An Evaluation of Livewell Transport as a Factor Contributing to Physiological Stress in Smallmouth Bass at Competitive Angling Events.

By

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A thesis submitted to the Department of Biology
In conformity with the requirements for
the degree of Master of Science

Queen’s University
Kingston, Ontario, Canada
(March, 2011)

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Abstract

This study was conducted to improve our understanding of the biological impacts of competitive angling events on fish. More specifically, this study examines the impacts of transporting Smallmouth bass (*Micropterus dolomieu*) in the livewells of bassboats on large water bodies. Fish were transported in an experimental livewell that recorded the amount of water turbulence experienced by the fish held in the tank, in Force (0.84ft²/lb/sec). A video recording of the transportation process was also taken to determine the amount of interactions between the fish and the walls of the livewell. It was determined that as water activity increased, so did the mean number of impacts per minute. In addition, as the number of impacts increased, so did the concentration of plasma lactate dehydrogenase (LDH). Levels of plasma LDH and creatine phosphokinase (CPK) were compared between fish that were transported in a padded livewell and fish that were transported in an unpadded livewell. Fish that were transported in an unpadded livewell showed significantly higher levels of both LDH and CPK (*P* < 0.05). Fish that were transported in the padded livewell did not show significantly higher levels of LDH or CPK than the control groups. This indicates that transportation of Smallmouth bass in livewells causes cellular damage and that this damage can be mitigated by simple modifications to the interior of the livewell.
Acknowledgements

I would like to thank my supervisor Dr. Bruce Tufts for the opportunity to pursue graduate research in fisheries biology. His guidance and experience have been instrumental in developing my understanding of scientific research and writing. I would also like to thank my supervisory committee, Dr. Yuxiang Wang and Dr. William Nelson, who were crucial in the completion of my thesis.

The field research in this project could not have been completed without the technical and logistical guidance of my father, Tom Brooke Sr. who helped incredibly with teaching me the finer points of Smallmouth on Lake Ontario, a passion and pursuit of his for over 25 years.

I would also like to thank Matthew DeMille for his assistance in some of the logistical aspects of the study as well as Andrew Lowles for field support and being there with the truck at a moment’s notice.

My family has been my supporting structure over the past several years during my post-secondary education; I would like to thank my mother Lin Brooke for her patience and writing ability.

Finally, I would like to thank my lovely wife, Heather Brooke who spent countless hours calming, consoling and encouraging me through this process, may we never forget the scent of clove oil and Smallmouth bass.
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6.1 Summary

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List of Abbreviations

\(\alpha\): Significance level

ANCOVA: Analysis of co-variance

ANOVA: Analysis of variance

CPK: Creatine phosphokinase

LDH: Lactate dehydrogenase

U/L: Units of enzyme per Litre

\(n\): Sample size

NAD\(^+\): Nicotinamide adenine dinucleotide

NADH: Nicotinamide adenine dinucleotide (reduced)

\(P\): Probability

\(R^2\): Explanation of variance
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Chapter 1

Introduction

Global fisheries, once considered an inexhaustible resource, are in a general state of decline. Given the massive expanse of the marine fish resources of the Earth’s Oceans, this decline is a serious issue for global biodiversity as well as an obvious concern for the future of mankind. Many books and research initiatives have shown that commercial over-exploitation is the leading cause of the dwindling resource (Pauly et al. 2005). Several well-known examples exist where huge populations of a target species have been so thoroughly overfished that the state of recovery of the species, not to mention the resource itself, is in question. As an example, the Peruvian anchoveta (*Engraulis ringens*), a species that occurred in massive numbers off the Pacific coast of South America was commercially exploited to such an extent that a complete collapse of the fishery ensued in 1972 (Csirke 1989). A more local example is the Atlantic cod (*Gadus morhua*) fishery collapse on the legendary Grand Banks of the north Atlantic coast of North America where again, overfishing was the most important factor in the fishery’s collapse (Myers et al. 1996).

North America’s inland fisheries are not as strongly influenced by commercial harvest as the fisheries on the Atlantic and Pacific coasts. In contrast to the situation in marine environments, recreational fishing is the most common fishing on inland lakes across Canada. Recreational fisheries differ fundamentally from commercial harvest in that target species are individually harvested, eliminating bycatch. In addition, the angler has the choice to keep his or her catch for later consumption or to release the fish. Releasing the fish alive after capture is known as live-release angling. Live-release angling is a popular and effective management tool
that allows responsible anglers to utilize the resource without over-exploitation (Noble & Jones 1999).

Recreational angling in Ontario and particularly in the Great Lakes region is a popular past-time. More than one quarter of Canada’s recreational fishing occurs on the Great Lakes (OMNR 2008). In 2005 alone, 215 million dollars were spent in the Great Lakes region on direct expenditures for recreational angling (Department of Fisheries and Oceans 2005).

As in marine environments, there are still many factors that can negatively impact freshwater fish populations. For example, Great Lakes fish populations have been greatly affected by a multitude of anthropogenic disturbances such as: commercial harvest, invasive or introduced species and habitat alteration or pollution. Specific examples include the American Eel (Anguilla rostrata), whose population has dropped significantly since the turn of the century due to commercial over-exploitation and habitat alteration (Cairns et al. 2008) and several commercially important whitefish (Coregonus spp.) species that have been affected over the past several decades by the introduction of the rainbow smelt (Osmerus mordax)(Crossman 1991).

Some species are less affected by the pressures of human settlement and increasing shoreline development. The black basses of North America are good examples of resilient species that are less affected by human disturbance than some other, more sensitive fish species. Native to the Saint Lawrence Seaway and the Great Lakes (Scott & Crossman 1998), these fish are found in both lacustrine and riverine habitats around the world. Black basses are popular game species because of their renowned fighting ability and the ferocity with which they are known to attack bait. Because of their popularity amongst anglers and their general habitat
requirements, most populations of black basses are growing and their range expanding, though this is mostly due to human introductions (Jackson 2002).
Chapter 2

Literature Review

2.1 Tournament Angling

Tournament angling has taken the live-release initiative and formed a very lucrative industry with a relatively small effect on the resource. The modern North American bass fishing tournament was first documented in 1955 in Texas (Kerr 1991). Since that time, the sport has grown across the United States and Canada. A survey in 1991 estimated that 30,000 events take place annually in North America targeting the black basses (*Micropterus* spp.) which include Largemouth bass (*Micropterus salmoides*) and Smallmouth bass (*Micropterus dolomieu*) (Kerr 1999). Tournaments are also commonly held for a variety of other species such as Walleye (*Sander vitreus*), Muskellunge (*Esox masquinongy*) and Northern pike (*Esox lucius*). These competitive events are held on a variety of lakes across North America.

