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

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

by

Kathryn Yvonne Guindon

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy
College of Marine Science
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DEDICATION

I dedicate this work to the hundreds of volunteer tarpon anglers and professional guides of Florida who supported me through the good, the bad and the ugly to get this accomplished. Without your support and aggravating frustrations I might not have been inclined to persevere through this. Your attitudes, comments, camaraderie, consideration and respect helped me to create an even better product than it would have been without your influence. I have grown and matured beyond what words can describe through my interactions with tarpon and tarpon anglers while doing this work on personal, professional and emotional levels. I have gained family and friends and a new understanding of and outlook on life, believe-it-or-not. I trust that you know who you are. There are too many to list.

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ABSTRACT

Atlantic tarpon are sought after because of their fighting ability on various tackle and support a popular, lucrative and predominantly catch-and-release recreational fishery in Florida. They are not commercially harvested or consumed by the general public, therefore assessing effects of catch-and-release angling on tarpon survival is critical to a sustainable fishery. Tarpon caught on artificial breakaway jig and traditional live bait fishing charters in Boca Grande Pass (n=42) and trips from the recreational fishery of Tampa Bay (n=40) were tagged with ultrasonic transmitters and tracked up to 6 hours immediately following release to estimate post-release mortality. Of the 82 tagged tarpon, 11 suffered mortality as inferred from movement patterns (or lack thereof) or visual confirmation (i.e. shark attacks) which yields a combined total estimated catch-and-release mortality rate of 13% (95% confidence interval: 6-21%). There was no significant difference in mortality between the two estuarine systems. Associations between tarpon mortality and angling duration, handling time, fish length, bait type (artificial versus natural), and hook type (circle versus “J”) were not significant. Hook location (foul-hooking) and swimming condition at release were significant factors on tarpon mortality (P<0.05). Shark predation was the primary cause of post-release mortality (64%). Excluding predation, the overall mortality rate was estimated at 5% and attributed to poor handling and irreparable physiological damage from angling.
Angling events will cause anaerobic activity resulting in physiological disruptions that may have consequences compromising the health and survival of tarpon. Both adult (mature, >70 pounds, 31.8 kg) and sub-adult (sexually immature, <20 pounds, 9 kg) tarpon support Florida’s recreational fishery, so maximizing post-release survival and minimizing sub-lethal stress effects of both size classes are critical to their sustainability.

In this study, stress responses after exhaustive exercise (angling) were measured using an array of blood chemistry parameters, including hematocrit, hemoglobin, and plasma glucose, lactate, sodium, potassium, chloride, calcium, phosphorus, magnesium and cortisol. Angled, adults (n=45) were compared to large tarpon in a resting state (controls, n=6). Angled, sub-adults (n=28) were compared to those in a resting state (n=9). Adult tarpon were then compared to sub-adults to determine any size-related, intra-species variation in stress responses after angling. Finally, because smaller tarpon are logistically easier to handle and may be subjected to prolonged air exposure by anglers for hook removal or photographs, we evaluated the effect of 60 seconds of air exposure with horizontal (n=9) or vertical (n=9) handling out of the water relative to non-air exposed (n=10) fish in angled sub-adult tarpon. Associations and interactions among the blood chemistry responses of tarpon from each treatment to angling duration, handling time, body size and environmental factors related to each capture event were evaluated using a non-parametric, multivariate redundancy analysis. The duration of the angling event had a positive effect on responses of some parameters, and responses were more extreme in adult tarpon than sub-adults. The exception was cortisol which was significantly higher in sub-adults. Environmental parameters were less influential than angling and handling on observed physiological responses. Sub-adults showed no difference in physiological
responses among handling treatments with and without air exposure and exhibited no short term mortality. Using appropriate tackle and gear to reduce fight times and handling should help minimize metabolic and acid-base imbalances.

Tagging studies coupled with physiology can be a valuable tool for estimating post-release mortality and secondary stress responses of game fish, especially for large species that might be difficult to maintain in floating pens or tanks. Yet adverse effects of catch-and-release angling could also have population level consequences. Future studies should integrate biology and fish physiology to evaluate post-release recovery windows and establish lethal thresholds to provide potential predictive capability of mortality. In general, it appears that sub-adult and adult Atlantic tarpon along the Gulf coast of Florida can recover from physiological disturbances incurred during routine catch-and-release angling events in the recreational fishery when they are released in the absence of large predators. The anglers themselves can play a key role in tarpon conservation.
CHAPTER ONE:

A GENERAL INTRODUCTION TO CATCH-AND-RELEASE ANGLING
AND THE TARPON FISHERY IN FLORIDA

A common practice when fishing with a hook and line, or angling, in recreational fisheries is the practice of catch-and-release which dates back to the early 15th century, in a printed treatise from 1496 or earlier (McDonald 1957). Catch-and-release tournaments have been documented in Britain since the late 1800s (Policanksy 2002). In more modern times, it was determined that current participation in recreational fishing varies between 1% and 40% by country and that recreational anglers account for 12% of the global harvest (Cooke and Cowx 2004).

In North America, the practice of catch-and-release is a frequently required management tool in marine and freshwater systems where fishing regulations impose minimum and maximum size limits and closed seasons on various species of fishes. An assumption of catch-and-release is that fish released alive back into their environment will survive and thus help maintain sustainability of the stock (Pollock and Pine 2007). Published articles that recognize the impact of commercial and recreational fishing on fish stocks (Schroeder and Love 2002, Coleman et al. 2004, Cooke and Cowx 2006) and that increase the awareness of animal welfare issues (Arlinghaus 2007) are causing angling ethics to change. More anglers are voluntarily releasing their fish as personal incentives to fish shift to non-retention factors such as improving their skills, being
outdoors, or fishing for sport depending on the species’ availability rather than retention factors (*i.e.* for food) (Calvert 2002). As long as the anglers’ motivations for fishing are satisfied without keeping their catch, they will continue fishing potentially resulting in increased fishing pressure.

One of Florida’s tourism campaigns promotes the state as being the Fishing Capital of the World. More than $5.4-billion is generated from Florida’s saltwater recreational fishery which outranks the state’s cattle and citrus industries (2006 US Fish and Wildlife Service Report). The number of fishing licenses sold (resident and non-resident), the average number of for-hire licenses sold to small vessels (up to four passengers), and the average number of registered vessels (fresh and saltwater) in the state have all increased from 1982 through 2007 (Hanson and Sauls, in prep). If Florida’s human population growth continues to increase as it has (Bureau of Economics and Business Research, http://www.bebr.ufl.edu/), and increasing trends in the sale of fishing licenses and registered vessels continue, it seems intuitive that more people will want to fish state waters as demonstrated in recent reports (Harper *et al.* 2000, Ault *et al.* 2005). It becomes imperative to understand the potential fate (lethal or sublethal) of all released fishes, whether they were released for regulatory or voluntary reasons. If government, biologists, resource managers and anglers take proactive steps to create successful and sustainable catch-and-release fisheries, it may make it easier for the angling public to accept more stringent management plans if deemed necessary for a fishery (Schramm & Gerard 2004). Yet, it is important to acknowledge from the start that there are mortalities associated with catch-and-release angling.
Two quite lucrative and extremely popular sport fisheries in Florida, bonefish and Atlantic tarpon, are already predominantly catch-and-release, as they are not commercially harvested or consumed by the general public (Bruger and Haddad 1986). Both species are economically important and support large recreational fisheries, so maximizing post-release survival and minimizing stress associated with angling are critical to the continued success of these fisheries.


Most studies on Atlantic tarpon have examined the early life history stages. Adult tarpon spawn presumably offshore, making spawning migrations from inshore feeding
areas to offshore spawning grounds as inferred from 3- to 6-day-old leptocephalus larvae collections made as far as 250 km off the west coast of Florida (Crabtree et al. 1992). Leptocephali go through three distinct growth phases. Crabtree et al. (1992) estimated ages of the Phase I larvae collected from 2 to 25 days and growth rates of ca. 0.92 mm per day. A Phase I leptocephalus typically resides in oceanic waters for 30 to 50 days, though this phase can be shortened to two to three weeks with the aid of storm events (Crabtree et al. 1992, Shenker et al. 2002). Phase II begins at the onset of metamorphosis where larvae shrink in size from about 26mm to 14mm (Harrington 1966). This metamorphosis takes place as they come inshore and are potentially triggered by environmental cues (Cyr 1991) that may induce the required changes to occur (Shiao and Hwang, 2006). Phase III is reflected by resumed positive growth through cycloid scale formation and is finished upon tarpon reaching sizes of ca. 40mm in length (Harrington 1958, Harrington and Harrington 1960). Phase II and Phase III larvae and juvenile tarpon will inhabit stagnant, back water, marsh and mangrove lined areas that are low in dissolved oxygen and high in organic matter (Robins 1977, Zerbi et al. 2001).

Juvenile tarpon (ca. 40mm to 300mm) remain in back-water habitats to feed and grow to attain sizes less vulnerable to predation (Breder 1944, Harrington and Harrington 1960, Poulakis et al. 2002). They are bimodal breathers and use their swim bladders as air-breathing organs, so these seemingly adverse and physiologically demanding habitats for most fishes are inhabitable for tarpon where they probably experience low predation rates and have little competition for resources (Schlaifer and Breder 1940, Geiger et al. 2000). Once attaining sizes of 250 to 400mm, juvenile tarpon start to venture out of these
back-water areas to upper estuarine, mangrove creeks and canals, and even into the rivers (Rickards 1968, Cyr 1991).

Atlantic tarpon are large fish that can attain lengths of over 2m and weights over 100kg (International Game Fish Association, 2008 World Record Game Fishes) and are a long-lived species (Crabtree et al. 1995) with ages that may exceed 78 years (Andrews et al. 2001). Growth is rapid until approximately age 12 when it slows considerably after sexual maturity (Cyr 1991, Crabtree et al. 1995). Based on Crabtree et al. (1997), the average size of sexual maturity for female tarpon in Florida is 1,285mm (51.4 inches) and 1,175mm (47 inches) for males and adult tarpon sexually mature by age 10. Only one female examined in that study was mature at a younger age (7) and she was unusually large for her age. From tarpon examined in Crabtree et al. (1997), it was determined that the spawning season in Florida lasts from April to July and by August 90% were spent; yet in other more tropical locations such as Costa Rica spawning may be year-round.

Despite this knowledge of tarpon biology and life history, relatively little is known about the tarpon fishery in Florida. State regulations implemented a two-fish daily bag limit in 1952 that is still in place today (2010) and granted tarpon gamefish status in 1953, so they could not be commercially harvested or sold. By the 1970’s, taxidermy was a booming million-dollar industry that provided a mainstay for many small Gulf-coast establishments and tarpon were killed routinely for mounts (Wade and Robins 1973). Yet, tarpon taxidermy records show that the number of fish mounted each year began to decline in the mid-70’s through the 1980’s (Crabtree unpublished data, 1990, Figure 1.1). Pflueger Taxidermy in particular offered a $50.00 cash incentive to customers who would try a fiberglass tarpon mount over a skin mount which helped to shift the focus of Florida
anglers from catch-and-kill to a more conservation oriented concept of catch-and-release (Capt. Bouncer Smith, personal communication, Miami).

Today tarpon harvest rates are low in Florida. In 1989, a new law was enacted and the harvest of tarpon became regulated by Florida Statute 370.062. The tarpon tag program, which allows for the harvest of tarpon through purchase of a permit (tag), is managed by the Florida Fish and Wildlife Conservation Commission (FWC). Any angler wanting to harvest or possess a tarpon must purchase a $50.00 permit and pay an additional $1.50 fee at a county tax collector office. Every angler who purchases a tarpon tag must also submit a return card at the end of year to report that tag’s use or expiration. Data from angler return cards in the FWC Tarpon Possession Tag program show that since fiscal year (FY) 2003-2004, 27 or fewer tarpon were killed annually, but non-compliance by anglers who forget to return their card is over 70% (Guindon unpublished data). Therefore, using numbers of permits sold as a proxy for harvest is a more conservative estimate of potential harvest. Only 282 tarpon permits were issued in FY 2008-2009 as compared to the 961 permits sold in 1989, and from FY 1993-1994 through FY 2008-2009, the maximum number of tarpon permits sold annually statewide was 534 (mean 341, Figure 1.2). The tarpon permit program seems to have substantially reduced the number of tarpon being harvested statewide. The acceptance of this shift in management was mostly positive and the fishery has evolved into a de facto catch-and-release fishery (Nelson 2002).

Most of the potential deleterious effects on tarpon populations (lethal or sub-lethal) will stem from the practice of catch-and-release fishing since most tarpon caught in Florida are released alive. However, there are no realistic monitoring programs in
place to evaluate or record fishing effort for Atlantic tarpon. To put this in perspective with respect to other species, the 2002 Florida angler intercepts recorded in the federal Marine Recreational Fisheries Statistics Survey (MRFSS) reported that more than 28,200 spotted sea trout, 5,700 red drum and 5,200 snook were harvested by recreational anglers that year (Table 1.1). This same survey intercepted only 128 anglers targeting tarpon who caught 178 fish of which one was harvested for the entire year (Table 1.1). Observations made on the waterways during peak tarpon season (May-June) in prime locations along the central Gulf Coast showed that numbers of recreational anglers and guides targeting this sport fish may exceed 70 boats with more than 100 anglers fishing on any given day (Guindon unpublished data). This far exceeds the 128 anglers intercepted during the given year (2002). There is extensive fishing pressure on tarpon stocks around the state and the tarpon season varies by region (Figure 1.3).

There is a need to discern whether or not a tarpon can withstand the fishing pressure placed on them by anglers. Fishing for giant tarpon is promoted on television, radio, websites, and in popular literature. News of popular fishing locales and advertisements of “required” equipment for successful fishing trips are now public domain through the internet, cellular telephones, and technical GPS navigational tools that will save your “spot” (Cooke and Cowx 2006). As the tarpon fishery is promoted, angler awareness increases, and fishing pressure may increase. Increasing recreational fishing effort can lead to more tarpon being caught and released, the effects of which are mostly unknown. In the case of common snook, where many anglers choose to practice catch-and-release or are required to release their fish because of regulated size and bag limits, studies indicate that the catch-and-release mortality of released snook is actually
approaching rates as high as if there were commercial harvest on the fishery (Muller and Taylor 2002). With time, these cryptic mortality rates can have significant population level effects some of which could arguably be equated to issues of by-catch and discards in the commercial fishing industry (Cooke and Cowx 2006, Coggins et al. 2007).

