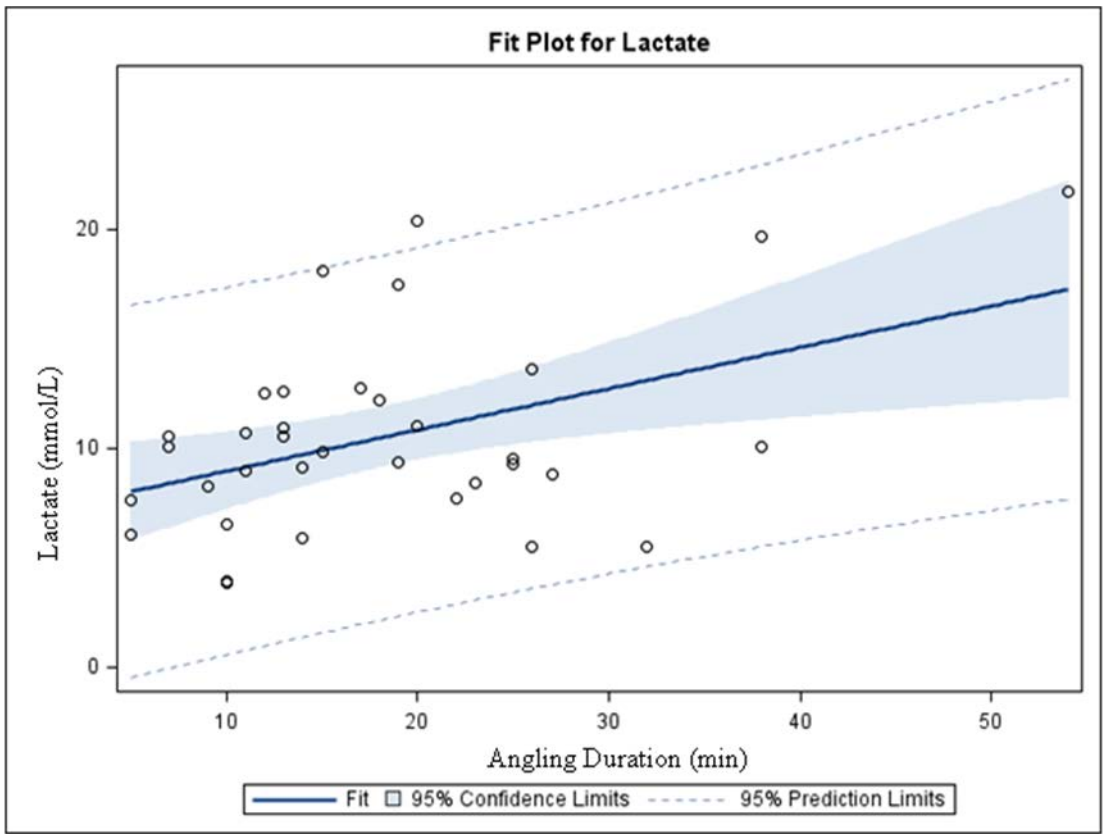


Figure 3.6: Linear regression of angling duration (in minutes) on plasma lactate concentrations in adult tarpon. The multiple regression equation for the lactate model is Y = 3.749575 + 0.10622 (Fight) + 0.00966 (Handling), (R^2 = 0.567, p<0.0001).

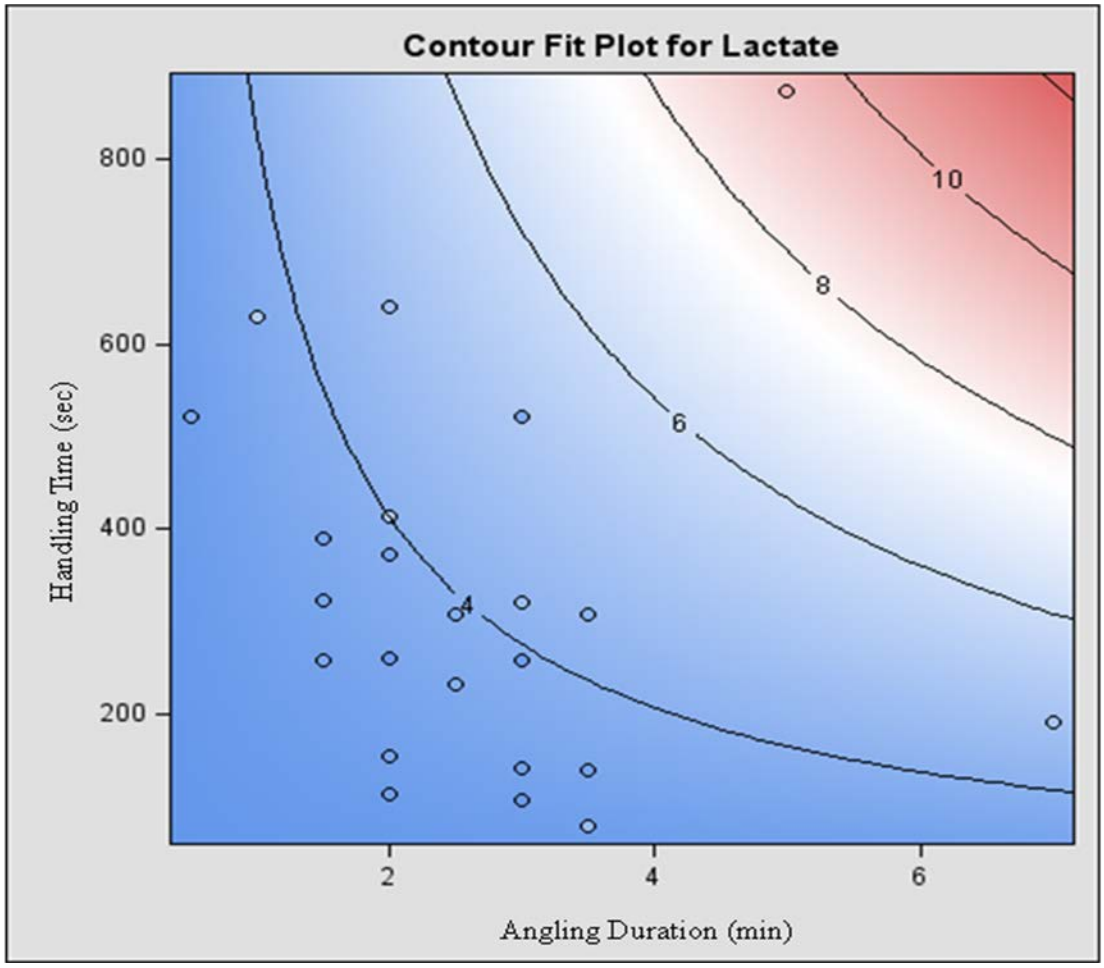


Figure 3.7: A visualization of the interaction effect between angling duration (in minutes) and handling time (in seconds) on lactate in sub-adult tarpon. Handling time is the combined time of pre-bleed handling plus total bleed time. The reduced multiple regression equation for the lactate model is Y = 2.7687 + 0.0015(Fight*Handling) (R^2 = 0.134, $p<0.0001$).