Tournament series and events vary not only in species targeted, size and type of water body, but also in number of anglers competing, number of sponsors, level of professionalism, purpose of tournament (some are fundraisers), size and types of prizes, etc. However, most tournament fishing typically follows a similar general pattern. A pre-set number of fish (most often 5 in Ontario to adhere to Ministry of Natural Resource regulations) which exceed a minimum size (generally 12 inches for the black basses) are captured using a rod and reel. Once the fish are captured, they are transferred to aerated holding tanks (referred to as livewells from this point on) in the angler’s boat which are typically inboard or incorporated into the hull of the boat, particularly in elite level competitions. A pre-set time is established when all of the anglers
must return to a final check-in point. The fish are then usually brought up on land in large plastic bags filled with water and held in aerated tanks until they are brought to the weigh scale. After the fish are weighed, they are transported to a custom-built boat commonly referred to as a “live-release boat” with large holding tanks. The fish are then brought to a pre-determined release point and set free. In the case of a multiple-day tournament, the daily weights are totalled for an overall result for each team or individual.

The individual tournament coordinator’s efforts to provide favourable conditions for the fish is obviously an important issue for the resource. Scientific research has been conducted to identify aspects of tournament events that could be damaging to fish. An example of a recent innovation that has improved the condition of fish involved in live-release tournaments and was developed through scientific research is the water weigh-in system. This system for weighing fish allows the fish to be submerged in water while being weighed, rather than simply being exposed to the atmosphere which causes significant stress during this stage of the tournament process (Suski 2004).

2.2 Tournament Stressors

Several stages of the tournament fishing process can potentially have an impact on the condition of the fish. The initial angling of the fish causes hook wounds. These wounds are very rarely serious in nature but they have been known to impair vision in some cases and they can cause mortality if the hook is swallowed by the fish when the fish strikes, thereby lodging the hook in the fish’s gullet (Cooke et al. 2003). The initial effort made by the fish as it is angled also causes changes in physiological variables associated with exhaustive exercise such as
muscle and plasma lactate (McDonald & Milligan 1992). The transportation of fish in a boat’s livewell can also have an impact on the condition of the fish, and is the focus of this study that will be discussed later. The final point of the tournament is the Weigh-in, where the fish are placed on a scale, weighed and then released. In the traditional weigh-in process, fish are usually exposed to the atmosphere during the period when their weight is being recorded. The gill filaments, which are responsible for respiration, are covered in tiny hair-like structures known as lamellae. If a fish is exposed to the atmosphere, the lamellae can collapse. This can reduce the ability of the fish to respire and can cause hypoxia. As mentioned, many tournaments have now adopted the new water weigh-in system, which eliminates the potential disturbance from air exposure because the fish is weighed while still submerged in water. Air exposure can cause significant physiological disturbances, very similar to exhaustive exercise, including depletion of muscle energy stores and increased lactate production. In this regard, it is noteworthy that Smallmouth bass are more susceptible to oxygen deprivation (i.e. anaerobic conditions) than their close relative the Largemouth bass (Suski 2004). Tournament seasonality is another aspect of tournaments that can influence the physiological condition of the fish. Extremely high water temperatures are known to be a stress factor for fish and late summer tournaments where high ambient water temperatures are observed can lead to higher levels of fish mortality (Schramm et al. 1987). The focus of this study is to examine the potential biological impacts of transporting Smallmouth bass in livewells.
2.3 Lactate Dehydrogenase (LDH) and Creatine Phosphokinase (CPK) activity in Smallmouth bass

LDH is an intracellular enzyme that is commonly used to identify cellular damage. It occurs in abundance in many tissues in the body of fish: It occurs in its highest concentration in the kidneys, followed by the skeletal muscle tissue and the liver. However, it is present in other organs such as cardiac muscle and the brain (Wroblewski and LaDue 1955). Because LDH is contained within cells it is not present in high concentrations in the blood of the fish. When a cell is damaged, the LDH enters the blood and as such, its relative concentration is indicative of the level of cellular disturbance caused. CPK is similarly an intracellular enzyme which is used in energy production within the cell. Again, it is present in organs but not in the blood, though unlike LDH, CPK is not found throughout the body, it is primarily contained within the skeletal muscle tissue of the fish (Hørder et al. 1990). These enzymes have been used in past assessments of the physiological effects of the weigh-in process of competitive angling events (Suski 2004), during these assessments; LDH was considered an indication of general cellular disturbance in the body because it can originate from many locations, while CPK is considered an indicator of skeletal muscle tissue damage.

2.4 Livewell Confinement

Several studies have been conducted to examine the importance of excretory wastes in the water of a livewell. Kwak & Henry (1995) suggested that a major factor of tournament fish mortality was the combined impact of sub-lethal stressors throughout the tournament, including elevated ammonia levels in the water of a livewell. This is generally not an issue in most
modern, elite-level tournaments because the water in the livewell of a modern bass boat is constantly exchanged with lake water through a built-in bilge system that simultaneously pumps water out of the livewell back in to the lake and brings fresh surface lake water back into the livewell as the boat travels.

The potential effects of reduced dissolved oxygen in the livewell were examined by Hartley & Morning (1993) who showed that if the oxygen levels dropped too low, fish were unable to recover from exercise quickly and there were some long-term effects on growth. During respiration, carbon dioxide will also be added to the water; potentially reducing water pH in the livewell. This issue can be dealt with by frequently exchanging the water in a livewell with fresh, oxygenated water and aerating the water to allow for some additional oxygen diffusion.

Fish size has been shown to be an influence on how a fish deals with different potential stressors within a tournament. Larger fish were shown to have a higher mortality rate at higher water temperatures and were more susceptible to physiological stress in a crowded environment than smaller fish (Meals and Miranda 1994). Temperature change has also been shown to have a significant effect on the condition of Largemouth bass in livewell confinement. According to Schramm et al., changes in water temperature can cause elevated energy consumption which can result in an increase in fish mortality (Schramm et al. 1985, 1987). Interestingly, an issue pertaining to livewell transport that has yet to be examined is the disturbance experienced by fish that might be caused by the movement of water inside of a livewell and the potential physical impact of the fish with the wall of the livewell. Anecdotal evidence and observations made by Suski et al. (2005) indicate that this could be an important issue during boat travel in rough water conditions caused by inclement weather. To date, few studies have focused on characterizing the cellular disturbance caused by the movement of the water within the livewell. Lake conditions
can be highly variable due to changes in weather and will influence the conditions within the livewell. Since this is the case, it is important to develop an understanding of the effect that lake surface disturbance (in the form of waves) and the subsequent water turbulence or “sloshing” in the livewell has on the condition of fish. A study in 2005 by Suski et al. demonstrated an increasing number of interactions between walleye and the sides of a holding tank when exposed to higher levels of water activity within the tank. Interestingly, Largemouth bass actually reduced their opercular rate and swimming speed as the disturbance increased, indicating that they were less active as turbulence increased. Because of this apparent difference in behaviour between species, it is important to determine how Smallmouth bass in particular will behave under increasingly elevated levels of water turbulence in a livewell. The danger of high levels of water turbulence in a livewell is most apparent on large bodies of water. The reason for this is the large areas of unobstructed open water which can lead to high wave heights which in turn translate to high levels of water turbulence inside a livewell.