Little is known about the post-release survival of tarpon. Fishes can die from the stress of exhaustive exercise such as that experienced by a tarpon during angling (Wood et al. 1983). If the duration and magnitude of the stressor, such as angling or improper handling of the fish, is beyond biological tolerance limits of the tarpon, the fish may suffer short-term mortality (within 0 to 6 hours) or delayed mortality (> 6 hours, Figure 1.4). In many mortality studies, fish are released into net pens for observation of post-release mortality (Malchoff and Heins 1997, Carbines 1999, Grover et al. 2002, Pope and Wilde 2004, Millard et al. 2003, Suski et al. 2004). Delayed mortality experienced by some of those fishes confined to pens for several days or weeks may have been attributed to caging artifacts and therefore bias mortality rate estimates. Adult tarpon are active, large, coastal pelagic teleosts and logistically are not conducive to net pen studies for post-release observations. Furthermore, net pens exclude predators which may have a significant effect on post-release mortality (Cooke and Philipp 2004), so catch-and-release mortality studies on tarpon in their natural environment where the fishery occurs would be best. Studies show that terminal tackle, hook locations, bait type, fight times, and angler experience can all affect the survival of released fishes (Muoenke and Childress 1994). The need to estimate post-release survival rates and evaluate the potentially lethal effects of tackle and angling duration for tarpon is a logical next step for protecting Florida stocks.
There have been no studies on the physiological sub-lethal effects of catch-and-release angling on Atlantic tarpon. Angling can cause physical and physiological damage to the fish which evokes a stress response that may have lethal or sub-lethal consequences (Mazeaud et al. 1977, Skomal 2006, Figure 1.4). Physical damage might include hook wounds, excessive bleeding, tissue tears or damage due to improper handling when removing the hook, holding the fish while taking a photo, tagging or gaffing the tarpon at the side of the boat, or be caused by predation. Physiological damage is reflected in the resultant imbalances that can occur internally via the interlinked cardio-vascular, respiratory, endocrine, nervous, immune, gastro-intestinal, and musculoskeletal systems causing a fish to respond and adapt to the angling event (Young et al. 2006). Tarpon are very aggressive, fight with great strength and stamina, and are known for acrobatic leaps into the air when hooked, all of which could exacerbate damage incurred during angling events. The damage causes stress (acute or chronic) to the animal.

Immediate stress responses in fishes are the primary effects mediated from the hypothalamus-pituitary-interrenal pathway or via chromaffin cells that trigger the release of catecholamines (i.e. adrenaline) and corticosteroids into the blood stream (Mazeaud et al. 1977, Figure 1.4). This is an alarm response on the order of seconds to minutes. In turn, these hormones trigger a compensatory response via secondary effects that are reflected in acid-base imbalances (metabolic and respiratory acidosis), electrolyte imbalance, glycogen depletion, lactate production, immunosuppression, and increased cardiovascular function as the animal begins to adapt and attempts to regulate back to normal, pre-stress conditions (Mazeaud et al. 1977, Wood 1991, Wendelaar Bonga 1997, Kieffer 2000). The level of disturbance as indicated through changes in these
physiological stress responses can be measured from a blood sample of the stressed animal when compared relative to a non-stressed animal or relative to the magnitude of the source of stress, such as angling and handling times or water temperatures.

The cascade of stress effects caused by physiological damage can often be regulated back to normal but at a high energy cost to the fish. A tarpon may adapt and recover from the stress of angling, as was observed in an Australian study on the Atlantic tarpon’s congener *Megalops cyprinoides* (Wells *et al.* 2003). However, if an Atlantic tarpon survives, but is unable to regulate back to normal, the cumulative impacts of chronic stressors on tarpon may affect the organism in more subtle, sub-lethal ways. These are termed tertiary effects (Mazeaud *et al.* 1977, Figure 1.4). In time, tertiary effects can have population-level implications such as reducing growth rates, reducing reproductive success, reducing spawning stock biomass, diminishing successful recruitment to the next life history stages, or reducing overall fitness (Wedemeyer *et al.* 1990, Cooke *et al.* 2002). Given the potential tertiary effects of angling on tarpon and understanding that tarpon are a periodic species, long-lived with delayed maturation and long generation times (Winemiller and Rose 1992, Winemiller and Dailey 2002, Schroeder and Love, 2002), one needs to also consider the effects of angling at the earlier life history stages also targeted in Florida’s fishery (Ricklefs and Wikelski 2002, Young *et al.* 2006).

This dissertation addresses the effects of catch-and-release fishing on survival and physiological stress responses of Atlantic tarpon caught along Florida’s central and southwest Gulf Coast. Chapter two is an observational study of guided tarpon trips that use two predominant tarpon fishing methods in Boca Grande Pass, a world famous tarpon
fishing destination, and the recreational fishery of Tampa Bay. The study estimates the short-term post-release mortality rates using acoustic telemetry and examines the effects of estuary, angling duration (fight times), handling time, fish size, bait type, hook type, hook location, and the condition of the fish at release relative to survival. A summary of tarpon movements after release is also presented. Chapter Three quantifies the physiological response of two size classes of tarpon to exhaustive exercise (angling) as determined from changes in select blood parameters. Chapter Three also examines the physiological response of angled sub-adult tarpon to effects of air exposure and varying handling practices prior to release. The level of disturbance for each selected blood parameter is then evaluated relative to angling duration, handling time, fish size and environmental variables. The final chapter summarizes findings from the current work into useful science-based guidelines for anglers and managers to increase post-release survival and minimize stress of tarpon caught-and-released in Florida’s recreational tarpon fishery in an effort to keep it sustainable.

**Literature Cited**


Crabtree, R.E. 1990. Summary of tarpon permit data and progress on tarpon life history research. State of Florida, Department of Natural Resources, Florida Marine Research Institute, St. Petersburg, Fl.


Hanson, C.W. and Sauls, B. 2011. Status of recreational saltwater fishing in Florida: characterization of license sales, participation, and fishing effort. (in prep) Bethesda, Maryland, USA: American Fisheries Society.


Table 1.1: Reported number of angler intercepts and number of fish harvested for select inshore fishes in Florida during 2002. East and Gulf Coast data were combined. Data are from the NMFS, Marine Recreational Fisheries Statistics Survey database.

<table>
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<th>Species</th>
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<tr>
<td>Red Drum</td>
<td>2,274</td>
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<td>178</td>
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<tr>
<td>Harvested Tarpon</td>
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<tr>
<td><strong>Total Angler Intercepts</strong></td>
<td><strong>52,643</strong></td>
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</tbody>
</table>
Figure 1.1: Numbers of tarpon mounted by Pflueger Taxidermy from 1975 to 1990. Plot reproduced from an unpublished State of Florida report (Crabtree 1990; FWC, formerly Department of Natural Resources).
Figure 1.2: Total number of $50.00 tarpon harvest and possession tags issued by the state of Florida since July 1, 1993. Numbers are reported by fiscal years (i.e. 9394 is the Fiscal Year from July 1, 1993 to June 30, 1994).
Figure 1.3: Images depicting examples of intense recreational fishing pressure for tarpon along Florida's Gulf coast. Images show evening fishing in BGP (A) daytime fishing in Tampa Bay (B) holiday weekend fishing on Memorial Day in Boca Grande Pass (C) and during tarpon tournaments (D).
Figure 1.4: A flow diagram summarizing some potential effects of catch-and-release angling on tarpon. Figure is adopted from Mazeaud et al. 1977 and Skomal 2006.
CHAPTER TWO:
AN OBSERVATIONAL STUDY ON THE ATLANTIC TARPON FISHERY IN BOCA GRANDE PASS AND TAMPA BAY TO ESTIMATE SHORT-TERM CATCH-AND-RELEASE MORTALITY

Introduction

Atlantic tarpon (Megalops atlanticus) have a history in Florida for being one of the most highly sought inshore sport fish in state waters (Mygatt 1890, Oppel and Meisel 1987). They are known for their acrobatic prowess and fight and the popularity of this gamefish supports a rapidly growing recreational fishery that contributes significantly to the state’s economy (Barbieri et al. 2008, Fedler 2011). Tarpon are commonly encountered in coastal and inshore waters throughout the state where people can fish for them from land and by boat using a variety of fishing techniques, gear (fly, spinning, conventional), baits, and tackle.

State regulations require anglers to purchase a $50.00 jaw tag (i.e., a permit) to harvest or possess a tarpon. The number of tarpon tags sold and used each year has been used as a proxy to estimate annual harvest; however, current regulations have created a predominantly catch-and-release fishery. In a catch-and-release fishery, the sustainability of local stocks relies on the assumption that most fish being caught and released will survive (Pollock and Pine 2007). Yet the reality is that a released tarpon could suffer potentially lethal or sub-lethal effects that may eventually have population-level effects.
on behavior, growth, or reproductive success (Mazeaud et al. 1977, Wood et al. 1983, Cooke et al. 2002).

The most severe endpoint of catch-and-release fishing is death of the fish. Lethal responses of fish to angling events are species specific, and there is much within species variation (Cooke and Suski 2005). Many fisheries studies have measured lethal effects of catch-and-release angling and associated factors contributing to mortality. A review paper by Muoenke and Childress (1994) summarized literature on 32 different taxa (marine and freshwater species) and found that most mortality occurs within 24 hours. They generally concluded that hooking mortality increases with the following: increasing water temperatures, increasing depth due to barotrauma, lowering dissolved oxygen levels, the length of the fish, single hooks as opposed to treble hooks, barbed hooks rather than barbless hooks, fish hooked in the gills or esophagus rather than non-vital areas, and when using natural baits rather than flies or lures. If post-release tarpon survival is in fact low, the future health of local stocks could be reduced since it is often the dense aggregations of reproductively mature fish during peak spawning season (May-June) that are exploited in the fishery. Survival studies would be beneficial to potentially identify ways to maximize post-release survival and minimize stress responses and promote the continued success of this fishery in the near absence of harvest; however, surprisingly little is known of the fates of tarpon after catch-and-release.

To date, only one study (Edwards 1998) has evaluated post-release survival of tarpon caught along the southwest Florida coast using acoustic telemetry in one of the world’s premier tarpon fisheries, Boca Grande Pass (Barbieri et al. 2008). Underwater telemetry has been successfully used to estimate mortality rates in marine fishes such as
sailfish (Jolley and Irby 1979), black marlin (Pepperell and Davis 1999), tunas (Skomal 2006), various sharks and rays (Sundstrom et al. 2001, Gurshin and Szedylmayer 2004, Skomal 2006), and bonefish (Cooke and Philipp 2004, Humston et al. 2005, Danylchuk et al. 2007a). Drawbacks of Edward’s study (1998) were its limited sample size and witness of one mortality. With the increasing awareness and growing popularity of the Boca Grande Pass tarpon fishery since Edwards’ study (1998), there was growing public concern that the subsequent fishing pressure and reports of increased shark predation in the pass could be affecting the numbers of tarpon locally available and cause the overall population to decline.

Tampa Bay also supports a large recreational catch-and-release tarpon fishery with intense fishing pressure during peak spawning season. Because of its location between the two major metropolitan areas of Tampa and St. Petersburg, Tampa Bay has many residential saltwater anglers. A five year record (fiscal year 0405 to 0809) showed that Hillsborough and Pinellas counties in the Tampa Bay area outnumbered sales of residential saltwater fishing licenses in Lee and Charlotte counties bordering Charlotte Harbor by more than 55,600 (Florida Fish and Wildlife Conservation Commission, Licensing and Permitting, unpublished data). Sales of tarpon tags during that same five-year interval were also higher in these two Tampa Bay counties (n=646) than Charlotte Harbor counties (n=548). Hundreds of tarpon anglers also participate in catch-and-release tournaments that are sponsored by local universities, private community groups, cities, and fishing clubs in both locations. Because of their proximity to each other and their growing tarpon sport fisheries, Boca Grande Pass and Tampa Bay were chosen to
represent the southwest and central Gulf Coast fishery in an investigation to re-evaluate post-release survival of tarpon.

The primary objective of this study was to obtain estimates of short-term, catch-and-release mortality rates for tarpon in Boca Grande Pass and Tampa Bay using acoustic telemetry. Secondary objectives were to evaluate the potentially lethal effects of catch-and-release fishing practices relative to angling duration (fight time), handling time, fish size, bait type, hook type, hook location (foul-hooking), and fish condition at release on tarpon mortality.

Methods

Boca Grande Pass (BGP) is a deep-water pass that is the primary inlet into Charlotte Harbor in southwest Florida. The boundaries of the pass have been defined by the Florida Fish and Wildlife Conservation Commission for regulatory purposes and are used in various tarpon tournaments (Figure 2.1A). The pass contains hard bottom and limestone ledges and is bordered with shoals to the north and south.

Tampa Bay (TB) is a shallow-water estuary located along the west central coast of Florida. The distribution of the Tampa Bay fishery (Figure 2.1B) is geographically more widespread than that observed within the boundaries of BGP. Angling for tarpon occurs throughout the bay (upper, middle and lower) and along adjacent Gulf of Mexico beaches (Figure 2.1A).

Sampling was conducted during a ten week period from late April to the first week of July in 2002 to 2004 in BGP, and from late April through August of 2005-2007 in TB with a goal of tagging a minimum of 30 tarpon in each location. Sampling effort in BGP was distributed among 36 professional fishing guides that used either traditional
live-bait or artificial breakaway jigs fishing methods on their charters; the two predominant tarpon fishing methods in BGP. In Tampa Bay, effort focused on either roving areas with high concentrations of tarpon anglers, such as the Sunshine Skyway Bridge in lower Tampa Bay or Egmont Channel at the mouth of the bay, or shadowing pre-arranged tarpon fishing trips. Cooperating trips in TB included both professionally guided and strictly recreational vessels.

In BGP, a research biologist accompanied one guided charter per day while two other biologists waited in a state research vessel to track the tagged tarpon. In TB, all three biologists were on the research vessel from the start of the trip. If any angler was observed hooking a tarpon during a roving trip, the research vessel approached the angler’s vessel to ask permission to tag it. If it was an arranged trip, staff would simply approach to tag the tarpon after being given an approving signal from the angler or guide.

Anglers and guides provided the tackle themselves and paying customers on the guide boats or recreational anglers did the fishing in most cases. Occasionally a guide fished or at least hooked the tarpon for a customer. No attempt was made to influence the angling event, handling methods, or tackle used to capture fish. This ensured angling techniques and gear would be realistic and consistent with what is normally practiced in the recreational fishery. Professional guides and recreational anglers were all volunteers which was a cost-effective way to sample an exclusive charter fleet in BGP and to observe many vessels at once in TB while directly involving public stakeholders in the fishery science.
Trips took place at any time of day, tide, or moon phase and these parameters were recorded for each trip. The following variables were recorded for each sonically tagged tarpon: hook type (“J”, circle, treble), bait type (live, dead, artificial, fly), time of hook-up, time of capture (defined as a leader touch with a controlled fish at the side of the boat), handling time (minutes from the leader touch until release, included tagging time), whether or not the angler spent time reviving the tarpon prior to release (yes/no), if the fish was gaffed (yes or no), girth (small, medium, large), estimated total length (in centimeters), estimated weight (in pounds, converted to kilograms), and a qualitative condition of the fish at release (Good, Fair, Poor). A highly active tarpon at the time of release was classified as a “Good” release condition, a moderately active fish swimming slowly at release was classified as “Fair”, and an inactive fish that sank at release or suffered from severe disequilibrium (unable to get upright) was classified as “Poor”.

Total lengths were approximated by using pencil marks on the gunnels or eye-balling two points along the side of the boat using marks, such as stickers, registration numbers, scuffs, and then measuring those lengths. Weights were estimated by guides in BGP and by staff in TB. Some anglers, but more specifically guides, did not want staff to measure or handle their fish for more than tagging purposes.

Bait types were classified into four categories: live-bait, cut-bait, artificial or fly. Artificial baits were MirrOlures™, DOA bait busters, or artificial breakaway jigs (Figure 2.2A). Live bait was a natural prey item fished alive with spinning or conventional tackle. The following live baits were used in this study: sand perch (*Diplodictum formosum*), scaled sardines (*Harengula jaguana*), threadfin herring (*Opisthonema ooglinum*), pinfish (*Lagodon rhomboides*), Atlantic bumper (*Chloroscombrus chrysurus*), shrimp *
(Farfantepenaeus spp.), blue crabs (Callinectes sapidus) and pass crabs (Portunus gibbesi, Figure 2.2B). Cut or dead baits were typically menhaden (Brevoortia spp.), striped mullet (Mugil cephalus) or Spanish mackerel (Scomberomorus maculatus) fished on the bottom.

The number of tarpon hooked and fought was counted for each trip. A fish hooked and fought for less than three minutes was tallied. Any tarpon fought for three minutes or more was assigned a fish identification number but may not have been caught. For each tarpon assigned a fish identification number, angling duration (total minutes from hook up to capture or break-off/escape), coordinates at hookup, time of release, hook location, shark activity, and if the hook was removed were also recorded. Specific hook locations were placed into one of the following categories: upper jaw (premaxillae, maxillae and supramaxillae sutures), lower jaw (dentary), cheek/head, gills, corner of mouth and surrounding soft buccal tissue, interior mouth (roof, tongue), fins (pectoral, pelvic, dorsal, caudal), eye, deep (gut or esophagus), body, and other. A fair- or foul-hooked designation was assigned to each tarpon prior to analysis. A foul-hooked fish was defined as one hooked in a part of the body other than the mouth (Figure 2.3A). Based upon the literature and an understanding of feeding behavior and functional morphology of tarpon, the premaxillary, maxillary bones comprise the upper jaw and the dentary bone the lower jaw (Grubich 2001, Gregory 2002). Hook locations in these areas were considered fair-hooked (Figure 2.3B). The soft buccal membrane behind the maxillary bone and in the corner of the mouth is inside the jaws of a tarpon when the mouth is closed. Therefore, tarpon hooked in this soft tissue were also considered to be fair-
hooked according to our definition. Further clumping combined hook locations in the upper jaw, lower jaw, and corner of the mouth into a “Jaw” category.

The first tarpon caught on each trip was tagged with a VEMCO V-22 ultrasonic continuous transmitter using a custom built tagging stick (Figure 2.4). Transmitters were attached to stainless steel Floy Tag Anchors (model # FH-69) that were slid under a tarpon scale and hooked onto the base of a pterygiophore (Figure 2.5) or into the muscle of the fish approximately two scale rows below and posterior to the base of the dorsal fin so that the tag would not impede the fish when swimming (Figure 2.6).

Transmitters of varied frequencies (34-50 kHz) were used in a sequence to prevent overlapping frequencies being used simultaneously. Sonically-tagged tarpon from BGP had to be initially hooked within the pass boundaries, but did not have to be landed within the boundaries. After tagging the guide or angler handled the fish as they normally would and then released it for tracking. Floats were used beginning in 2003 to enable a transmitter to float to the surface and eliminated the possibility of assigning mortality to a stationary signal from a tag that had fallen out of the fish, which would be resting on the bottom otherwise (Figures 2.4 and 2.6). The floats also aided in tracking some of the fish visually when the tag signal was poor.

Immediately following release, a tagged tarpon was manually tracked for up to 6 hours from a separate research vessel staffed with state biologists to evaluate short-term survival. The direction of the signal from the tracking boat was determined using a VEMCO V-11 directional hydrophone, VR-60 receiver, and a magnetic compass. Based on testing performed in Tampa Bay, the audible range of the tags under ideal conditions in open water was approximately one mile.
At the time of release and every subsequent quarter hour during each tracking event, GPS location (latitude and longitude), signal direction from the tracking boat, and fish behavior based on swimming activity levels and movement relative to current speed and other schools of tarpon were recorded. Starting in 2003, if a signal stopped moving and staff did not witness the tarpon’s death, an underwater drop camera or remotely operated vehicle (ROV) was deployed from the research vessel in an attempt to visually confirm the suspected mortality. Tracking continued until the fate of the fish was established, the signal was lost, or the tracking period expired. After the initial tracking event was over, opportunistic monitoring for frequencies of recently tagged fish took place on subsequent days within the zones of the subsequent trips until the termination of the estimated battery life (~3 weeks).

Statistical Analysis. Tarpon trip and catch data were summarized and analyzed to estimate catch-and-release mortality rates of tarpon tagged in Boca Grande Pass and Tampa Bay area. Count data of mortalities and survivors between Tampa Bay and Boca Grande Pass were compared using a Fisher’s Exact test. Data were then combined to obtain an overall catch-and-release mortality rate for tarpon from both estuaries to represent the central and southwest Gulf coast tarpon fishery. Parametric Student T-tests \((\alpha=0.05)\) were used to determine significant differences between the means of angling duration (min), handling times (min), and estimated fish size (cm) between estuaries and of tarpon that survived versus those that died. A non-parametric Wilcoxon two-sample test \((\alpha=0.05)\) was used when assumptions of normality were not met. The relationship between bait types (artificial and live), hook type (circle vs. J), foul hooking (fair or foul),
and tarpon release condition (good, fair, poor) and survival were examined using Fisher’s Exact tests. Analyses were performed using SAS vs. 9.2.

Plots of individual tarpon movement were prepared using GIS (ArcView). Vector maps indicating the direction of the strongest signal heard from each 15-minute waypoint (boat position) were created for each tagged fish. By cross referencing the variables time of day, bearing and direction of signal, tidal stage, and recorded fish behaviors at each data point, one could further assess fish movement. For each tarpon, survival was determined as a yes or no classification and specified whether or not it was a visually confirmed mortality. All visually confirmed mortalities and suspected mortalities were included as deaths when calculating catch-and-release mortality rates. Criteria used to determine a suspected mortality were the cessation of signal movements in the field verified with post-season analyses of vector maps and consideration of the incidence of shark activity at the time of tagging.

Results

Research staff took a total of 207 trips from 2002-2007 to sonically tag and track tarpon from Boca Grande Pass (BGP) and Tampa Bay (TB) and estimate catch-and-release mortality rates for the gulf coast recreational tarpon fishery. Observations came from 70 different fishing vessels, 36 in BGP and 34 in Tampa Bay. Eighty-eight trips took place in BGP. Of the 231 tarpon hooked, 85 (37%) were caught and 42 of the caught tarpon were tagged with acoustic transmitters and then released (Table 2.1). In TB, 123 tarpon were hooked on 119 trips; 53 (43%) were caught, and 40 of those caught were tagged prior to release (Table 2.1). Two other tarpon were tagged (one in each system), but the tags malfunctioned, were never heard and were removed from any
analyses. Catch success for both systems combined was 39%; 37% in BGP and 43% in TB (Table 2.1). A total of 82 tagged tarpon were acoustically tagged during this study to estimate post-release mortality rates.

The estimated catch-and-release mortality rate for BGP was 17% (7 out of 42 tarpon died; Table 2.1, Figure 2.7) with a 95% confidence interval ranging from 5% to 28% (Wilde 2002). Five of the seven mortalities in BGP were attributed to shark attacks and two fish were not able to recover from the angling event for unknown reasons. The estimated catch-and-release mortality rate for TB was 10% (4 out of 40 tarpon died; Table 2.1, Figure 2.7) with a 95% confidence interval ranging from 1% to 19% (Wilde 2002). Two fish suffered mortality as a result of shark predation and two tarpon suffered mortality from the inability to recover from the angling event (Table 2.1).

The combined catch-and-release mortality estimate for both locations was 13% (11 out of 82 tarpon died; Figure 2.7) with a 95% confidence interval ranging from 6% to 21% (Wilde 2002). Of the eleven mortalities (confirmed and suspected), sharks were responsible for seven of them (64%) and accounted for 9% of the total catch-and-release mortality (Table 2.1). Sources other than predation accounted for 36% of the mortalities (4 out of 11). Ancillary observations noted that twelve of the tagged and released tarpon from Tampa Bay were lip-gaffed and one of those twelve suffered immediate post-release mortality (Figure 2.6 A and B). No significant differences were found between the counts of observed mortalities and survivors in each estuary (Figure 2.7; Fisher’s, p-value=0.5203); therefore, data were combined to evaluate the potentially lethal effects of other variables associated with catch-and-release angling. Samples size is limited to detect statistical differences in mortality between estuaries. Power tests revealed 636
observations would be needed to achieve a power of 0.7. Regardless, the proportion of survivors in each estuary was similar, so combining them to represent the Gulf coast fishery is acceptable. Excluding the seven deaths attributed to shark predation from the calculation reduces the estimated catch-and-release mortality to 5.3% (4 out of 75 tarpon; Table 2.1).

Average angling duration (length of fight) was not different between estuaries (Wilcoxon, p-value = 0.134) and ranged between 4 and 139 minutes (Figure 2.8). The average angling duration in BGP was 21.2 minutes ± 20.3 S.D. (14.9 to 27.5, 95% confidence intervals) and 24.3 minutes ± 23.3 S.D. (16.9 to 31.7, 95% confidence intervals) in TB. Pooled data for both systems yielded an average angling duration of 22.7 minutes ± 21.7 S.D. (17.9 to 27.5, 95% confidence intervals). No significant differences were observed between average fight times of fish that survived and those that died (Wilcoxon, p-value = 0.340, Table 2.2).

Boat-side handling times (time of capture until release) ranged between 0 and 7 minutes and were not significantly different between estuaries (Wilcoxon, P-value = 0.588). The average handling time of tagged tarpon observed from pooled data was 2.3 minutes ± 1.6 S.D. (1.9 to 2.7, 95% confidence intervals). No significant differences were observed between average handling times of fish that lived and those that died (t-test, p-value = 0.168, Table 2.2).

Estimated total lengths of tarpon that were caught, tagged and released in this study ranged between 91cm and 245cm, and average fish size was not significantly different between estuaries (t-test, p-value = 0.309; Figure 2.9). The average size of tagged tarpon in BGP was 161.9cm ± 31.1 S.D. (152.2 to 171.6, 95% confidence intervals) and
155.1 cm ± 27.6 S.D. (145.7 to 164.4, 95% confidence intervals) in TB. The average size of tagged tarpon from pooled data was 158.8cm ± 29.6 S.D. (152 to 165cm, 95% confidence intervals). No significant differences were observed between average total lengths of tarpon that survived and those that died (t-test, p-value=0.1375, Table 2.2).

There was no significant difference between the proportions of observed mortalities of tarpon caught using live bait (n=5) and artificial baits (n=6) (Fisher’s Exact Test, p-value=0.1655; Table 2.3). Twenty-six tagged tarpon were caught using artificial baits, 52 tarpon were caught using live bait, two were caught using cut or dead bait, and two bait types were not observed at the time of tagging. Both tarpon caught using cut bait survived. No tarpon were caught on fly.

There was no association between using circle hooks or J-hooks and the frequencies of observed mortalities from both estuaries (Fisher’s Exact Test, p = 0.1464). A total of 22 tagged tarpon were caught on circle hooks, 53 were caught on J-hooks, and five caught with each hook type suffered mortality (Table 2.3). Three tagged tarpon were caught with treble hooks and one of those fish died (Table 2.3). Four hook types were not noted at the time of tagging.

Foul-hooked tarpon had a significantly higher mortality rate than tarpon fair-hooked in the jaw or roof of the mouth (Fisher’s Exact Test, p-value=0.0187; Figure 2.10). Nine tarpon out of 79 were classified as being foul hooked (11.4%), 70 tarpon were classified as being fair-hooked, and three hook locations were not recorded at the time of tagging. Four of the 9 foul-hooked fish died (44.4%). Specific hook locations of the foul-hooked tarpon can be found in Appendix A.
The swimming condition of a tarpon at release is critical to its survival. A total of 33 of the tagged tarpon were highly active at the time of release (good), 30 were classified as being released in fair condition (moderately active), and sixteen were released in poor condition (Figure 2.11). The release condition was not observed for three tarpon in this study and they were removed from analysis. Percent mortality was highest (37.5%) for tarpon released in poor condition and there were significant differences among the counts of observed mortalities of tarpon released at varying conditions (Fisher’s Exact Test, p-value=0.0173).

Tracking periods were planned to last 4 to 5 hours (240 to 300 minutes) in order to estimate the short-term catch-and-release mortality rates of tarpon. The average track time in Boca Grande Pass was 178 minutes (Range: 0 to 525) and the average track time of tagged tarpon from Tampa Bay was 140 minutes (Range: 0 to 300). In BGP, 2003 had significantly lower average tracking times than the other two years in the pass (mean 119 minutes, t-test p= 0.04), and in TB, 2007 had the lowest average track times (mean 94 minutes, t-test p= 0.003).

Plots created from the tracking data were used to evaluate short-term movements and survival. Several tarpon swam away upon release but returned to the release vicinity within the short-term tracking period (Figure 2.12) or up to days later (Figure 2.13). Subsequent monitoring for signals was opportunistic and not part of the formal sampling protocol, but provided evidence for long-term (>24-hours) survival. Excluding the eleven mortalities, 23 out of 71 (32%) surviving tarpon were heard again on subsequent days. In BGP, signals were reacquired for 13 out of 35 surviving tarpon (37%). In Tampa Bay, 10 of the 36 (28%) tarpon classified as having survived the short-
term tracking period were heard again on subsequent days (Figure 2.12). Reacquired signals also helped to verify that a tarpon survived the short-term tracking time when it was not tracked the full term (Figure 2.13). A summary of tarpon movements can be found in Appendix B.

**Discussion**

Ultrasonic telemetry was successfully used as a tool to actively track tarpon post-release and estimate short-term mortality rates for the Gulf Coast fishery. Because this was an observational and not experimental study, there was little replication of exact types of gear and tackle used; however, the data came from 70 different fishing vessels between the two systems. Hundreds were watched while waiting for successful tarpon catches. Catch success was less than 40%, so many tarpon break off before they get to the boats. These methods also provided a realistic view of the fishery (*i.e.* fish handling practices and fight times) by utilizing direct angler involvement in the research (Siepker *et al.* 2007).

The only other study to date that estimated short-term, post-release, tarpon mortality, had several limitations including observing a small number of fish angled within a single season (May 25 to July 12, 1992) from the geographically small location of Boca Grande Pass (Edwards 1998). Only one of these fish died. This research was the first to observe tarpon from two geographic areas along the Gulf coast during six consecutive seasons (2002-2007) and estimated short-term catch-and-release mortality rates that ranged between 5.3% and 13.4%. Despite its coverage in time and space, the estimates may still be low, as only post-release survival of tagged tarpon was estimated. There were cases in which tarpon were attacked by sharks during the fight and could not
be tagged. In other cases caught tarpon were observed being attacked post-release but had not been tagged because another fish was already being tracked. Such data were not used in this analysis.