2.5 Livewell Transport

It is not uncommon to find external evidence of the effects of rough livewell transport in fish at tournament weigh-ins (Suski 2005). There are several common identifiable traits that fish will exhibit: bruising of the lips and fin rays, lacerations on the body and broken or separated spiny fin rays. In some cases these injuries are inflicted by the water inside the livewell moving erratically and causing impacts between fish and the sides of the tank wall (Suski 2005). Lacerations on the body are often attributed to impacts between fish as the water is violently sloshed around the tank. There can also be the incidence of fatigue (Gustaveson et al. 1991). If
the fish is severely fatigued, it may no longer be able to maintain equilibrium (i.e. remain upright) in the water column. The end result can be an unresponsive fish that is floating on its side or upside-down in the tank. In a situation like this, the fish may be even more susceptible to further damage due to the mechanical action or “sloshing” of the water inside the tank. It is also important to recognize that livewell transport is not the only potential source of some of these wounds. Bruising or haemorrhaging of the lips and fins are also common indicators of barotrauma in Smallmouth bass (Morrissey et al. 2005).

2.6 Barotrauma in Smallmouth Bass

The Smallmouth bass is classified as a facultative benthivore; this means that it feeds primarily on available benthic species such as the round goby (*Neogobius melanostromus*), sculpins (*Cottidae* spp.), zebra mussels (*Dreissnia polymorpha*) and crayfish. This being the case, they are often found seasonally at depths greater than 20 feet in large lakes, such as Lake Ontario as an example. Fish regulate themselves for the water pressure at which they are foraging (Morrissey et al. 2005). If a fish is at a significant depth, the pressure of the water is much higher than atmospheric pressure at the surface. When a fish at significant depth is caught by an angler, it is quickly retrieved through the water column and the external water pressure decreases too rapidly for the fish to regulate itself, causing barotrauma. The result is something that resembles the “bends” in human divers. The fish can experience ruptured blood vessels causing bruising and haemorrhaging of the fin rays as well as bloating caused by the distension of the internal gas or swim bladder of the fish (Feathers & Knable 1983, Morrissey et al. 2005).
This bloating of the gas bladder causes the fish to be positively buoyant and float on the surface of the water on its side or upside-down depending on the severity of the barotrauma.

With this crossover of symptoms between barotrauma and transportation damage (bruising and positive buoyancy), it is possible that there is misidentification of barotrauma in some fish during a tournament. The most common treatment for barotrauma is a controversial method known as “fizzling”. Fizzling is the deflation of the gas bladder using a hypodermic needle that is either passed through the body wall of the fish just posterior to the pectoral fin or through the mouth (Keniry et al. 1996, Shasteen & Sheehan 1997). Fizzling is a controversial treatment method because it is difficult for untrained anglers to consistently penetrate the gas bladder of the fish without damaging other internal organs potentially causing fatality. It is evident then, that if there is a possibility of a misdiagnosis, the process of transportation damage must become better understood so researchers and anglers can further refine the tournament process so as to improve the condition of the fish.

2.7 Smallmouth Bass in Tournaments

Smallmouth bass are seen as a preferential target species in most bass tournaments on large waterbodies, such as the Canadian Great Lakes. In general, competitive anglers can accumulate higher weights when targeting Smallmouth bass over Largemouth because the Smallmouth occur at consistently larger body sizes. Unfortunately, Smallmouth bass are more likely to be negatively affected by livewell transport. As was mentioned above, Smallmouth bass are prone to barotrauma because of their preferential seasonal foraging depth. They also respond
poorly to low dissolved oxygen content (Hartley & Morning 1993) which is further affected by increasing body size (Meals & Miranda 1994).

With the number of annual events held on large waterbodies such as the Great Lakes and the apparent focus that anglers have on capturing Smallmouth bass, a more complete understanding of the stresses experienced by Smallmouth bass in a tournament transportation situation is warranted. The necessary experiments cannot be accomplished in a laboratory setting because it is the natural variability in environmental conditions (i.e. wave height, wind speed) which largely determines physical conditions within the livewell that need to be examined. Furthermore, simple observations of the conditions of the day, such as wave height and wind speed, will not suffice as a predictor of livewell water turbulence as there are a multitude of other factors (e.g. boat speed, direction of travel, etc.) that also influence the amount of water turbulence in a livewell. Rather than attempting to characterize all of the influencing factors that create turbulence in a livewell, the researcher has chosen to measure the turbulence inside of the livewell itself. Although challenging, it is therefore essential that these experiments be carried out under real conditions on the lake to properly observe the fish under the conditions they experience in a tournament.

The purpose of this study is to determine biological impacts of livewell transport on the condition of Smallmouth bass under actual field conditions. Anecdotal observations suggest that fish are in worse condition on days where higher wind speeds and consequently, larger wave heights are observed. This is often attributed to the greater amount of water turbulence within the livewells of tournament boats under such conditions, but this has never been thoroughly examined with appropriate experiments. By recording the amount of water activity inside the experimental livewell, the present study will determine whether or not higher amounts of lake
water surface activity will cause more turbulent water conditions within a livewell and whether these conditions will result in a greater biological impact on fish during livewell transport.
Chapter 3

Materials and Methods

3.1 Fish Collection

Smallmouth bass were angled on Lake Ontario from August to mid-November of 2009 and June to mid-August of 2010. Ambient surface water temperatures ranged from 14.3°C to 25.0°C. Fish were angled using only synthetic lures in keeping with tournament regulations. Only fish that exceeded 12 inches in total length and 1.5 pounds in weight were kept for experimentation. These criteria for fish size were used in order to adhere to tournament length standards and to ensure that the fish were very similar to fish held in livewells by professional anglers within real tournaments.

3.2 Blood Collection

Approximately 3 ml of blood was taken from all specimens using a 3ml syringe and 22 gauge needle rinsed in a heparinized saline solution (Morrissey et al. 2005). To obtain blood samples, fish were anesthetized in a mixture of clove oil (a naturally occurring substance) and lake water at a concentration of 0.06ml of clove oil for every 1 litre of lake water (Anderson et al. 1997). Clove oil was selected over the more commonly used MS-222 (3- aminobenzoic acid ethyl ester methanesulfate) because the fish were intended to be released back into the wild after blood collection and MS-222 is a carcinogen, so it is not recommended to be used on specimens that may be consumed by humans. Blood was taken from the branchial artery on the first gill
arch on the left side of the fish. The blood was immediately placed in two, 1.5ml microcentrifuge tubes and spun in a centrifuge at 10,000 x gravity for 3 minutes. The plasma was then immediately removed using a pipet and placed in a 1.5ml microcentrifuge tube. All tubes were then frozen in dry ice and transported back to the Biosciences complex at Queen’s University. The samples were then transferred to the -80°C freezer for storage until processing.