Short-term mortality in this study was defined as mortality within the first six hours post-release. Sharks (sharp nose 1.5 hours, Gurshin and Szedlmayer 2004; scalloped hammerhead 2 hours; Mako 30-90 minutes, blue 3 hours, Skomal 2006) tunas (skipjacks 90 minutes, bluefin 120 minutes, Skomal 2006) and billfish (marlin, 4 to 6 hours, Block et al. 1992) were all able to recover from physiological disturbances caused by angling within 6 hours. A mortality study on bonefish showed most fish died within the first 30-minutes post release (Cooke and Philipp 2004). A study on oxeye tarpon (<300mm) showed recovery from angling effects was fast (<1 hour) when the fish was allowed to swim sustainably and access the air during recovery (Wells et al. 2003). Edwards (1998) witnessed his only tarpon mortality at 1.5 hours post-release. Based on previous studies that evaluated lethal and sublethal effects of angling on several active marine species, six hours should be an adequate time to determine short-term survival.

Manual tracking was often shorter than the proposed six hour window and proved to be challenging and labor intensive to complete. Transmitter signals were sometimes difficult to receive due to acoustic interference from both man-made and natural causes: boat traffic, waves, submerged metal or concrete structures, depth sounders, sandbars, swimming behaviors of the released tarpon, and dense schools of fish making them difficult to track. Shortened track times were also partially driven by staff experience. Both years in which that new staff took over tracking procedures (2003 in BGP, 2007 in TB), significantly lower average tracking times were encountered than the other two
years from each respective system. In addition, storms, opposing wind and tides, and
equipment failure in 2007 caused several trips to end before the desired tracking period
expired and resulted in the lowest average tracking times of the study. Other times the
tarpon swam away so quickly that keeping up with the fish would have required breaking
or bending the hydrophone pole in the boat side mount (Figure 2.13). Despite these
obstacles, acoustic telemetry proved to be a valuable tool to track movements and
survival of tarpon.

The range of estimated tarpon mortality rates in this study were comparable to
rates measured for other popular inshore species along the Gulf coast such as spotted sea
tROUT (7.3%, Matlock et al. 1993; 4.6%, Murphy et al. 1995), red drum (4.1%, Matlock et
al. 1993; 7%, Murphy et al. 1995), and common snook (2.13%, Taylor et al. 2001). The
seemingly higher mortality rate of tarpon compared to these inshore species may simply
be attributed to the use of net pens when monitoring fishes post-release which excluded
predation and biased results. The use of net pens is not feasible with large tarpon. If
predation was excluded from the analysis, the resulting catch-and-release mortality rate
was 5% in both systems. Tarpon mortality was more similar to rates measured in other
large, coastal pelagic species such as sailfish (12.5%, Jolley and Irby 1979), bluefin tuna
(16%, Skomal et al. 2002), sharpnose sharks (10%, Gurshin and Szedlmayer 2004), blue
marlin (11%, Graves et al. 2002; 22%, Kerstetter et al. 2003), black marlin (12.5%,
Pepperell and Davis 1999), striped marlin (29% Domeier et al. 2003), and white marlin
(range varied by hook type 0-35%, Horodysky and Graves 2005). Several of these works
reported shark predation (Jolley and Irby 1979, Pepperell and Davis 1999, Kerstetter et
al. 2004) or mention it as a possibility (Horodysky and Graves 2005).
Sharks were identified as the primary cause of post-release tarpon mortality. All of the tagged tarpon released in “good” condition that died were victims of shark attacks, and all but one of the lethal attacks occurred within the first 20 minutes post-release. Incidence of shark attacks varied within and between seasons and was unpredictable. However, if sharks were present and feeding, most tarpon were at risk. A study in the Bahamas showed bonefish, the other predominantly catch-and-release game fish in Florida, released into waters with high abundance of sharks and barracuda had mortality rates as high as 39% (Cooke and Philipp 2004). If estuaries were examined separately, tarpon in BGP had a higher incidence of fatal shark attacks than did tarpon in Tampa Bay (Table 2.1). While not designed to evaluate predation rates, this study clearly identified predation as the primary cause of post-release tarpon mortality.

A potential concern for indirect mortality related to the tags was whether or not sharks could hear the ultrasonic signals, but this was unlikely. The sonic tags used in this study operated in the ultrasonic frequency range of 20 kHz and 200 kHz (kilohertz), which was above the hearing range that has been measured in sharks (20-100 Hz (hertz), Casper and Mann 2006, Casper and Mann 2009). It is more likely that the sharks were able to detect the vibrations or noise from a hooked tarpon or sense the olfactory cues being released from a distressed or bleeding fish (Smith 1992, Bleckmann and Hoffmann 1999, Dallas et al. 2010).

The shark and tarpon predator-prey interaction has been documented in southwest Florida and BGP history for more than 100 years (Mygatt 1890, Dimock 1915). Early tarpon tagging research near BGP ceased due to excessive shark predation (Breder 1939 and 1944), yet sharks are not unique to southwest Florida. Reports of large sharks
attacking tarpon in Homosassa, along East Coast beaches and in the Florida Keys are common. Studies designed to evaluate localized predation effects, that have been suggested as being influential on diminishing local stocks in areas with dense aggregations of tarpon and anglers (Cooke et al. 2006), could be addressed in future work. Until then, it becomes a matter of angler ethics to move their fishing activity to another location when shark attack incidence is high.

In the short term, some released tarpon survived observed shark attacks which were contrary to expectations. One fish from BGP was attacked by a shark 67 minutes after its release while swimming northward along the beach of Gasparilla Island, then rapidly swam into the Gulf faster than it could be tracked. This fish was presumed to live in the short term, but may still have died. Another tarpon tagged in TB was tracked offshore where researchers aboard the tracking vessel witnessed the tagged tarpon in the jaws of a hammerhead shark above the surface of the water. Almost immediately after the sighting, the transmitter’s signal began dissipating at a fast pace to the south, but this time researchers kept up with the signal. Minutes into this portion of the track, this tarpon rolled at the surface to gulp air and the transmitter was visually observed by staff in the tarpon. Such air-breathing activity added a visual verification component to the acoustic tracking and was observed in 19 tagged tarpon in TB and anecdotally noted in BGP. Air-breathing post-release may be linked to the Atlantic tarpon’s physiological recovery and its ability to use atmospheric oxygen to supplement its oxygen debt incurred during the fight as was observed with oxeye tarpon, *Megalops cyprinoides* (Wells et al. 2003, Wells et al. 2007). Neither of these tarpon was detected when listening for opportunistic subsequent signal acquisition. Formal monitoring for long-term survival was not part of
the study’s formal protocol, so measurements of delayed mortality that might have occurred from the shark attacks remain unknown. Delayed mortality was another reason why mortality rates herein might be underestimated.

Reacquired signals from 32% of the tagged tarpon on subsequent days confirmed a more long-term (>6 hours) post-release survival, but formal studies on delayed mortality are needed. Popup archival satellite tags may be more appropriate for estimating long-term survival through large scale movements and migrations. Such tagging programs are already in place using this technology on tarpon (Luo et al. 2008) and have been successfully used in other large marine fishes such as billfishes (Graves et al. 2002, Prince et al. 2002, Kerstetter et al. 2003, Kerstetter et al. 2004; Horodysky and Graves 2005), tunas (Skomal 2007), and sharks (Skomal 2006). In addition, the use of passive telemetry arrays in these major passes (BGP and TB) would further evaluate long-term survival based on movement patterns during spawning season and post-spawning season, and would provide new and useful information on the biology of the species.

Not all post-release mortality is caused by sharks. Of the four tarpon that did not die from predation, two experienced gill damage - one from two sets of treble hooks and one from the captain handling the fish through the gill arches (Table 2.3), and two others died from causes unknown. Neither of the latter two fish showed any exterior sign of physical damage, but individual variation in fitness, strength and condition all play a role in fish survival (Kieffer, 2000). Angling techniques, bait type, hook characteristics and type, tackle configuration, and degrees of disorientation and exhaustion achieved during the fight are all examples of other factors that can have a cumulative impact and

Average angling duration, handling times, and size (total length) of the tagged tarpon had no significant effect on survival. The tarpon that experienced the longest angling duration in this study (139 minutes) was not exhausted at release, but quite agitated, and swam so fast that staff could not follow it (Figure 2.13). Power tests indicated that sample size limited the ability to detect a true effect of handling time (power = 0.51) or total lengths (power = 0.44) on tarpon mortality, if one existed. Doubling the number of observed mortalities (n=22) in this study would increase the power of the tests to more than 0.8 for both variables. Despite this low statistical power, handling times were short on average (ca. two minutes), which included time spent tagging the tarpon, and most fish survived. It was observed that some anglers and particularly guides rarely, if ever, handled their fish and many people were unsure about the tagging process at the start of the project in each system. Only large adult tarpon were targeted for this study, so the non-significant effect of total lengths on mortality was not surprising. Tarpon in Florida sexually mature at sizes of approximately 128.5 cm (51.4”) for females and 117.5 cm (47”) for males (Crabtree et al. 1997), and only four tagged fish were smaller than this (Figure 2.9).

Bait type (artificial versus live) showed no significant effect on post-release tarpon survival, however, observations were limited (power=0.24). A power analysis indicated that a sample size of 278 or 362 tarpon would need to be tagged and tracked to increase the power of the test to 0.8 or 0.9, respectively. In general, artificial baits tend to shallow hook fish relative to natural baits (Muoneke and Childress 1994, Cooke and

Hook type (circle versus “J”) also showed no effect on tarpon survival. In the literature, circle hooks have been shown to have a propensity of shallow-hooking fish in the corner of the mouth and can be of a greater benefit for survival in some species (Orsi et al. 1993, Prince et al. 2002, Skomal et al. 2002, Cooke et al. 2003, Cooke and Suski 2004, Aalbers et al. 2004, Horodisky and Graves 2005, Prince et al. 2007, Vecchio and Wenner 2007). Limiting anglers to a specific hook type when fishing for large tarpon may not be necessary based on this study, but again, it is important to note that our observations were limited (power=0.27). Tests of statistical power indicated that a sample size of 306 hook type observations would have been adequate to achieve a power 0.9 to detect a difference in tarpon survival at the observed proportions of 0.77 and 0.91.

Hook location had a significant effect on post-release survival. Calculated tarpon foul-hooking rates (11%) were comparable to those calculated for other marine fisheries (13% Lukacovic 2001, 3% Prince et al. 2002, 7%, Falterman and Graves 2002, 3% Skomal et al. 2002, 17% Grover et al. 2002, 9% Caruso 2000), and results agreed with other studies on marine and freshwater species that found foul-hooked fish had higher mortality rates than fair-hooked fish (Murphy et al. 1995, Schill 1996, Nelson 1998, Taylor et al. 2001, Millard et al. 2003, Kerstetter and Graves 2006, Alos et al. 2008, Grixti et al. 2008, Grixti et al. 2010). However, most hook locations resulting in fatalities from these works were attributed to deep hooking the fish (i.e. in vital organs). Only two tarpon were deep-hooked in this study and both were caught on live bait (Appendix A).
In both cases, fishing lines were cut and the hooks remained in the tarpon which has been shown to increase survival in other fish species (Schill 1996, Aalbers et al. 2004, Fobert et al. 2009). The tarpon released in “poor” condition and not revived prior to release was attacked by a shark. The tarpon released in “fair” condition survived and emphasized the importance of a tarpon’s ability to swim at release to short-term survival.

Tarpon released in poor condition (no swimming ability or with severe disequilibrium) suffered a significantly higher percent mortality, although individual variation in resilience was evident. Other research concluded that the release condition of fish significantly affects survival (Cooke and Philipp 2004, Horodysky and Graves 2005, Danylchuk et al. 2007a, Prince et al. 2007). A swimming fish is likely better able to avoid predation upon release (Cooke and Philipp 2004, Danylchuk et al. 2007b), rise to the surface to breathe air if it needs to (Wells et al. 2003, Seymour et al. 2003) or regulate itself for optimal swimming speeds needed for faster recovery (Milligan et al. 2000, Farrell et al. 2001). Based on results of those studies, if a caught tarpon suffers from severe disequilibrium or is unable to swim from exhaustion incurred during the fight, an angler should be encouraged to wait until the fish regains some equilibrium and can swim before it is released. Small changes to increase the chance of survival can make large differences in overall population sizes in species with a periodic life history strategy, such as tarpon (Schroeder and Love 2002, Winemiller and Dailey 2002).

One lingering question relative to tarpon survival revolves around the use of lip-gaffs to control tarpon at the side of the boat (Figure 2.6A and B). Based on a prey capture feeding study on Atlantic tarpon (Grubich 2001), it is unlikely that a tarpon
gaffed around the lower jaw at the center of the dentary bone would have its feeding permanently affected by the pierced tissue. The only gaffed tarpon that died in this study was the one caught and released with extensive gill damage from treble hooks (Table 2.3). All other gaffed tarpon survived in the short-term and some were confirmed to have survived on the long-term. Other indirect evidence that supported gaffs were safe for handling large tarpon was provided by the successful gaffing, transporting and survival of six adult tarpon to captivity for physiology studies (Chapter 3 herein). Further investigations into the effects of gaffing may be warranted.

Other types of data are also missing from this study. Lethal and sub-lethal effects of lifting large fish into a boat were not assessed. None of the fish from BGP and only one in TB (Figure 2.6A) were lifted from the water and brought into the boat which was done to the only observed tarpon mortality in Edwards’ (1998) study. The law requiring anglers in Florida to have a $50.00 permit to possess the tarpon legally probably reduces the amount of tarpon handled in this manner, but some anglers choose to do so. Two other unknowns are the effects of tournament weigh-in procedures that involve towing tarpon long distances to weigh-scales and excessive boat noise on tarpon behavior, physiology and survival. Studies on largemouth bass show both factors can cause significant lethal and sub-lethal physiological responses (Weathers and Newman 1997, Suski et al. 2004, Graham and Cooke 2008).

**Conclusions**

This was the first study to estimate catch-and-release mortality rates and relate specific factors associated with angling to tarpon survival from more than one area over multiple years. Shark predation, which is sometimes unavoidable, was the primary cause
of tarpon mortality and all but one of the fatal attacks happened in the first 20 minutes post-release. Factors other than predation affecting mortality in 34% of the tagged tarpon were likely attributed to physical and physiological damages experienced by the tarpon during the angling event.

Hook location and the condition of a tarpon at the time of release significantly affected mortality. A foul-hooked tarpon or one released in poor condition significantly reduced its chances for survival. Angling duration, handling time and estimated total lengths of these tagged tarpon did not significantly affect survival. At this time, to restrict anglers to a certain hook type (circle or J) or bait type (natural or live) does not appear to be justified, but more observations not confounded with predation are needed to make stronger statistical conclusions.

Most tarpon in this study survived catch-and-release fishing on the short-term when released in the absence of large predators. In addition, the probability of catching a hooked tarpon was less than 50%, so many fish escape. This implies there could be a sustainable adult catch-and-release fishery in Florida’s future if adequate numbers of fish recruiting to the adult spawning population and limited harvest. However, the lethal effects catch-and-release angling on juvenile tarpon, where Florida’s adult tarpon recruit from, and the effects of harvest in other countries are all unknown. Several Central and South American countries support Atlantic tarpon subsistence fisheries (Ault et al. 2008). In addition, tagging studies reported in Luo et al. (2008) and genetic diversity suggests (McMillen-Jackson et al. 2005) there is connectivity between tarpon in the western Atlantic that crosses international boundaries. Finally, an estimate of the population size
is also needed to determine whether or not the estimated catch-and-release mortality rates from this study are sustainable.

If Florida’s human population and coastal development is forecasted to increase and fishing pressure in the tarpon recreational fishery continues to increase, effects of angling on tarpon survival should be monitored. It would be prudent to periodically repeat this work to determine if post-release mortality rates have increased or remained the same. Acoustic telemetry can be used as a tool to evaluate catch-and-release mortality rates of fishes, particularly for large pelagic or migratory species difficult to maintain in pens for observation.

**Literature Cited**


Table 2.1: A summary of sonic tagging trips in Boca Grande Pass (BGP, 2002-2004) and Tampa Bay (TB, 2005-2007) performed to estimate catch-and-release mortality rates for the recreational Atlantic tarpon fishery along the central and southwest Gulf Coast. The table presents totals by estuarine system (BGP and TB) and the cumulative total (TOTAL) for the entire study. Numbers represent the number of trips taken, the number of tarpon hooked, the number of tarpon hooked that were fought for less than (<) and greater than or equal to (≥) 3 minutes, the number of tarpon caught (defined by a leader touch) and released, the percent of hooked tarpon caught, the number of tarpon tagged, the number of assigned mortalities (confirmed and suspected), and the estimated mortality rate (percent). The number of deaths attributed to shark attacks and other non-predatory causes and associated mortality rates (percentage) are also presented.

<table>
<thead>
<tr>
<th></th>
<th>BGP</th>
<th>TB</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trips</td>
<td>88</td>
<td>119</td>
<td>207</td>
</tr>
<tr>
<td>Hooked</td>
<td>231</td>
<td>123</td>
<td>354</td>
</tr>
<tr>
<td>Fought &lt; 3min</td>
<td>79</td>
<td>29</td>
<td>108</td>
</tr>
<tr>
<td>Fought ≥ 3min</td>
<td>152</td>
<td>94</td>
<td>246</td>
</tr>
<tr>
<td>Caught</td>
<td>85</td>
<td>53</td>
<td>138</td>
</tr>
<tr>
<td>Percent Caught</td>
<td>37</td>
<td>43</td>
<td>39</td>
</tr>
<tr>
<td>Tagged</td>
<td>42</td>
<td>40</td>
<td>82</td>
</tr>
<tr>
<td>Mortalites (%)</td>
<td>7 (17)</td>
<td>4 (10)</td>
<td>11 (13)</td>
</tr>
<tr>
<td>Sharks (%)</td>
<td>5 (13)</td>
<td>2 (5)</td>
<td>7 (9)</td>
</tr>
<tr>
<td>Other (%)</td>
<td>2 (5)</td>
<td>2 (5)</td>
<td>4 (5)</td>
</tr>
</tbody>
</table>
Table 2.2: A summary of angling duration (minutes), boat-side handling times (minutes), and estimated total lengths (centimeters) for tarpon that were tagged, tracked and released in Boca Grande Pass (n=42) and Tampa Bay (n=40) from 2002-2007. Variable means, standard errors (Std. Err.) and minimum (Min) and maximum (Max) values are presented for tarpon that survived and those that suffered mortality. Mean handling time and total lengths were compared with Student T-tests (α=0.05) and mean angling duration (fight time) was compared with a Wilcoxon non-normal two-sided test. No significant differences (N.S.) were observed between average angling duration, handling times, or fish size between tarpon that lived and those that died.

<table>
<thead>
<tr>
<th></th>
<th>Survivor</th>
<th>Mortality</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angling Duration (min)</td>
<td>23.7</td>
<td>16.5</td>
<td>80</td>
<td>0.340</td>
</tr>
<tr>
<td>Std. Err.</td>
<td>2.7</td>
<td>3.3</td>
<td></td>
<td>N.S.</td>
</tr>
<tr>
<td>Min</td>
<td>4</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>139</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handling Times (min)</td>
<td>2.2</td>
<td>3.2</td>
<td>78</td>
<td>0.168</td>
</tr>
<tr>
<td>Std. Err.</td>
<td>0.2</td>
<td>0.7</td>
<td></td>
<td>N.S.</td>
</tr>
<tr>
<td>Min</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>7</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Est. Total Length (cm)</td>
<td>160.8</td>
<td>146.5</td>
<td>75</td>
<td>0.138</td>
</tr>
<tr>
<td>Std. Err.</td>
<td>3.4</td>
<td>11.0</td>
<td></td>
<td>N.S.</td>
</tr>
<tr>
<td>Min</td>
<td>91</td>
<td>92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>245</td>
<td>218</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2.3: Field data for the eleven acoustically tagged tarpon recorded as mortalities (suspected and confirmed) in Boca Grande Pass (BGP) and Tampa Bay (TB) from 2002-2007. Variables included are date of capture, angling duration (Fight, in minutes), estimated total length (TL, in centimeters), bait type (artificial: breakaway jigs (ABJ) and MirrOlures, or live bait), hook type (circle (C), straight shank (J), or treble (T)), hook location, condition of tarpon at release (Good, Fair, Poor-assigned as a qualitative measure of tarpon activity level at release), and observational notes on the catch-and-release event.

<table>
<thead>
<tr>
<th>Date</th>
<th>Fight (min)</th>
<th>TL (cm)</th>
<th>Bait Type</th>
<th>Hook Type</th>
<th>Hook Location</th>
<th>Condition at Release</th>
<th>Field Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/7/2002</td>
<td>10</td>
<td>152</td>
<td>ABJ</td>
<td>C</td>
<td>Jaw</td>
<td>Fair</td>
<td>At time of release, captain said the fish didn't look good. The fish swam slowly against the current for some time—therefore alive. Then it slowly drifted with the current. Eventually the signal stopped moving and stayed in the same general area for about three hours. Fish was presumed dead. Since the mortality was unconfirmed, it is possible that the tag could have fallen out of the fish. No floats in 2002.</td>
</tr>
<tr>
<td>6/24/2002</td>
<td>19</td>
<td>160</td>
<td>ABJ</td>
<td>J</td>
<td>Cheek</td>
<td>Poor</td>
<td>Fish handled and held for tagging between gill arches. At time of tagging, the fish did not flinch. Revival of fish was attempted over ~50yds. Eventually, fish responded but was not doing well. It came back up to surface twice but didn't move much. Tag signal essentially stayed in the same area in which the tracking boat’s receiver last detected the fish. Believe fish to be dead.</td>
</tr>
<tr>
<td>6/4/2003</td>
<td>14</td>
<td>120</td>
<td>ABJ</td>
<td>J</td>
<td>Jaw</td>
<td>Poor</td>
<td>Shark Attack—The tag was returned later; it had teeth marks and slashes in the float.</td>
</tr>
</tbody>
</table>
Table 2.3: Continued.

<table>
<thead>
<tr>
<th>Date</th>
<th>Fight (min)</th>
<th>TL (cm)</th>
<th>Bait Type</th>
<th>Hook Type</th>
<th>Hook Location</th>
<th>Condition at Release</th>
<th>Field Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/1/2004</td>
<td>5</td>
<td>130</td>
<td>ABJ</td>
<td>C</td>
<td>Cheek / Head*</td>
<td>Good</td>
<td>Shark Attack—witnessed</td>
</tr>
<tr>
<td>7/9/2002</td>
<td>5</td>
<td>109</td>
<td>Live</td>
<td>J</td>
<td>Jaw</td>
<td>Good</td>
<td>Suspected shark attack. First tarpon hooked on trip was attacked on the line during the fight. At release time for the tagged tarpon, the captain was worried about sharks. He ran boat in fast circles to scare away the sharks. After release, fish was moving very slowly; tracking boat followed the &quot;very strong&quot; signal, which just suddenly disappeared. Tracking boat searched two more hours and found no signal. It vanished.</td>
</tr>
</tbody>
</table>

*(isthmus) This was a secondary hook location. Fish was originally hooked on the upper jaw.
Table 2.3: Continued.

<table>
<thead>
<tr>
<th>Date</th>
<th>Fight (min)</th>
<th>TL (cm)</th>
<th>Bait Type</th>
<th>Hook Type</th>
<th>Hook Location</th>
<th>Condition at Release</th>
<th>Field Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB</td>
<td>7/24/2006</td>
<td>9</td>
<td>92</td>
<td>Live</td>
<td>J</td>
<td>Deep</td>
<td>Poor</td>
</tr>
<tr>
<td>8/4/2006</td>
<td>20</td>
<td>178</td>
<td>MirrOlure</td>
<td>T</td>
<td>Gills</td>
<td>Fair</td>
<td>Treble hook in the gills. Plug left in fish, much bleeding. Fish swam slowly and steadily and gulped four times in first 5 minutes post-release. Then it did three sideways glances rising in water but making it just beneath the surface. Final view was head up and tail down when it sank. Signal did not move after that. A storm prevented deployment of the ROV.</td>
</tr>
</tbody>
</table>
Table 2.3: Continued.

<table>
<thead>
<tr>
<th>Date</th>
<th>Fight (min)</th>
<th>TL (cm)</th>
<th>Bait Type</th>
<th>Hook Type</th>
<th>Hook Location</th>
<th>Condition at Release</th>
<th>Field Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB</td>
<td>5/3/2007</td>
<td>22</td>
<td>122</td>
<td>Live</td>
<td>C</td>
<td>Jaw</td>
<td>Poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hook position was not seen; no resuscitation performed on fish. It was handled for 6-7 minutes boatside before tagging. Fish made 4 rapid gulps at 12 minutes post-release. Then it made three more gulps within a two-minute interval which ended in a large blow out of bubbles from the mouth at the surface. A minute later it came up sideways to the surface. A final minute later was its last breath when it rolled flat and sank like a log. Signal never moved again. Tag later recovered on rocks by Skyway Bridge.</td>
</tr>
<tr>
<td>6/14/2007</td>
<td>29</td>
<td>218</td>
<td>Live</td>
<td>C</td>
<td>Jaw</td>
<td>Poor</td>
<td>Suspected mortality from shark attack incurred during fight. Fish bleeding and missing scales when tagged. Inactive at release. Hammerhead chasing seemed to have slowed down but then signal disappeared. Fish signal was not found or heard from again - presumed to be dead based on condition of fish at release and the active sharks in the area.</td>
</tr>
</tbody>
</table>
Figure 2.1: Study areas for evaluating catch-and-release tarpon mortality. The boundary of Boca Grande Pass (BGP) as defined by the Fish and Wildlife Conservation Commission is located at the mouth of Charlotte Harbor along the southwest coast of Florida and also supports a popular recreational tarpon fishery (A, grey box on inset). The Tampa Bay area tarpon fishery is located along the central west coast of Florida and is distributed throughout the bay and adjacent Gulf of Mexico beaches from Longboat Key to Anclote Key (B, black box on inset).
Figure 2.2: Examples of artificial lures and live baits used in the catch-and-release mortality study in Tampa Bay and Boca Grande Pass (2002-2007). Artificial lures used included MirrOlures™, D.O.A. bait busters, and breakaway jigs (A). Pass crabs and blue crabs are natural prey items commonly used for bait as seen in tarpon stomach contents (B). Images used with permission from the FWC-FWRI.
Figure 2.3: Hook locations observed in tarpon. Image of a foul-hooked tarpon that was hooked in the cheek (A) and a tarpon skull with arrows depicting fair hook locations that were observed in the sutures between the premaxillae, maxillae, and supramaxillae bones of the upper jaw (B). Images used with permission from the FWC-FWRI.
Figure 2.4: Custom built tagging stick loaded with an ultrasonic transmitter and attached orange and white float for tagging tarpon. Inset shows stainless anchor tag.

Figure 2.5: An x-ray of a tagged tarpon. The stainless Floy anchor firmly lodged on a dorsal fin pterygiophore. Pterygiophores were faint and have been enhanced by the lines drawn over them. Inset is image of a V-22 transmitter with attached anchor. Images used with permission from the FWC-FWRI.
Figure 2.6: Images of sonically tagged tarpon from Tampa Bay (A, B) and Boca Grande Pass (C). Transmitters in Tampa Bay were sleeved by the float as opposed to followed by the float in BGP. All three tarpon presented here survived the short-term tracking period despite handling differences. Images used with permission from FWC-FWRI (A) and Robert McCue (C).
Figure 2.7: Percent catch-and-release mortality calculated for Boca Grande Pass (BGP, blue fill), Tampa Bay (TB, red outline) and both study areas (TOTAL, grey fill) combined (2002-2007). Fisher’s Exact tests were used to determine significance of the observed mortality rates based on count frequencies. There were no significant differences in observed tarpon mortalities between estuaries (Fisher’s Exact, p-value=0.5203). Numbers over the bars in plots represent the number of assigned mortalities per total number of tagged tarpon in that category (i.e. 7 out of 42 tagged tarpon died in BGP).
Figure 2.8: Angling duration (in minutes) for each of the 82 tagged and tracked tarpon in Boca Grande Pass (BGP, blue fill) and Tampa Bay (TB, red outline) during 2002-2007. Fight times were not significantly different between estuaries (Wilcoxon, p-value = 0.134).
Figure 2.9: Estimated total length frequencies (in centimeters) for 78 of the 82 tagged and tracked tarpon in Boca Grande Pass (BGP, blue fill) and Tampa Bay (TB, red outline) during 2002-2007. Mean tarpon lengths were not significantly different between estuaries (t-test, p-value = 0.309).
Figure 2.10: Percent mortality calculated for fair- and foul-hooked tarpon from TB and BGP (n=79). A fair-hooked tarpon was defined as one hooked in any part of the mouth or jaw (Premaxillary, maxillary, corner, and roof of the mouth). A foul-hooked tarpon was one hooked in the head, cheek, fins, gills or deep inside the throat or gut. Foul-hooked tarpon experienced significantly higher mortality rates than fair-hooked tarpon (Fisher’s Exact, p-value=0.0187). Plot details are as in Figure 2.7.
Figure 2.11: Percent mortality calculated for three assigned qualitative conditions based on the tarpon’s activity level at the time of release in TB and BGP (n=79). A highly active tarpon was classified as a “Good” condition at release, a moderately active fish was classified as “Fair”, and an inactive fish was classified as “Poor”. Tarpon released in poor condition had a significantly higher percent mortality rate than tarpon released in good and fair conditions (Fisher’s Exact, p-value=0.0173). Plot details are as in Figure 2.7.
Figure 2.12: Representative plot of post-release movement of a tagged tarpon tracked in lower Tampa Bay at the Sunshine Skyway Bridge. The inset map indicates the area where the tarpon remained for the latter portion of its track in a thick school of baitfish. Filled colored points represent the tarpon’s approximate GPS position every 15 minutes on date(s) the signal was heard and are shown overlaid on a GIS depth contour map. Arrows with tarpon silhouettes exemplify its path in chronological order.
Figure 2.13: Representative plot of post-release movement of a tagged tarpon hooked in Egmont Channel, north end of Egmont Key in Tampa Bay. The signal was lost after 30 minutes of tracking because the research vessel could not keep up with swimming speeds. The tarpon was detected two weeks later in Southwest Channel (green point). Symbol details as in Figure 2.12.
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 (α=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≤0.95). 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 (α=0.05). The mean lengths and weights of tarpon and environmental data were also compared for any significant differences between and among treatments (α=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 ($\alpha=0.05$). 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 ($^\circ$C), Water Temp ($^\circ$C), dissolved oxygen (DO), salinity (SAL), pH, total length (TL), weight, angling duration (Figtr), 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. R² =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 Bonga 1997). 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). Nonetheless, 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

96
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 (α = 0.05). Sub-adult handling treatments were tested with a one-way ANOVA (α = 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.