3.3 Plasma Analysis

Plasma samples were analyzed spectrophotometrically at a wavelength of 340 nm, first for lactate dehydrogenase (LDH) using the method outlined by Wroblewski and LaDue (1955), and secondly, for creatine phosphokinase (CPK) following the method outlined by Hørder et al. (1990). Briefly, a change in the concentration of a known amount of NADH (nicotinamide adenine dinucleotide, reduced) was used to quantitatively estimate the activity levels of both LDH and CPK which both act as catalysts to the following separate reactions:

\[
\text{LDH: } \text{Pyruvate} + \text{NADH} \leftrightarrow \text{Lactate} + \text{NAD}^+ \\
\text{CPK: } \text{Phosphocreatine} + \text{ADP} \leftrightarrow \text{Creatine} + \text{ATP} \\
\text{Hexokinase: } \text{ATP} + \text{Glucose} \leftrightarrow \text{ADP} + \text{Glucose-6-phosphate} \\
\text{G-6-PDH: } \text{Glucose-6-phosphate} + \text{NAD} \leftrightarrow \text{6-phosphogluatanate} + \text{NADH}
\]

In both cases, the enzymes of interest occur in direct proportion to the amount of NAD⁺ (nicotinamide adenine dinucleotide) present in the substrate.
3.4 The Experimental Holding Tank

A clear, 72 liter ‘plexiglass’ tank (Length: 30.5 in., Width: 12 in., Depth: 12 in.) was constructed as an experimental holding and transportation tank. This tank was designed to simulate a livewell that would be found in a tournament-style bassboat (and will subsequently be referred to as the experimental livewell). Tank construction incorporated a pressure sensor to facilitate the recording of water movement within the livewell in order to characterize the amount of water turbulence that was experienced by the fish that were placed inside, and to allow video recording of the transportation. Additionally, the tank was built with a pump incorporated to ensure a constant supply of fresh water. At the front or bow-oriented end of the tank, a digital load cell (Loadstar™ Tr. 400) was mounted externally to record water activity. A two-inch diameter hole was tapped through the end of the tank and a threaded bolt was attached to the receiver of the sensor through the hole in the tank. To prevent water loss, a 3 inch gasket was mounted around the perimeter of the hole. A panel of plexiglass sized to fit over the inside front wall was then attached to the top of the bolt which ran to the sensor. The pressure sensor measured the weight shift of the water inside of the tank to characterize the relative amount of turbulence the fish experienced over the course of the experiment. Another gasket was glued to the top of the perimeter of the tank and a clear plexiglass top was fitted to prevent water loss. Two wide-angle, waterproof digital video cameras (GoPro™ Hero™) were mounted at the front and back of the tank to observe the orientation and activity of the fish. To ensure that there was adequate dissolved oxygen for the fish and no significant buildup of excretory wastes, a 12 volt bilge pump (Seasense 600 gallon/hour) was bracketed into the bottom back corner of the tank and a 1-inch diameter plastic hose was run from the bilge pump through a hole drilled in the top of the tank into the inboard livewell of the boat. Another 12 volt bilge pump was bracketed into
the livewell of the boat and a hose was run back into the experimental holding tank through a second hole drilled in the top of the tank. Both bilge pumps were powered by a 12 volt deep-cycle marine battery strapped under the console of the passenger side of the vessel. The water in the livewell of the boat was then replaced with fresh lake water by an integrated pump built into the hull of the vessel ensuring a constant supply of fresh water in the experimental holding tank. A digital thermometer was attached to the interior of the tank to monitor the water temperature throughout the experiment. At no time did the water temperature change by more than 2°C between the beginning and the end of the experiment.

3.5 Simulated Livewell Transport

A series of experiments were performed to simulate the transport of fish in livewells that occurs in a real tournament situation. The purpose of these experiments was to evaluate the amount of physical and cellular disturbance caused by the mechanical action of the water turbulence inside of a livewell. Lake water was collected from the surface of Lake Ontario and poured into the experimental livewell to a depth of 4 inches below the rim of the tank. A maximum of 3 fish were placed inside the experimental holding tank. The top of the tank was secured using ratchet straps to ensure that the tank was water tight and secure on the deck of the boat. The tank was secured on the bow deck of the boat lengthwise, with the end resting approximately 2 inches from the bow (Figure 1). The fish were then transported for 60 minutes from their point of capture to a docking point (Portsmouth Olympic harbour in 2009, Treasure Island Marina in 2010). During the transportation, the fish were recorded using the video camera described above. To identify each individual fish during when analysing the footage, each fish
was colour coded using a small coloured, spring-loaded lip clip. This type of colour coding is often used in tournament angling to expedite the culling of fish. The watercraft used for the experimentation was a Lowe™ 18.5 foot deep V hull with a 150 horse-power Mercury Optimax two-stroke outboard motor. The fish were then placed in a different, dark and aerated holding tank for a period of 6 hours. This period of time was used to simulate an average holding time of fish in a livewell under tournament conditions. After the 6 hour holding period, the fish were sampled using the methods described above, rehabilitated and released outside of the harbour.

3.6 Padded Treatment Group

A second experimental series was conducted to determine whether the damage caused by impacts between fish and the walls of the tank could be reduced by padding the interior walls of the tank. These experiments were identical to those described above with the following exception: In these experiments, 2-inch thick soft foam (Hero™ Cellulose multi-purpose cleaning sponges) was added to the interior of the front and rear of the tank to reduce the impact between the fish and the wall of the tank. For this series of experiments, 9 fish were angled from Lake Ontario and transported in the experimental holding tank using the methods and equipment described above. The interior dimensions of the tank with the addition of 2 inches of foam on either end of the tank became 62.56 Litres of open water.
3.7 Control Sample Collection

Six fish were collected by angling using synthetic bait on Lake Ontario; these fish were immediately sampled with no further handling. The purpose of this group was to obtain a blood sample before the intracellular enzymes used as indicators of cellular damage in this study would have had an opportunity to become significantly elevated in the blood stream. These samples provided values that should be very close to those in undisturbed free swimming fish in the wild. A second group was collected by angling 5 Smallmouth bass from Lake Ontario and holding them in a darkened, circulated and aerated holding tank for 6 hours before sampling. This group was collected to provide some insight into the relative amount of cellular damage that is caused by the simple act of angling the fish without significant livewell transport. Research suggests that angling causes increases in muscle and plasma lactate (Suski 2004) but there has been no evaluation of the impact of angling on the indicators of cellular damage used in this study (Referred to as ‘Angling’ group).

3.8 Tournament Sample Collection

Samples were also collected at a professional bass fishing tournament on Lake Ontario that took place in Sept of 2009 in order to determine the levels of LDH and CPK found in Smallmouth bass after a typical professional angling event held on a large body of water. In this case, 6 Smallmouth bass were randomly selected from the live-release boat at the Big Jim Pro-Am event on Lake Ontario in September of 2009. A relatively small number of fish were collected for this series because previous studies have also obtained values for these variables at real tournaments and this was simply to confirm that my procedures for Lake Ontario fish
obtained values within the same range as those collected at other real tournaments. Table I compares samples taken by Morrissey et al. (2005) at competitive events in 2004 with the values collected in the summer of 2009. These values are also included for comparison in some aspects of this study (Figures 7 and 8).

3.9 Data Analysis

Data analysis was completed using Microsoft Excel and SPSS inc. (by IBM). Comparisons of damage indicating enzymes between groups was carried out using an ANOVA with an α of 0.05. Comparisons analyzing the relationships between the number of mean impacts per minute between the fish and the wall of the experimental livewell and the relative activity of the water in the experimental livewell were carried out using a regression analysis. ANCOVA analyses (Zar 1984) were carried out to compare the slope and y-intercept between the padded treatment groups and the non-padded tank treatments for both the relationship between the mean number of impacts per minute and the damage indicating enzymes, as well as the force generated by the water disturbance inside of the tank measured in 0.84 ft.²/lb./sec. and the damage indicating enzymes (LDH and CPK).
Table 1. A comparison between values of creatine phosphokinase (CPK) and lactate dehydrogenase (LDH) collected by gill puncture by Morrissey et al. in 2004 and by Brooke, T. in 2009.

<table>
<thead>
<tr>
<th>Year Collected</th>
<th>2004</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPK (mMol/L)</td>
<td>26.4 +/-</td>
<td>30.5 +/-</td>
</tr>
<tr>
<td>LDH (mMol/L)</td>
<td>27.3 +/-</td>
<td>20.16 +/-</td>
</tr>
</tbody>
</table>

Figure 1. The experimental holding tanks being filled on the bow of the boat. The padded experimental tank is on the left and the unpadded tank is on the right with the sensors oriented to the bow of the boat.
Chapter 4

Results

4.1 Cellular Damage Caused by Impacts

Figure 2 is a histogram showing the projected number of impacts over the 60 minute transportation experiment, based on the mean number of impacts between the Smallmouth bass and the wall of the livewell per minute. According to these projections, 97% of 32 fish collided with the walls of the livewell over 100 times during the transportation experiments.

Figure 3 shows the different levels of LDH found in the control group, the angled group, the fish collected at tournaments (in both 2004 and 2009) and the fish transported in unpadded (‘normal’) and padded conditions. A single factor ANOVA shows that there is a significant difference between the levels of LDH found in the groups \((P = 0.0094)\) and a Dunnett’s test reveals that the unpadded treatment group has significantly higher levels of LDH than both the control group and the angling group \((P < 0.05)\) and that the padded treatment group did not show a significantly higher level of LDH than either the control or the angling groups. Both tournament values (2009 and 2004) were significantly higher than the control and angling groups. Figure 4 shows that the same trend exists for CPK levels in the different groups. A single factor ANOVA shows that there is a significant difference between the levels of CPK in the control groups, the unpadded ‘normal’ treatment group, the padded treatment and the tournament groups \((P = 0.0125)\). A subsequent Dunnett’s test reveals that the unpadded treatment group has a significantly higher level of CPK than both the control groups and the angling treatment group \((P < 0.05)\). The levels of CPK in the padded treatment are not significantly higher than the control or angled groups. Additionally, the fish collected at the tournament in 2009 show a
significantly higher level of cellular damage than both the control and angling group. The tournament samples collected in 2004 show a significantly higher level of cellular damage than the angling group but not the control group. To demonstrate the comparability between the numbers of impacts experienced between the fish transported in padded tanks and unpadded tanks, the mean number of impacts per minute of each fish is displayed in table 4.

Figure 5 illustrates the effects of water activity on the number of impacts between the Smallmouth bass and the sides of the experimental livewell. As the amount of activity increases, so do the mean number of impacts per minute ($R^2 = 0.283$). The numbers of impacts are then related to the amount of cellular damage a fish sustains over a transportation period by looking at the mean number of impacts per minute and the amount of LDH and CPK found in the plasma of the fish. Here, the treatments are separated into padded and non-padded groups referring to the presence or absence of foam, lining the inside of the experimental livewell. Figure 6 shows the relationship between LDH and mean number of impacts per minute. An analysis of co-variance (ANCOVA) determined that there is a significant difference between the slope of the padded and the unpadded treatments ($F = 0.00097$). As LDH is a general indicator of cellular damage, the addition of foam padding has been shown to reduce the amount of cellular damage experienced by the Smallmouth bass. A similar trend is shown in Figure 7 which illustrates the relationship between impacts of the fish with the sides of the tank and the level of CPK in the plasma. Again, an ANCOVA showed that the slope of the two treatments (padded and non-padded) differed significantly ($F = 0.00071$) indicating that the addition of the padding reduced on the amount of damage sustained by the fish in relation to the number of impacts they experienced over the treatment.
4.2 Cellular Damage Caused by Water Disturbance

Figure 8 shows that there is no significant relationship \((F = 0.126)\) between the force generated by the water inside of the livewell and the extent of cellular damage indicated by the levels of LDH in the plasma. This indicates that the extent of the damage to the fish is not directly related to the amount of water turbulence measured in the experimental livewell, at least within the range of force created in these experiments. A similar trend is seen in figure 9, which shows a negative relationship \((R^2 = 0.0299)\) between Force \((0.84\text{ft}^2/\text{lb/sec})\) and CPK. In both cases, ANCOVA’s testing for difference in slope between the padded treatment group and non-padded treatment group show significant differences (LDH: \(F = 0.01169\), CPK: \(F = 0.00904\)) indicating that the amount of cellular damage caused by the transportation sequence is significantly different between the padded and the non-padded groups.

4.3 The Role of Environmental Variables

Figure 10 is a three dimensional representation of the relationships between wave height, wind speed and water activity in the experimental livewell. This figure shows that there is a negative relationship between the wave heights, wind speed and the force generated by the water inside of the holding tank \((R^2 = 0.313)\). Details of the weather observations, dates and corresponding water disturbance are included in Table 2.
4.4 Incidence of Inversion

During these experiments, 10 fish in the unpadded experimental livewell lost equilibrium and were observed floating upside-down. These fish showed no signs of decompression after capture or upon immersion in the experimental holding tank and were simply categorized as inverted. The mean number of impacts the fish experienced prior to inversion was compared to the mean number of impacts experienced after inversion to determine whether or not an inverted fish is less capable of maintaining a neutral position in the water column and will thereby experience a higher number of impacts (Figure 11). A two-tailed t-test showed no significant difference between the mean number of impacts experienced by Smallmouth bass before or after inversion in the livewell ($P = 0.745$), ($n = 10$).

A comparison was also done to determine whether or not fish that became inverted experienced a higher number of impacts than fish that remained upright in the water column (Figure 12). A two-tailed t-test showed a significant difference between the number of times fish that remained upright in the water column impacted with the side of the tank and the number of times inverted fish impacted ($P = 0.0004$).