<table>
<thead>
<tr>
<th>Size Class</th>
<th>Treatment</th>
<th>N</th>
<th>TL (mm)</th>
<th>Wt (kg)</th>
<th>Angling (min)</th>
<th>Handling (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult</td>
<td>Angled</td>
<td>45</td>
<td>1872 ± 22.58*</td>
<td>50.95 ± 2.02*</td>
<td>22.36 ± 2.37</td>
<td>472.29 ± 45.15</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>6</td>
<td>1732 ± 58.12</td>
<td>35.73 ± 3.15</td>
<td>0</td>
<td>411.00 ± 62.98</td>
</tr>
<tr>
<td>Sub-adult</td>
<td>Air-H</td>
<td>9</td>
<td>563 ± 18.89a</td>
<td>1.26 ± 0.10a</td>
<td>2.11 ± 0.26</td>
<td>277.33 ± 52.70</td>
</tr>
<tr>
<td></td>
<td>Air-V</td>
<td>9</td>
<td>581 ± 28.05a</td>
<td>1.56 ± 0.25a</td>
<td>1.72 ± 0.30</td>
<td>425.44 ± 47.59</td>
</tr>
<tr>
<td></td>
<td>No Air</td>
<td>10</td>
<td>567 ± 16.78a</td>
<td>1.33 ± 0.12a</td>
<td>3.40 ± 0.49</td>
<td>295.10 ± 74.81</td>
</tr>
<tr>
<td></td>
<td>RS Control</td>
<td>9</td>
<td>703 ± 20.70b</td>
<td>2.42 ± 0.22b</td>
<td>0.11 ± 0.07</td>
<td>258.56 ± 44.12</td>
</tr>
</tbody>
</table>
Table 3.1: Continued.

<table>
<thead>
<tr>
<th>Size Class</th>
<th>Treatment</th>
<th>N</th>
<th>Air Temp (°C)</th>
<th>Water Temp (°C)</th>
<th>Salinity (ppt)</th>
<th>DO (ppm)</th>
<th>pH</th>
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<tbody>
<tr>
<td>Adult</td>
<td>Angled</td>
<td>45</td>
<td>30.5 ± 0.38*</td>
<td>29.11 ± 0.11*</td>
<td>38.08 ± 0.06*</td>
<td>6.11 ± 0.07</td>
<td>8.29 ± 0.02*</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>6</td>
<td>26.7 ± 0.80</td>
<td>24.34 ± 0.74</td>
<td>35.88 ± 0.18</td>
<td>6.62 ± 0.29</td>
<td>7.97 ± 0.05</td>
</tr>
<tr>
<td>Sub-adult</td>
<td>Air-H</td>
<td>9</td>
<td>30.6 ± 0.58</td>
<td>28.92 ± 0.63a</td>
<td>28.16 ± 1.22a</td>
<td>5.97 ± 0.96</td>
<td>8.29 ± 0.09a</td>
</tr>
<tr>
<td></td>
<td>Air-V</td>
<td>9</td>
<td>31.3 ± 0.91</td>
<td>29.24 ± 0.60a</td>
<td>26.72 ± 1.4a</td>
<td>6.40 ± 0.57</td>
<td>8.30 ± 0.08a</td>
</tr>
<tr>
<td></td>
<td>No Air</td>
<td>10</td>
<td>31.5 ± 1.04</td>
<td>30.18 ± 0.36a</td>
<td>29.53 ± 0.79a</td>
<td>6.33 ± 1.00</td>
<td>8.37 ± 0.05a</td>
</tr>
<tr>
<td></td>
<td>RS Control</td>
<td>9</td>
<td>29.4 ± 0.94</td>
<td>27.27 ± 0.14b</td>
<td>36.45 ± 0.08b</td>
<td>6.26 ± 0.05</td>
<td>7.98 ± 0.02b</td>
</tr>
</tbody>
</table>
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 (α = 0.05). Mean concentrations among sub-adult handling treatments were tested with a one-way ANOVA (α = 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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Hematology</th>
<th>Metabolites</th>
<th>Hormone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HCT</td>
<td>Hb</td>
<td>Lactate</td>
</tr>
<tr>
<td><strong>Adult</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angled</td>
<td>46.9 ± 0.85* (41)</td>
<td>19.4 ± 0.36 (29)*</td>
<td>10.5 ± 0.75 (35)*</td>
</tr>
<tr>
<td>Control</td>
<td>31.8 ± 2.99 (6)</td>
<td>11.2 ± 1.73 (4)</td>
<td>0.3 ± 0.20 (6)</td>
</tr>
<tr>
<td><strong>Sub-Adult</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air-Horizontal</td>
<td>45.6 ± 1.15 (9)a</td>
<td>15.9 ± 1.40 (6)</td>
<td>3.5 ± 0.17 (8)a</td>
</tr>
<tr>
<td>Air-Vertical</td>
<td>45.7 ± 1.83 (9)a</td>
<td>17.3 ± 0.81 (8)</td>
<td>3.7 ± 0.33 (7)a</td>
</tr>
<tr>
<td>No Air</td>
<td>45.1 ± 1.22 (10)a</td>
<td>17.5 ± 1.07 (7)</td>
<td>4.4 ± 0.64 (10)a</td>
</tr>
<tr>
<td>Control (RS-C)</td>
<td>38.8 ± 1.48 (9)b</td>
<td>15.8 ± 0.87 (7)</td>
<td>1.1 ± 0.20 (8)b</td>
</tr>
</tbody>
</table>
Table 3.2: Continued.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Electrolytes</th>
<th>Calcium</th>
<th>Sodium</th>
<th>Potassium</th>
<th>Chloride</th>
<th>Phosphorus</th>
<th>Magnesium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angled</td>
<td></td>
<td>15.9 ± 0.39(36)*</td>
<td>192.8 ± 1.99(27)*</td>
<td>5.4 ± 0.13(38)*</td>
<td>167.4 ± 2.53(37)*</td>
<td>10.0 ± 0.36(38)*</td>
<td>5.0 ± 0.29(38)*</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>11.4 ± 0.41(6)</td>
<td>162.0 ± 1.95(6)</td>
<td>3.7 ± 0.14(6)</td>
<td>149.0 ± 2.22(6)</td>
<td>5.8 ± 0.16(6)</td>
<td>3.0 ± 0.32(6)</td>
</tr>
<tr>
<td>Sub-Adult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air-Horizontal</td>
<td></td>
<td>11.7 ± 0.36(9)</td>
<td>162.7 ± 3.09(9)</td>
<td>5.0 ± 0.16(9)</td>
<td>139.2 ± 4.38(9)</td>
<td>7.7 ± 0.41(9)</td>
<td>3.0 ± 0.11(9)*</td>
</tr>
<tr>
<td>Air-Vertical</td>
<td></td>
<td>11.7 ± 0.31(8)</td>
<td>164.3 ± 2.76(9)</td>
<td>5.2 ± 0.21(8)</td>
<td>142.4 ± 3.72(9)</td>
<td>7.3 ± 0.45(9)</td>
<td>3.5 ± 0.46(9)*&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>No Air</td>
<td></td>
<td>12.3 ± 0.34(10)</td>
<td>163.8 ± 3.97(10)</td>
<td>5.2 ± 0.20(10)</td>
<td>140.0 ± 5.67(10)</td>
<td>7.2 ± 0.63(10)</td>
<td>4.0 ± 0.48(10)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control (RS-C)</td>
<td></td>
<td>11.9 ± 0.23(9)</td>
<td>167.8 ± 1.85(9)</td>
<td>5.1 ± 0.17(9)</td>
<td>143.6 ± 2.50(9)</td>
<td>6.6 ± 0.20(9)</td>
<td>2.6 ± 0.08(9)&lt;sup&gt;a,c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
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 (α = 0.05). The two non-significant tests are in bold. Only angled fish were used in these comparisons.

| Response Variable | Adult Mean | Adult S.E. | Sub-Adult Mean | Sub-Adult S.E. | Wilcoxon 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<sub>e</sub>) 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.
<table>
<thead>
<tr>
<th></th>
<th>CV N</th>
<th>Mean ± SE</th>
<th>Gill N</th>
<th>Mean ± SE</th>
<th>Student T-test</th>
<th>Wilcoxon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>T   df     P</td>
<td>Statistic</td>
</tr>
<tr>
<td>HCT (%)</td>
<td>14</td>
<td>44.25 ± 1.16</td>
<td>27</td>
<td>48.26 ± 1.06</td>
<td>-2.37 39    0.0230</td>
<td>297.5     0.0003</td>
</tr>
<tr>
<td>Hb (g/LdL)</td>
<td>7</td>
<td>18 ± 0.53</td>
<td>22</td>
<td>19.8 ± 0.4</td>
<td>-2.32 27    0.0283</td>
<td>89.5      0.0008</td>
</tr>
<tr>
<td>Lactate (mmol/L)</td>
<td>10</td>
<td>12.54 ± 1.54</td>
<td>25</td>
<td>9.72 ± 0.82</td>
<td>1.75 33     0.0890</td>
<td></td>
</tr>
<tr>
<td>Glucose (mg/dL)</td>
<td>12</td>
<td>110.2 ± 6.13</td>
<td>26</td>
<td>116.2 ± 5.19</td>
<td>-0.7 36     0.4909</td>
<td></td>
</tr>
<tr>
<td>Calcium (mg/dL)</td>
<td>10</td>
<td>15.77 ± 0.93</td>
<td>26</td>
<td>16 ± 0.41</td>
<td>-0.26 34    0.7943</td>
<td></td>
</tr>
<tr>
<td>Sodium (mEq/L)</td>
<td>12</td>
<td>197.6 ± 5</td>
<td>25</td>
<td>190.5 ± 1.62</td>
<td>1.34 35     0.2015</td>
<td></td>
</tr>
<tr>
<td>Potassium (mEq/L)</td>
<td>13</td>
<td>5.99 ± 0.25</td>
<td>25</td>
<td>5.09 ± 0.12</td>
<td>3.73 36     0.0007</td>
<td></td>
</tr>
<tr>
<td>Chloride (mEq/L)</td>
<td>12</td>
<td>170.3 ± 7.3</td>
<td>25</td>
<td>166 ± 1.5</td>
<td>0.59 35     0.5682</td>
<td></td>
</tr>
<tr>
<td>Phosphorus (mg/dL)</td>
<td>12</td>
<td>11.33 ± 0.54</td>
<td>26</td>
<td>9.32 ± 0.42</td>
<td>2.81 36     0.0008</td>
<td></td>
</tr>
<tr>
<td>Magnesium (mEq/L)*</td>
<td>12</td>
<td>5.89 ± 0.78</td>
<td>26</td>
<td>4.58 ± 0.2</td>
<td>1.73 36     0.1054*</td>
<td></td>
</tr>
<tr>
<td>Cortisol (µg/dL)*</td>
<td>16</td>
<td>0.71 ± 0.1</td>
<td>27</td>
<td>0.78 ± 0.13</td>
<td>0.47 41     0.6389*</td>
<td></td>
</tr>
<tr>
<td>TL (mm)</td>
<td>18</td>
<td>1881.7 ± 32.9</td>
<td>27</td>
<td>1864.9 ± 31</td>
<td>0.36 43     0.7197</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>18</td>
<td>50.46 ± 3.01</td>
<td>27</td>
<td>51.28 ± 2.7</td>
<td>-0.2 43     0.8450</td>
<td></td>
</tr>
<tr>
<td>Angling Duration (min)</td>
<td>18</td>
<td>28.8 ± 4.7</td>
<td>27</td>
<td>18.04 ± 2.06</td>
<td>2.09 43     0.0236</td>
<td></td>
</tr>
<tr>
<td>PBH (min)</td>
<td>18</td>
<td>4.51 ± 0.6</td>
<td>27</td>
<td>4.15 ± 0.63</td>
<td>0.39 43     0.7012</td>
<td></td>
</tr>
<tr>
<td>TBT (sec)</td>
<td>18</td>
<td>363.6 ± 51.3</td>
<td>27</td>
<td>144.4 ± 40.13</td>
<td>3.39 43     0.0015</td>
<td></td>
</tr>
<tr>
<td>TBTg (sec)</td>
<td>18</td>
<td>295.8 ± 49.95</td>
<td>27</td>
<td>72.77 ± 20.58</td>
<td>4.13 42     0.0004</td>
<td></td>
</tr>
<tr>
<td>TBTg (sec)</td>
<td>18</td>
<td>403.8 ± 59.56</td>
<td>27</td>
<td>173.2 ± 46.04</td>
<td>2.88 34     0.0068</td>
<td></td>
</tr>
<tr>
<td>BoatH (secs)</td>
<td>18</td>
<td>586.5 ± 68.15</td>
<td>27</td>
<td>396.1 ± 56.3</td>
<td>2.15 43     0.0373</td>
<td></td>
</tr>
<tr>
<td>BoatHgn (sec)</td>
<td>18</td>
<td>555.2 ± 55.03</td>
<td>27</td>
<td>359.2 ± 56.7</td>
<td>2.37 43     0.0225</td>
<td></td>
</tr>
<tr>
<td>BoatHgy (sec)</td>
<td>11</td>
<td>706.9 ± 76.4</td>
<td>25</td>
<td>431.7 ± 58.4</td>
<td>2.7 34      0.0106</td>
<td></td>
</tr>
<tr>
<td>THT (min)</td>
<td>18</td>
<td>39.24 ± 5.15</td>
<td>27</td>
<td>25 ± 2.17</td>
<td>2.55 43     0.0179</td>
<td></td>
</tr>
</tbody>
</table>
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.
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).
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: $Y = 2.4847 + 0.38305 \times \text{Weight}$; $p<0.001$. 
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 $Y = 3.749575 + 0.10622 \times \text{(Fight)} + 0.00966 \times \text{(Handling)}$, $(R^2 = 0.567$, $p<0.0001)$. 
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 $Y = 2.7687 + 0.0015(\text{Fight} \times \text{Handling})$ ($R^2 = 0.134$, $p<0.0001$).
CHAPTER FOUR:
MANAGEMENT APPLICATIONS AND FUTURE RESEARCH

Florida’s tarpon permit system and the conservation-mindset of Florida’s tarpon anglers have restricted the harvest of tarpon to such a low level that the largest source of fishing mortality is from the practice of catch-and-release angling. Using the number of issued permits (Guindon unpublished data) as a proxy for annual harvest against statewide total catch estimates (Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division. 2010), showed that less than 1% of the total catch is harvested. Traditional fisheries management does not play a role with Atlantic tarpon in Florida as catch limits and size limits do not apply with the permit system. Catch-at-age matrices used to estimate fishing mortality (F) or catch curve analyses used to estimate instantaneous total mortality (Z, Hilborn and Walters 1992) are not useful for tarpon, because few fish are harvested and ages are not readily available. Fishing effort and subsequent post-release mortality, sometimes referred to as cryptic mortality or death associated with physical injury, handling stress or post-release predation (Coggins et al. 2007), is more influential on the total population size than harvest. Therefore, as fishing pressure (effort) increases and more tarpon are caught and released, understanding the lethal and sub-lethal effects of catch-and-release angling on tarpon stocks becomes necessary to maintain the sustainability of the fishery. Most
importantly, reliable estimates of population size and accurate measures of fishing effort are needed.