4.5 Impact Frequency during the 60 Minute Transportation Sequence

To determine if fish experience impacts at the same rate over the transportation sequence (60 minutes), the number of impacts per minute is displayed for 12 fish in figure 13. On average, 39% of the impacts occur in the first 15 minutes and over 80% of the impacts occur within the first 30 minutes of transportation. In comparison, an average of 18% of the impacts occur in the
last 30 minutes of the transportation sequence within these experiments. These values are presented in detail in table 3.
Figure 2. A histogram of the projected number of impacts between Smallmouth bass and the sides of the experimental livewell over the 60 minute transportation experiment.
Figure 3. A comparison of the amount of plasma lactate dehydrogenase (LDH, log₁₀ U/L) in the different experimental groups. Two tournament values are provided for comparison. The 2009 tournament values were collected on Lake Ontario in September of 2009, while the 2004 values were taken during a professional angling event on Lake Ontario by M. Morrissey (2005). The (*) symbol indicates an experimental mean that is significantly different from the control mean (Dunnett’s test, $P \leq 0.05$). The (+) symbol indicates an experimental mean that is significantly different from the Angled mean (Dunnett’s test, $P \leq 0.05$).
Figure 4. A comparison of the amount of plasma creatine phosphokinase (CPK, log_{10} U/L) in the different experimental groups. Two tournament values are provided for comparison. The 2009 tournament values were collected on Lake Ontario in September of 2009, while the 2004 values were taken during a professional angling event on Lake Ontario by M. Morrissey (2005). The (*) symbol indicates an experimental mean that is significantly different from the control mean (Dunnett’s test, $P \leq 0.05$). The (+) symbol indicates an experimental mean that is significantly different from the Angled mean (Dunnett’s test, $P \leq 0.05$).
Figure 5. A regression analysis comparing the mean number of impacts experienced by fish per minute and the amount of water activity measured inside of the experimental holding tank during the transportation sequence, represented by Force in 0.84ft²/lb/sec.
Figure 6. A regression analysis comparing the mean number of impacts Smallmouth bass experience per minute with the Log_{10} level of plasma lactate dehydrogenase (LDH). Foam padding was applied to the interior of the tank that is represented by the red squares in an attempt to reduce the amount of cellular damage experienced by the Smallmouth bass. The blue diamonds represent the experimental holding tank without padding.
Figure 7. A regression analysis comparing the mean number of impacts Smallmouth bass experience per minute with the Log$_{10}$ level of plasma creatine phosphokinase (CPK). Foam padding was applied to the interior of the tank (represented by the red squares) in an attempt to reduce the amount of cellular damage experienced by the Smallmouth bass. The blue diamonds represent the experimental holding tank without padding.
Figure 8. A regression analysis comparing the amount of force generated by the disturbance of the water in the experimental holding tank during the transportation sequence (0.84ft²/lb/sec) and the amount of cellular damage represented by log₁₀ LDH (U/L). The red squares represent fish that were transported in a padded tank and the blue diamonds represent fish transported in an unpadded tank.
Figure 9. A regression analysis comparing the amount of force generated by the disturbance of the water in the experimental holding tank during the transportation sequence (0.84ft$^2$/lb/sec) and the amount of cellular damage represented by log$_{10}$ CPK (U/L). The red squares represent fish that were transported in a padded tank and the blue diamonds represent fish transported in an unpadded tank.
Figure 10. Multiple regression illustrating the negative relationship between the daily observed wave heights in meters, the daily observed wind speed in meters per second and the measured water disturbance inside of the experimental holding tank during the transportation sequence in Force, 0.84ft² per pound (lb) per second.
Table 2. The weather observations and measured disturbance in the experimental holding tank for days when the transportation experiments were carried out on Lake Ontario in the summer and fall of 2009 and the summer of 2010.

<table>
<thead>
<tr>
<th>Date</th>
<th>Wave Height (m)</th>
<th>Force (0.84ft²/lb/sec) (m/sec)</th>
<th>Wind Speed (m/sec)</th>
<th>Wind Direction</th>
<th>Water Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 15/09</td>
<td>0.4</td>
<td>0.231008</td>
<td>3.9</td>
<td>SSW</td>
<td>24.2</td>
</tr>
<tr>
<td>Aug 19/09</td>
<td>0.4</td>
<td>0.889426</td>
<td>3.4</td>
<td>W</td>
<td>25</td>
</tr>
<tr>
<td>Sept 3/09</td>
<td>0.1</td>
<td>0.244511</td>
<td>1.7</td>
<td>NNE</td>
<td>23</td>
</tr>
<tr>
<td>Sept 8/09</td>
<td>0.1</td>
<td>0.384692</td>
<td>2.4</td>
<td>SE</td>
<td>21.9</td>
</tr>
<tr>
<td>Sept 17/09</td>
<td>0.7</td>
<td>0.239519</td>
<td>7</td>
<td>SSE</td>
<td>19.9</td>
</tr>
<tr>
<td>Sept 22/09</td>
<td>0.7</td>
<td>0.453014</td>
<td>7.6</td>
<td>SSE</td>
<td>18.8</td>
</tr>
<tr>
<td>Sept 23/09</td>
<td>0.5</td>
<td>0.219375</td>
<td>6.5</td>
<td>S</td>
<td>19.2</td>
</tr>
<tr>
<td>June 22/10</td>
<td>0.2</td>
<td>0.273</td>
<td>4</td>
<td>SE</td>
<td>15.9</td>
</tr>
<tr>
<td>June 23/10</td>
<td>0.4</td>
<td>0.3799</td>
<td>4</td>
<td>W</td>
<td>15.9</td>
</tr>
<tr>
<td>June 25/10</td>
<td>0.5</td>
<td>0.1940</td>
<td>4</td>
<td>SW</td>
<td>16.1</td>
</tr>
<tr>
<td>July 5/10</td>
<td>0.1</td>
<td>0.4637</td>
<td>4</td>
<td>WSW</td>
<td>19.4</td>
</tr>
<tr>
<td>July 7/10</td>
<td>0.1</td>
<td>0.3744</td>
<td>4</td>
<td>WSW</td>
<td>22.5</td>
</tr>
<tr>
<td>Sept 13/09</td>
<td>0.6</td>
<td>0.4009</td>
<td>7.9</td>
<td>WNW</td>
<td>20.9</td>
</tr>
<tr>
<td>Oct 1/09</td>
<td>0.7</td>
<td>0.3702</td>
<td>7.1</td>
<td>NW</td>
<td>15.4</td>
</tr>
<tr>
<td>Oct 6/09</td>
<td>0.9</td>
<td>0.1886</td>
<td>6.5</td>
<td>W</td>
<td>15.2</td>
</tr>
<tr>
<td>Oct 8/09</td>
<td>0.7</td>
<td>0.1744</td>
<td>5.2</td>
<td>W</td>
<td>14.2</td>
</tr>
<tr>
<td>Oct 14/09</td>
<td>0.6</td>
<td>0.5472</td>
<td>5.5</td>
<td>N</td>
<td>14.3</td>
</tr>
</tbody>
</table>
Figure 11. Mean number of impacts per minute before fish became inverted and after they inverted. Comparing the mean number of times a fish impacted with the wall of the experimental holding tank when it was upright in the water column and after it had become inverted and unable to maintain its position in the water column.
Mean number of impacts experienced by Smallmouth bass. The group labelled ‘Normal’ were fish that did not invert over the transportation sequence. The group labelled ‘Inverted’ were fish that became inverted during the transportation sequence and did not recover until after the experiment.

Figure 12. Mean number of impacts experienced by Smallmouth bass. The group labelled ‘Normal’ were fish that did not invert over the transportation sequence. The group labelled ‘Inverted’ were fish that became inverted during the transportation sequence and did not recover until after the experiment.
**Figure 13.** The distribution of impacts between 12 fish and the walls of the experimental holding tank over a 60 minute transportation sequence. Each bar represents the number of impacts one fish experienced during one minute of transportation.
Table 3. Details of the distribution of impacts in percentages for each of the twelve Smallmouth bass. The distributions are broken down into the first 15 minutes, the first 30 minutes and the last 30 minutes.

<table>
<thead>
<tr>
<th>Fish Identification</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of impacts in the first 30 minutes</td>
<td>68.2</td>
<td>62.0</td>
<td>70.4</td>
<td>78.3</td>
<td>87.1</td>
<td>58.0</td>
</tr>
<tr>
<td>% of impacts in the first 15 minutes</td>
<td>31.0</td>
<td>34.6</td>
<td>41.8</td>
<td>44.0</td>
<td>57.7</td>
<td>42.6</td>
</tr>
<tr>
<td>% of impacts in the last 30 minutes</td>
<td>31.8</td>
<td>38.0</td>
<td>29.6</td>
<td>21.7</td>
<td>12.9</td>
<td>42.0</td>
</tr>
<tr>
<td>Fish Identification</td>
<td>A10</td>
<td>A11</td>
<td>A12</td>
<td>A13</td>
<td>A14</td>
<td>A15</td>
</tr>
<tr>
<td>% of impacts in the first 30 minutes</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>87.7</td>
<td>80.0</td>
<td>86.5</td>
</tr>
<tr>
<td>% of impacts in the first 15 minutes</td>
<td>50.6</td>
<td>53.1</td>
<td>49.9</td>
<td>26.3</td>
<td>20.0</td>
<td>19.7</td>
</tr>
<tr>
<td>% of impacts in the last 30 minutes</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>12.3</td>
<td>20.0</td>
<td>13.5</td>
</tr>
</tbody>
</table>
**Table 4.** A table displaying the numbers of impacts between the unpadded or ‘normal’ experimental group and the experimental group that was transported in a padded tank.

<table>
<thead>
<tr>
<th>Mean number of impacts per minute</th>
<th>Unpadded 'normal'</th>
<th>Unpadded 'normal' (Cont)</th>
<th>Padded</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.9</td>
<td>5.5</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>7.0</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>11.9</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>21.9</td>
<td>11.1</td>
<td>8.7</td>
<td></td>
</tr>
<tr>
<td>11.1</td>
<td>5.6</td>
<td>14.6</td>
<td></td>
</tr>
<tr>
<td>5.4</td>
<td>0.1</td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td>5.4</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>0.0</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>8.5</td>
<td>8.9</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>7.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>9.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.7</td>
<td>9.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.2</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>
5.1 General Discussion

The nature of the physiological disturbances in fish caused by angling has been well documented over the last 50 years. In recent years, numerous studies have also examined the biological impacts of tournaments on fish. These studies have resulted in several significant improvements to the tournament process (mainly through fish handling at tournaments). Nonetheless, there are still circumstances, mainly at events on large waterbodies, which result in obvious physiological stress and significant mortalities for tournament fish. Anecdotal observations suggest that these remaining problems may be due to the physical impacts between the fish with the walls of the livewell during transport, a problem which is exacerbated on large waterbodies. To date however, this issue has not been thoroughly investigated in scientific experiments. The purpose of the present study was therefore to evaluate the process of livewell transport as a factor contributing to physiological stress in fish at competitive angling events. It must be considered however, that there are some limitations to this assessment and that in some cases, the stresses placed on fish in an actual tournament situation may be more sustained and to a greater level of intensity.

5.2 The Incidence of Collisions between Smallmouth bass and the Walls of a Livewell

One of the primary focuses of this study was to observe the conditions inside of a livewell while fish were being transported in a real tournament situation. This required driving
the boat containing the experimental livewell in a range of weather conditions with fish that were of an appropriate size. In reviewing the footage that was recorded during the course of this study, it became apparent that there were frequent interactions between fish and the walls of the tank. Figure 2 shows that all but one fish were projected to have impacted over 100 times in the 60 minute transportation sequence and that the mean projected number of impacts was over 400 times. It must also be noted that in many cases during the course of a competitive angling event, anglers will hold and transport fish for several hours over the course of a day. The mean number of impacts per minute was related to the relative amount of water turbulence measured inside of the livewell (Figure 5). As the water turbulence increased, so did the number of impacts. Thus, the results of this study indicate that Smallmouth bass may experience a very high number of impacts in a livewell within a real tournament, especially during a day of travel through inclement weather conditions.

The other main focus of this study was to determine whether the impacts that fish experienced over the course of a day of transport in a livewell result in significant levels of cell damage. As figures 3 and 4 showed, the levels of lactate dehydrogenase (LDH) and creatine phosphokinase (CPK) in unpadded or ‘normal’ treatment groups were significantly higher than the control values that were collected. The levels of plasma creatine phosphokinase found in the unpadded treatment group are comparable to incidence of heart failure and third degree burns in humans (Huang et al. 2010) and the levels of plasma lactate dehydrogenase are comparable to non-fatal attacks by sea lamprey (Petromyzon marinus) on salmonids (Edsal and Swink 2001). Additionally, it must be noted that these values were obtained by using an arterial puncture on the gill arch which is most appropriate for analysis of these enzymes as a caudal puncture requires penetrating the substantial muscle of the caudal peduncle thus causing cellular damage.
to muscle tissue. This tissue damage would over-emphasize the LDH and CPK activities in the fish as both of these enzymes are found in muscle tissue in abundance.

5.3 Reducing the Amount of Cellular Disturbance Caused by Impacts

An additional series of experiments were conducted to determine whether the amount of cell damage caused by impacts between the Smallmouth bass and the walls of a livewell could be reduced by padding the walls of the livewell. The results of these experiments showed that the levels of LDH and CPK in fish from padded livewells were not significantly different from the levels in control fish (Figures 3 and 4). As it was specified in the methods and materials section, the control values represent fish that would be in a natural, free-swimming state. Thus, padding the livewell appears to eliminate the cell damage caused by livewell transport. In addition, the levels of cellular disturbance observed in fish that were transported in a padded tank were significantly lower than those in fish transported in an unpadded or ‘normal’ tank. Taken together, collisions between the interior walls of the livewell and Smallmouth bass cause a significant amount of damage, but this damage is mitigated with the addition of foam padding to the interior of the tank. It should also be noted that the observed differences between the normal livewell and the padded livewell experiments were not due to differences in the number of collisions. Table 4 compares the mean number of impacts between fish transported in an unpadded ‘normal’ livewell, and the fish transported in a padded livewell. This isolates the addition of foam padding as the mitigating factor in the reduction of cell damage in the fish.
5.4 Weather Observations in Relation to Livewell Water Turbulence

One aspect that is unique to this study (in this field) is the measurement of turbulence that a fish experiences during transportation. Earlier experiments attempted to characterize what was happening inside the livewell based on external conditions such as weather or the speed and direction of travel in a boat. If weather was characterized, it was most often done with casual observation of wave height, wind speed and wind direction. In addition to these observations, this study quantified the amount of water turbulence inside the livewell itself in Force (0.84ft²/lb/sec). The purpose of this measurement was to determine if weather observations are good predictors of water turbulence inside of a livewell. Many physical factors affect the magnitude of the water turbulence inside a livewell within a moving watercraft, such as the location of the boat geographically in relation to the maximum fetch of the wind, or the longest stretch of open water unobstructed by landmass in relation to wind direction (If the boat is sheltered by an island the water activity may be altered.) Other factors influencing livewell water turbulence are the direction of travel of the boat as well as the speed of travel, which is variable, as it is nearly impossible to maintain an exact speed particularly on a windy, rough day on the water. There are also variables related to the type of watercraft used and the location of the livewell (bow or stern) on the vessel. For example, the depth of the hull on the boat may affect the way it handles in rough travel conditions and will therefore affect the extent of water turbulence inside the livewell. Finally, the level of experience of the driver of the boat can also affect livewell water activity.