This study evaluated short-term catch-and-release mortality and sub-lethal physiological disturbances separately from each other. However, studies combining physiological stress indicators with survival using telemetry can be a powerful tool to create appropriate science-based management decisions could have tertiary implications for the fishery (Davis et al. 2001 in Barton et al. 2002, Young et al. 2006, Wikelski and Cooke 2006, Skomal 2007). If population size and fishing effort remain unknown for tarpon, periodic monitoring of catch-and-release mortality should occur so that managers can watch for signs of increasing trends in mortality rates within the recreational fishery.

An alternative management approach to reduce post-release mortality would be to simply limit fishing effort (angling). Limited entry is a widely used practice in wildlife management areas (Dimmick and Klimstra 1964). A review by Bartholomew and Bohnsack (2005) has gone so far as to suggest that the practice of catch-and-release angling in some instances may be so influential on post-release morality that the conservation concept of no-take Marine Protected Areas (MPA) may be a better option thereby eliminating post-release mortality. This was countered by Cooke et al. (2006) who suggested that each of the eight factors synthesized by Bartholomew and Bohnsack (2005) be reviewed as species-specific cases because catch-and-release may be compatible with the concept of a no-take MPAs (Table 1 in Cooke et al. 2006). One of these eight factors was predation.

This study showed that post-release predation influenced tarpon survival. Tarpon experienced lethal shark attacks in both systems, but more were observed in Boca Grande
Pass. Boca Grande Pass has legally defined boundaries for management purposes. The boundaries, coupled with the fact that caught tarpon are released back into the pass, creates an area that could be considered a de facto MPA, which allows catch-and-release tarpon fishing to occur. A topic for investigation now is to determine whether or not fishing in the de facto MPA of BGP influences predator abundance. Cooke et al. (2006) stated that research on lobsters in MPAs and modeling exercises on MPAs showed that MPAs may unintentionally create areas with increased predator densities. Calculated catch-and-release mortality rates attributed to shark attacks in this study were higher (13%) in BPG, than in Tampa Bay (5%). However, part of the observed inter- and intra-seasonal variability in shark abundance and incidence of attacks in BGP may be related to the life-history of the shark species. The predator-prey interaction of the two (tarpon and sharks) and their abundances should be evaluated. In the mean time, when predator burdens are high, angler ethics and behavior will play a role in determining the fate of tarpon (Cooke et al. 2006).

Most tarpon in Florida’s recreational fishery are caught along the Gulf Coast. Statewide estimates of the total number of tarpon caught based on random angler intercepts from the National Marine Fishery Service’s Marine Recreational Fisheries Statistical Survey (MRFSS) are variable and somewhat unreliable because of the extremely low number of intercepts with tarpon anglers. However, they are best data currently available to monitor the recreational catches of tarpon. The MRFSS data from 2003 through 2009, the years encompassing this research, estimated that tarpon total catches ranged from 44,019 ± 15.7 percent standard error (PSE) to 62,896 ± 14.2 PSE tarpon on Florida’s Gulf coast and from 8,629 ± 39.8 PSE to 38,929 ± 21.6 PSE tarpon.
on Florida’s Atlantic coast (Table 4.1). Statewide estimates of the total catch between 2003 and 2009 ranged from a low of 54,894 ± 14.4 PSE fish in 2009 to a maximum of 89,558 ± 13.5 PSE in 2005. Catch data estimates on the Atlantic coast had higher (>20%) PSEs, or lower precision, than Gulf Coast estimates and were not as statistically reliable.

Application of the mortality rates from this study could be applied to the MRFSS catch estimates for other states within the species range or along the Gulf Coast, or even statewide for Florida since tarpon is a migratory species. However, recent genetic evidence by Ward et al. (2008) revealed tight groupings of most locations sampled for Atlantic tarpon, but found samples from the Florida population to be genetically divergent from the other locations sampled. This potential isolation, coupled with the fact that sampling for this study took place along the central and southwest Florida Gulf coast, only MRFSS data on released tarpon along the Gulf Coast were used to estimate population mortality. Using sonic telemetry, it was estimated that 87% of released tarpon survive. Assuming a 13% mortality rate (including predation) for released tarpon and using the mean MRFSS estimate of the total released tarpon along the Gulf coast during 2003-2009 (50,955 ± 15.8 PSE, Table 4.1), an average of 6,828± 1,079 tarpon died each year from catch-and-release angling. Annual estimates of release mortality among these years ranged from a low of 5,899 ± 926 fish in 2009 to a maximum of 8,105 ± 1,167 in 2004 (Figure 4.1).

Angler education, not necessarily regulation, could help to increase the numbers of tarpon surviving catch-and-release angling. Causes other than predation were responsible for 5% of the observed mortality in this study. Poor handling practices causing irreparable physical and physiological damage can be somewhat controlled
through education and awareness campaigns while other significant factors on survival, such as foul-hooking and predation, are more difficult to control whether by education or regulation. Communicating these results to the public through education and outreach materials that provide guidelines on suggested best handling practices for tarpon, may reduce this 5% mortality rate. A 5% decrease in mortality would result in an annual increase of approximately $2,701 \pm 427$ tarpon surviving catch-and-release events (Figure 4.1). Small changes increasing survival can have a large effect on long-lived species (Schroeder and Love 2002).

Sub-adult and adult Atlantic tarpon are an important part of Florida’s economy and tourism. An economic study has attempted to quantify the monetary value of the tarpon fishery for the southwest region of Florida to stress its importance to businessmen, public and private sectors, governments, and anglers alike (Tony Fedler, personal communication). Tarpon conservation efforts in Florida should focus on these sub-adult and adult life-history stages where threats are predominantly related to predation and the effects of catch-and-release angling.

The effects of international tarpon fishing on the numbers of tarpon reaching Florida waters are unknown. While harvest rates that could decrease a tarpon population are low in Florida, landings in other countries which support subsistence fisheries should be evaluated. Tarpon fisheries in other Central and South American countries may record commercial landings high enough to cause the number of tarpon in Florida’s recreational fishery to decline since tarpon are a migratory species (Ault et al. 2008). Knowing where the tarpon supplying Florida’s recreational fishery come from is an important question that satellite tagging programs evaluating long term movements and migrations (Luo et
coupled with genetic tagging studies being conducted by the Florida Fish and Wildlife Conservation Commission’s Fish and Wildlife Research Institute (Seyoum et al. 2008) hope to address. While state governments cannot regulate other countries, they can communicate relevant state findings to other countries via publications and information, to help conserve these fish.

Biologists are increasingly being asked to provide the best possible science to resource managers, environmental conservation groups, and legislators so everyone can understand potential impacts of recreational fishing practices to make good decisions for the resource (Wikelski and Cooke 2006). In turn, the anglers look to government natural resource agencies for guidelines on how to handle fish. However, when regulations are needed, the regulation should be communicated in such a way that everyone (scientist, manager, government, enforcement and public) understands why it is needed and the rule should be fair and enforceable (Miller 1990). In a review by Pelletier et al. (2007), the state of Florida was poorly ranked as having inadequate easy-to-access outreach materials available to the public regarding best practices for catch-and-release angling. A number of variables pertaining to the Atlantic tarpon’s physiology and post-release mortality in response to angling were addressed in this work. Future efforts will be made to provide products and coordinated outreach activities to anglers, guides, and conservation groups that include suggestions and guidance for minimizing tarpon stress responses and maximizing post-release recovery and survival.

Biologists should start to integrate biology and fish physiology with management and conservation applications into their programs. Defining hypotheses to be tested that link to potential tertiary effects for tarpon will be the most beneficial (Cooke and
Continuing this research should include measuring blood responses throughout the recovery period following exhaustive exercise or angling by sampling tarpon up to 24 hours post-release and establishing lethal thresholds for select physiological parameters (i.e. lactate) in response to angling. The cortisol response could be investigated to understand the underlying mechanism of suppressed levels observed in angled fish. In addition, to fully understand the scope of metabolic and respiratory acidosis caused by angling in tarpon, muscle enzymes, muscle energy reserves and blood gases to produce oxygen-equilibrium curves should be measured. Doing so will generate data that could be used to provide predictive capability in potential mortality and allow for better science-based management decisions rather than just reducing fishing effort.

Future work within the fishery should include investigating the cumulative effect of multiple captures on tarpon and estimating delayed mortality in adult tarpon. Tournament procedures that require extensive handling of tarpon should be evaluated relative to tarpon physiology and survival. Other unknowns that could be disruptive to tarpon are related to the effects of ambient sound (i.e. boat engine noise) on tarpon movement, behavior and stress physiology that have been shown to influence other species (Sand et al. 2000, Popper 2003, McCauley et al. 2003). Finally, peak season for tarpon angling in the major geographical areas along the Gulf central and southwest coasts and Florida Keys is typically late spring and summer (May to July), which coincides with peak spawning season (Crabtree et al. 1997) and targets the largest tarpon in spawning aggregations. Information linking the sub-lethal and potential tertiary effects of angling on reproductive success (spawning, frequency, productivity, gamete size and
quality) is a needed area of research. Much of the reproductive biology of the species is still unknown.

Based on field observations and the results from this study, it appears that sub-adult and adult Atlantic tarpon along the Gulf coast of Florida are resilient and can recover from physiological disturbances incurred during routine catch-and-release angling events in the recreational fishery when they are released in the absence of large predators. The anglers themselves can play a key role in tarpon conservation.

**Literature Cited**


Table 4.1: Estimates of Atlantic tarpon total annual catch and number released from 2003-2009. Data presented are total catch (harvested + released) and reported percent standard errors (PSE) and numbers of tarpon reported as being caught and released alive by anglers and the associated PSE presented for the state of Florida and for the Gulf and Atlantic coasts using the National Marine Fisheries Service’s Marine Recreational Fisheries Statistics Survey (MRFSS). The asterisk (*) denotes where PSE is greater than 20%, and therefore statistically unreliable. All fishing modes and areas were combined for this analysis.

<table>
<thead>
<tr>
<th>Year</th>
<th>Florida Catch</th>
<th>PSE</th>
<th>Released Catch</th>
<th>PSE</th>
<th>Gulf Coast Catch</th>
<th>PSE</th>
<th>Released Catch</th>
<th>PSE</th>
<th>Atlantic Coast Catch</th>
<th>PSE*</th>
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<tbody>
<tr>
<td>2003</td>
<td>56,520</td>
<td>10.8</td>
<td>55,824</td>
<td>10.9</td>
<td>44,541</td>
<td>12.0</td>
<td>44,541</td>
<td>12.0</td>
<td>11,979</td>
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<tr>
<td>2004</td>
<td>74,585</td>
<td>12.8</td>
<td>72,173</td>
<td>13</td>
<td>62,896</td>
<td>14.2</td>
<td>60,485</td>
<td>14.4</td>
<td>11,689</td>
<td>28.7</td>
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<tr>
<td>2005</td>
<td>89,558</td>
<td>13.5</td>
<td>89,558</td>
<td>13.5</td>
<td>58,680</td>
<td>17.3</td>
<td>58,680</td>
<td>17.3</td>
<td>30,878</td>
<td>21.3</td>
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<td>2006</td>
<td>64,070</td>
<td>14.8</td>
<td>64,070</td>
<td>14.8</td>
<td>47,212</td>
<td>18.3</td>
<td>47,212</td>
<td>18.3</td>
<td>16,858</td>
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<td>2007</td>
<td>82,948</td>
<td>13.1</td>
<td>76,679</td>
<td>12.5</td>
<td>44,019</td>
<td>15.7</td>
<td>44,019</td>
<td>15.7</td>
<td>38,929</td>
<td>21.6</td>
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<td>2008</td>
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<td>84,776</td>
<td>13.8</td>
<td>55,485</td>
<td>17.6</td>
<td>55,485</td>
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<td>29,291</td>
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</tr>
<tr>
<td>2009</td>
<td>54,894</td>
<td>14.4</td>
<td>54,894</td>
<td>14.4</td>
<td>46,265</td>
<td>15.4</td>
<td>46,265</td>
<td>15.4</td>
<td>8,629</td>
<td>39.8</td>
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<tr>
<td>Mean</td>
<td>72,479</td>
<td>13.3</td>
<td>71,139</td>
<td>13.3</td>
<td>51,300</td>
<td>15.8</td>
<td>50,955</td>
<td>15.8</td>
<td>21,179</td>
<td>26.0</td>
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</table>
Figure 4.1: Estimated annual release mortality based on the National Marine Fisheries Service’s Marine Recreational Fisheries Statistics Survey (MRFSS) data for released tarpon along the Gulf coast of Florida during 2003-2009. Numbers are calculated using the combined catch-and-release mortality rate of 13% representative of the southwest and west central recreational fishery (Gulf Coast, broken, red line) that includes post-release shark predation. The estimated release mortality excluding shark attacks (solid, blue line) attributed to handling and physiological disruptions (5%) during angling events represent the number of tarpon that could be potentially controlled for by anglers to increase survival. Error bars represent plus and minus the proportional standard errors reported with the MRFSS data.
APPENDIX A:

FOUL-HOOKED TARPON
APPENDIX A (CONTINUED)

Table AA.1: Specific hook locations for the nine tarpon that were classified as foul-hooked and their associated fate (survivor, mortality) in the catch-and-release mortality study in BGP and TB, 2002-2007. An “*” indicates a post-release shark attack. A foul-hooked fish was defined as one hooked in a part of the body other than the mouth. Fish hooked in the sutures of the premaxillary, maxillary bones (upper jaw) and the dentary bone (lower jaw) or the soft buccal tissues in the corner of the mouth were considered fair-hooked. Hook type (straight-shank (J), circle (C), treble (T)), bait type (artificial (A), cut (C), live (L)), whether or not the hook was removed prior to release, and the condition of the tarpon at the time of release qualitatively assigned based on observations of the tarpon’s equilibrium and swimming capability are also included.