A multiple regression showed a negative relationship between water activity measured inside the livewell, wave height in meters and wind speed in meters per second (Figure 10). This is counter-intuitive because it would mean that as the wave height and wind speed increased,
there would be less water activity inside the livewell. There could be many explanations for this result, but most would be related to the way in which the boat was driven on windy days where large waves are commonly encountered. More care has to be taken while driving on rough days as high speed impact with large waves can be dangerous for the anglers on board the vessel and the hull of the boat can be damaged or compromised. So, if large waves are encountered, the angler should drive carefully to avoid damaging their equipment or endangering themselves.

5.5 Comparing Impacts between Upright and Inverted Fish

In ten (10) instances, fish were observed floating inverted in the experimental livewell during the transportation sequence. Because these fish had shown no signs of decompression after their capture or during the onset of the experiment, they were categorized as ‘inverted’. This provided an opportunity to determine whether fish will impact with the walls of a livewell at a higher frequency when they are inverted and unable to right themselves. This comparison was approached in two ways: The mean numbers of impacts per minute of fish that became inverted and did not recover were compared to fish that did not invert for any significant period of time during the experiment. Figure 12 shows that there is a statistical difference between the normal and inverted Smallmouth bass \( P = 0.0004 \). This could be indicative of impacts being related to inversions in fish as the fish that became inverted during the transportation experienced roughly 3 times as many impacts as the fish that did not invert for any significant period of time. The other approach was to determine if a fish that became inverted over the course of the transportation experiment impacted more on average before it became inverted or more after it
became inverted. Figure 11 shows that there was little difference between the mean impacts per minute and the orientation of the fish in the livewell \( P = 0.745 \).

Based on the observations made during this study, impacts appear to be related to inversions in Smallmouth bass. However, contrary to long-held beliefs of anglers, it appears that the impacts may in some cases cause the buoyancy rather than buoyancy causing a higher number of impacts. To further explore this issue and to develop a better understanding of how positively buoyant fish behave and respond to turbulent livewell conditions, more scientific research focusing on this specific topic is required. This could be important in further improving the tournament process as the occurrence of severe barotrauma causing buoyancy and inversion is common on large bodies of water, particularly in deep-water species like the Smallmouth bass (Schreer et al. 2009).

5.6 The incidence of Inversions and the Potential Misdiagnosis of Barotrauma

Observations made during the course of this study suggest that in certain cases, there may be alternative explanations for the fact that fish in the livewell have become buoyant and non-responsive. Earlier in this section, it was indicated that ten (10) fish were observed upside-down in the experimental holding tank during the transportation experiment and that these fish showed no initial signs of decompression. Interestingly, the fish inverted between 13 and 47 minutes after the beginning of the experiment. Expansion of the fish’s swim bladder due to barotrauma is characterized as a rapid expansion (Parker et al. 2006) not a delayed reaction. So, it seems unlikely that this observation was due to barotrauma.
Additionally, in casual interviews at the various angling events visited during the course of this study, some anglers have expressed alarm at observing barotrauma in fish that were caught in depths not exceeding 10 feet (3.05 meters). Schreer et al. (2009) indicated that fish angled below 6 meters in lake depth can be displaying barotraumatic symptoms to varying degrees. Shasteen and Sheehan (1997) showed occurrences of mild (Light bruising but not inversion which is a sign of severe barotrauma) barotraumatic symptoms in fish that were depressurized from a simulated 3.5 meter depth in a laboratory setting. This seems to suggest that anglers are observing inversions and immediately diagnosing the fish as barotraumatic even though the fish were caught at depths too shallow to correspond with severe barotraumatic symptoms such as inversion and buoyancy.

As mentioned earlier in this paper, the common method of treatment for a fish that is bloated because of barotrauma is puncturing the swim bladder with a hypodermic needle releasing the internal gas pressure and allowing the fish to return below the water surface. If the above postulate is correct regarding a misdiagnosis of barotrauma, it seems that puncturing an internal organ could be an inappropriate treatment method as the reason for the inversion is not understood.

Further research is required to fully understand the possibility of misdiagnosis of barotrauma and to determine what the actual cause is.
Chapter 6
Conclusions and Summary

The occurrence of physiological stress in the form of cellular disturbance was directly related to the transportation of Smallmouth bass in a livewell. It was shown that fish can experience hundreds of collisions with the walls of a livewell in a 60 minute experiment. In addition, as water turbulence inside of a livewell increased, so did the number of impacts experienced by the fish over the course of transport. These collisions between the Smallmouth bass and the walls of the livewell were shown to have caused a significant amount of cellular disturbance. However, fish transported under similar conditions with the addition of soft foam lining the interior of the tank showed no significantly elevated levels of cellular disturbance. This result simultaneously isolates the collisions between Smallmouth bass and the walls of a livewell as the cause of the cellular disturbance observed in this study and it provides a simple and effective modification to a livewell that reduces damage caused by transport.

Wave height and wind direction were determined not to be accurate predictors of the level of disturbance recorded in the livewell during transportation. A number of other factors must be taken into account in addition to weather observations to predict the conditions experienced by the fish during transportation.

Fish that were inverted in the livewell were compared against fish that were not inverted to determine if inverted fish experience more impacts with the walls of the livewell. Smallmouth bass that became inverted during the transportation sequence experienced a significantly higher number of impacts per minute than fish that remained upright. Further study is required to
determine if the impacts were the actual cause of the inversions which seems to be suggested by the absence of symptoms of barotrauma in the 10 inverted fish.

Observations made during the course of the study suggest that there are multiple explanations for fish inversion in the livewell during transportation. This is most important when considering the treatment method for dealing with inversions. More research should be directed towards positive identification of barotraumatic symptoms to avoid any possible misidentification and subsequent mistreatment.

If modifications based on these results are incorporated to the transport of Smallmouth bass, such as the padding of the interior of a livewell, then the impacts caused by angling tournaments on the resource will be further reduced, improving the overall sustainability of competitive angling.
6.1 Summary

1. Smallmouth bass can experience hundreds of impacts in a 60 minute span.

2. An increase in water activity in a livewell will increase the mean number of impacts a Smallmouth bass experiences per minute.

3. Transportation in an unpadded livewell caused a significant elevation in cellular disturbance.

4. Fish transported in padded livewells showed no significant elevations in cellular disturbance.

5. Wave height and wind speed are insufficient predictors of water turbulence inside a livewell during transportation.

6. Inverted fish do impact with the walls of a livewell at a significantly greater frequency.
Literature Cited


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