<table>
<thead>
<tr>
<th>Date</th>
<th>Hook Location</th>
<th>Fate</th>
<th>Hook Type</th>
<th>Bait Type</th>
<th>Hook Removed</th>
<th>Release Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/24/2002</td>
<td>Cheek/Head</td>
<td>Mortality</td>
<td>J</td>
<td>A</td>
<td>Yes</td>
<td>Poor</td>
</tr>
<tr>
<td>6/26/2002</td>
<td>Cheek/Head</td>
<td>Survivor</td>
<td>J</td>
<td>A</td>
<td>Yes</td>
<td>Good</td>
</tr>
<tr>
<td>6/1/2004</td>
<td>Cheek/Head</td>
<td>Mortality*</td>
<td>C</td>
<td>A</td>
<td>Yes</td>
<td>Good</td>
</tr>
<tr>
<td>6/15/2005</td>
<td>Cheek/Head</td>
<td>Survivor</td>
<td>J</td>
<td>C</td>
<td>No</td>
<td>Poor</td>
</tr>
<tr>
<td>6/22/2007</td>
<td>Cheek/Head</td>
<td>Survivor</td>
<td>C</td>
<td>C</td>
<td>No</td>
<td>Fair</td>
</tr>
<tr>
<td>5/6/2003</td>
<td>PecFin</td>
<td>Survivor</td>
<td>J</td>
<td>L</td>
<td>Yes</td>
<td>Poor</td>
</tr>
<tr>
<td>7/12/2006</td>
<td>Deep</td>
<td>Survivor</td>
<td>J</td>
<td>L</td>
<td>No</td>
<td>Fair</td>
</tr>
<tr>
<td>7/24/2006</td>
<td>Deep</td>
<td>Mortality*</td>
<td>J</td>
<td>L</td>
<td>No</td>
<td>Poor</td>
</tr>
<tr>
<td>8/4/2006</td>
<td>Gills</td>
<td>Mortality</td>
<td>T</td>
<td>A</td>
<td>No</td>
<td>Fair</td>
</tr>
</tbody>
</table>
APPENDIX B:

A SUMMARY OF SELECTED POST-RELEASE MOVEMENTS FROM
ACoustically tagged atlantic Tarpon in Boca grande Pass AND
Tampa Bay 2002-2007
Acoustic telemetry was used to assess the effects of catch-and-release fishing on the survival of Atlantic tarpon, *Megalops atlantics*, in two Gulf coast locations that support a popular recreational fishery, Boca Grande Pass (BGP) and Tampa Bay (TB) during the 2002-2007 seasons. Understanding the effect of fishing on the survival of these released tarpon is critical to understanding how a stock might be impacted when harvest is not occurring. Details of the study design and references for the concepts behind this study may be found in Chapter Two.

Presented here is a brief summary of some of the tarpon movements observed in this study. Plots of individual tarpon movement were prepared using GIS (ArcView). Swimming speeds in km/hour were calculated based on the straight-line distances measured between each way point on the plot and divided by the total number of minutes the tarpon was tracked.

In general, each of the 82 tarpon ultrasonically tagged and tracked from 2002-2007 in BGP and Tampa Bay did one of three things after release: remained in the vicinity where it was tagged, swam immediately towards or up into Charlotte Harbor or Tampa Bay, or swam immediately toward the Gulf away from its release site (offshore towards open water or along the beaches; Figure AB.1 A-C). Some tarpon swam away rapidly upon release but returned to the release vicinity within the short-term tracking period (Figure AB.2).

Tarpon tagged in the upper, middle and lower portions of TB mid-to-late-season (June-July) typically remained in the vicinity of where they were tagged. Each of the
APPENDIX B (CONTINUED)

tarpon whose movements are depicted in Figure AB.3 was heard on subsequent sampling days and the reacquired signals came from within visible bait schools. Fish number 150 was, in fact, visually observed feeding at the surface just 1.5 hours post-release (Figure AB.3 B).

Excluding mortalities, 23 out of 71 (32%) of the tagged and tracked tarpon that survived the angling event were heard again on subsequent days. Tarpon tagged in the passes that left the area during the short-term tracking period often returned to the vicinity of capture the following day or up to two weeks later throughout the season (May-August, Figure AB.4A to D). This indicated that tarpon exhibited site fidelity to the pass early and late in the spawning season. Reacquired signals also helped to verify that a tarpon survived the short-term tracking time when it was not tracked the full term due to equipment failure (Figure AB.4 C) or highly active swimming behavior upon release (Figure AB4.D). If keeping up with extremely active fish would have required breaking or bending the hydrophone pole in the boat-side mount the tracks were terminated early. Tarpon number 200 (Figure AB4.D) experienced the longest angling duration of tagged tarpon in this study (139 minutes) and was not exhausted from the fight. The tarpon had “settled into” the fight and was given free access to gulp air at the surface which tended to make the fights longer. At its release, research biologists were unable to keep up with it, but the tarpon’s transmitter signal was detected and tracked just south of Egmont Key two weeks later, so it survived. When fish number 200 was lost 30 minutes post-release, it had swam a total of 8.77 km as determined by summing the straight-line distances traveled between each waypoint (Figure AB.4D).
The average swimming speed of tarpon tracked in Tampa Bay was 2.85 km/hour ± 0.51 S.E. and ranged from 0.12 to 17.54 km/hr. The 17.54 km/hour was simply the 8.77km distance doubled as if fish number 200 (Figure AB4.D) had maintained its swimming speed for the full hour. Excluding that fish because it was not tracked a full hour, the upper range of average swimming speeds during a tracking period was 5.86 km/hour (Figure AB.2, fish number 146.). The average swimming speed in TB was slightly lower than the average (4.46 km/hr) observed by Edwards (1998) in BGP (range: 3.33 to 5.37 km/hr). In general, distance traveled by tagged tarpon was highest during the first hour post-release (Figure AB.5).

Angling duration did not seem to affect the direction of movement exhibited by the tarpon despite the range of observed fight times (4 to 139 minutes). Four different tarpon each fought for 30 minutes in BGP showed four different movement patterns post-release (Figure AB.6). A 30 minute fight time was longer than average (22.7min) for tagged tarpon in this study.

Tarpon subjected to extreme circumstances during the angling events (for example catch-and-release followed by a shark attack) sometimes made long journeys immediately following release and survived (Figure AB.1C). Fish number 175 was witnessed in the jaws of a hammerhead shark, but minutes after during the tracking a tarpon rolled off the bow of the research vessel and the transmitter was visually observed and acoustically confirmed in the fish by the field crew when it gulped air at the surface. Tarpon number 180 was not as fortunate and suffered a fatal attack despite its ability to recover from a poor release condition and swim for three hours (Figure AB.7A). Tarpon
such as this one, whether offshore or in the bay, tended to follow the contours of the bottom and “rested” when there was some relief along one of their sides. Other tarpon followed shorelines or channels after release (AB.7B and AB.2). Topography and bait availability were two of the anecdotal observations that seemed to affect where tarpon remained after catch-and-release.

In cases where the signal stopped moving but no obvious attack was witnessed and mortality was suspected, the representative plots showed the waypoint tracking data piling up in one place (Figure AB.8). This particular fish was viewed on a deployed SplashCam and was missing its tail and had a bite out of its stomach. The associated vector plot also showed the signal bearings from latter waypoints were in the same direction.

Acoustic telemetry proved to be a valuable tool to track movements of tarpon after catch-and-release angling events. Several tracked tarpon were observed back in the schools of fish and feeding after release. Topography and prey availability seemed to influence post-release movements. Numerous signals were heard on subsequent days which also confirm a more long-term post-release survival. True long-term studies are needed to confirm survival rates beyond six hours, but these studies are costly and labor intensive. The data collected were used to estimate the short-term catch-and-release mortality rate of tarpon in BGP and TB and telemetry continues to be a successful method used to evaluate fisheries that are predominantly catch-and-release, particularly for large pelagic or migratory species.
Figure AB.1: Representative plots of post-release movements of three tagged tarpon from Tampa Bay that: A) remained in the vicinity of where it was tagged, B) returned to the pass or place of release, and C) swam into the Gulf of Mexico. Each circle represents the tarpon’s approximate GPS position every 15 minutes. Arrows with tarpon silhouettes exemplify its path in chronological order. Filled colored points indicate date(s) the signal was heard and are also shown overlaid on a GIS depth contour map.
APPENDIX B (CONTINUED)

B. Figure AB.1: Continued.
APPENDIX B (CONTINUED)

C.
Figure AB.1: Continued.
APPENDIX B (CONTINUED)

Figure AB.2: Representative plots of post-release movements of two tagged tarpon from the beaches of St. Petersburg, FL, that returned to its place of release within the short-term tracking period (A and B). Each circle represents the tarpon’s approximate GPS position every 15 minutes. Symbol details as in Figure AB.1.
B. Figure AB.2: Continued.
A.

Figure AB.3: Representative plots of post-release movements of three tagged and tracked tarpon that were heard again on subsequent days in each portion of Tampa Bay: upper bay (A), middle bay (B) and lower Bay at the Sunshine Skyway Bridge (C). The inset map of (B and C) indicates the area where the tarpon remained for the latter portion of its track in a thick school of baitfish. Symbol details as in Figure AB.1.
B.

Figure AB.3: Continued.
C.
Figure AB.3: Continued.
A.

Figure AB.4: Representative plots of post-release movements of four tagged and tracked tarpon from the mouth of Tampa Bay near Egmont Key that were heard again on subsequent days (A-D). Tarpon showed some site fidelity to the pass early in the season (A) and late in the season (B). Other times the signal was reacquired as a way to confirm survival of a fish that was not tracked the full term due to technical failures of the tracking equipment (C) or when the fish was swimming so quickly at release that the tracking vessel could not keep up with it (D). Symbol details as in Figure AB.1.
APPENDIX B (CONTINUED)

B.
Figure AB.4: Continued.
C.
Figure AB.4: Continued.
D.
Figure AB.4: Continued.
Figure AB.5: Mean distance traveled (in kilometers) by tagged tarpon tracked during the first four hours post-release in Tampa Bay, 2005-2007.
Figure AB.6: Representative plots of post-release movements of four tagged tarpon that were caught using artificial breakaway jigs and fought for 30 minutes in Boca Grande Pass and: A) swam into Charlotte Harbor, B) remained in the pass, C) swam into the Gulf of Mexico and returned, and D) swam into the Gulf but was not detected again.
Figure AB.7: Representative plots of tarpon movements for fish number 180 (A) and fish number 179 (B) which exemplify fish that followed depth contours and channels along its path. Note: Fish number 180 was preyed upon three hours post-release. Symbol details as in Figure AB.1.
B.

Figure AB.7. Continued.
Figure AB.8: Representative plot of a tarpon whose signal stopped moving in Boca Grande Pass and was later confirmed to be dead when the image of the fish was captured on the deployed splash-cam.
APPENDIX C:

LIST OF VARIABLES RECORDED AND CREATED AND THEIR DESCRIPTIONS

FOR TARPON PHYSIOLOGY
Variable ($denotes categorical): Description:

FishID$: Unique identifier for each tarpon
Month$: Month of sample
Year$: Year of sample
AirTemp: Air temperature in Degrees Celsius
Weather$: Categorical variable qualitatively describing weather
WaterTemp: Water temperature in Degrees Celsius
DO: Dissolved oxygen (ppm)
SAL: Salinity (ppt)
pH: pH of water
SizeClass$: Adult or Sub-adult
Angle$: Angled or control adults

HandlingTrt$: Sub-adults: Air-H, 60 seconds of air exposure while held horizontally out of the water; Air-V, 60 seconds of air exposure while held vertically out of the water; NoAir, no air exposure; RS-C – rapidly sampled control animals.
Adults: Percussion, euthanized control animals; Angled.

Hook up: The time a tarpon was hooked, recorded as clock time

Time Landed/TOD: TOD-time of death for adult control animals.
  **Time Landed**-For adults released alive after angling, this was the time a tarpon was put in someone’s hand, gaffed, leadered and under human “control” prior to biologists getting the fish in the sling. In some cases it might have been recorded as the time in the sling, but not too often. For sub-adults, landed is the time the fish was placed in the v-tray (No-air, RS-C) or net (Air-V, Air-H). If it was a tarpon subjected to 60 seconds of air exposure, the fish was considered landed BEFORE this treatment started.

Fightr: Fight time (rounded to nearest half minute). This was calculated as the **Time Landed** minus **Hook-up** time; also called angling duration.
APPENDIX C (CONTINUED)

PBHr:  **Pre-Bleed Handling** time (rounded to nearest quarter minute). Defined as all excess handling of the fish after it was landed but before it was stuck with a needle. This may include gaffing, towing, photos, logistics and struggles associated with getting the fish into the v-try or sling, removing scales for sticks, and the 60 seconds of air exposure in treatment. All PBH was measured prior to the 1st stick of a needle. Calculated as **Bleed Time Start** minus **Time Landed**.

Bleed Time Start:  This was the time of 1st needle stick (typically a green tube).

Bleed Time End:  Time noted when blood filled the tube (green and grey) that was placed onto ice. If it was a quick bleed, where the green and grey tubes filled rapidly, the time when “blood” entered tube was used. If it was a long bleed, the time the tube was done being filled was used.

TBT_secs:  **Total Bleed Time** (in seconds); Calculated as **Bleed Time End** minus **Bleed Time Start**, or alternatively, the time of first needle stick until the last tube fills (Green or grey, but usually grey). This is the amount of time the tarpon was in the sling or v-tray until all blood was drawn.

TBTgn_secs:  Total bleed time for green tube (seconds)

TBTgy_secs:  Total bleed time for grey tube (seconds, used for lactate test only)

THTr:  **Total Handling Time** (rounded to nearest quarter minute). It is the sum of three times: **Fightr + PBHr + TBTr**

Time placed on ice:  Green and grey tubes may have had different times. Stopwatch times were converted to clock time, so person at the field laboratory could use a watch for processing times.

Time Spun:  Clock time green and grey tubes were placed in centrifuge for plasma separation

Total processing time:  Calculated as **Time Spun** minus **Time placed on ice**. This was recorded in minutes. Time included transport via boat to get blood to the beach for processing. If total processing time was 60 minutes or more the sample was discarded.

SL:  Standard Length (mm)

FL:  Fork Length (mm)

TL:  Total Length (mm)
APPENDIX C (CONTINUED)

Girth: Measured in front of dorsal fin and around the fish (mm)

Weight: Formula estimated weight or measured weight of tarpon (kg)

Release Time: Clock time of when tarpon was released to pond or Gulf of Mexico

RlsCondition$: Qualitative release condition 1, 2, 3 (good, fair, poor)

BleedMethod$: Gill vs. Caudal venipuncture – only adults have this

HCT: Whole Blood parameter hematocrit (percent RBC volume)

Hb: Whole Blood parameter hemoglobin (g/dL)

Lactate: Metabolite in plasma (mmol/L)

Glucose: Metabolite in plasma (mg/dL)

Calcium: Electrolyte in plasma (mg/dL)

Sodium: Electrolyte in plasma (mEq/L)

Potassium: Electrolyte in plasma (mEq/L)

Chloride: Electrolyte in plasma (mEq/L)

Magnesium: Electrolyte in plasma (mEq/L)

Phosphorus: Electrolyte in plasma (mg/dL)

Cortisol: Hormone in plasma (µg/dL)

Sticks: Number of needle sticks tarpon received before bleeding.

BoatH_secs: Variable created post-hoc as sum of pre-bleed handling seconds and total bleed time seconds to evaluate “handling” vs. “angling” effects.

BoatHgn_secs: Variable created post-hoc as above but for the handling time to fill the green tube used in analyses.

BoatHgy_secs: Variable created post-hoc as above but for the handling time to fill the green tube used in analyses.
APPENDIX C (CONTINUED)

Grey, Time on needle:

Time GREY tube went on the needle before blood starts filling. It might have been the same as fill time if a fast bleeder. If multiple sticks were required, the time that the grey tube which was successfully filled with blood was placed on the needle was recorded. As an aside, the number of sticks needed before blood was successfully drawn was noted.

Green, Time on needle:

Time GREEN tube went on the needle before blood starts filling. It might be the same as fill time if a fast bleeder. If multiple sticks were required, the time that the green tube which was successfully filled with blood was placed on the needle was recorded. It may have been multiple tubes. As an aside, the number of sticks needed before blood was successfully drawn was noted.