Evaluating the effects of catch-and-release angling on *Argyrosomus japonicus* in South African estuaries

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Abstract

Catch-and-release (C&R) angling is important for recreational anglers to adhere to several fisheries regulations, such as size and bag limits, and is becoming increasingly popular as a strategy to manage recreational fish stocks as well as a voluntary activity among conservation conscious recreational anglers. However, research has indicated that there are high levels of variability in the survival of released fishes and that the impacts appear to be context and species-specific. Little research has been done on the effects of C&R on South African line-fish species and even less in estuarine environments. In this MSc the effects of C&R angling on *A. japonicus*, which dominates the catch in estuaries and provides a vital source of food for many subsistence fishers, were evaluated. Angler behaviour (e.g. gear choice, handling practices, air exposure time) is a primary component of C&R and is critical to predicting and understanding the outcome of a C&R event, yet there is a scarcity of baseline information on angler behaviour. Initially covert angler observations were conducted in two South African estuaries, and average air exposure times were recorded. It was found that anglers exposed fish to an average of 75 s (range 10 – 240 s) air exposure. As the full physiological stress response only manifests itself after a delay, it is critical to understand the time course of the indicators used to describe the true physiological impact of catch and release.

Argyrosomus japonicus (mean: 410.2 mm, range: 285–530 Full Length) were captured from the Kowie River estuary and placed into tanks (n=3 fish per tank) and allowed to acclimatize. Fish were then exposed to a simulated C&R event, involving chasing the fish for 45s and exposing it to air for 75s. Blood glucose, lactate and cortisol concentrations were measured at different time treatments; 0, 30, 60 90 and 150 minutes (n=9 fish per treatment) to determine when the peak physiological disturbance occurred. It was found that time had a significant effect on the concentration of blood glucose ($p < 0.05$) and lactate ($p < 0.05$) and that they both peaked between 30 and 40 minutes after the stressor and returned to a concentration similar to the 0-minute time treatment after 150 minutes. Plasma cortisol levels did not peak through the study and there was no significant relationship between time and the concentration of plasma cortisol ($p > 0.05$). This was attributed to the high individual variation observed in this study.

To determine the effects of C&R angling on their health and survival, 68 (mean: 283 mm [SD 75.9] range: 190–645 mm) *A. japonicus* were angled from the Great Fish Estuary using traditional estuarine rods and tackle. Fight times were recorded, and captured fish were measured and then exposed to one of three air exposure treatments (10s, 75s or 240s) which corresponded to the minimum, mean and maximum air exposure times in the observation experiment. Blood was taken from fish (approximately 30-40 minutes after capture, based on the peaks observed in the physiological time course experiment) and the glucose and lactate concentrations were estimated using point-of-contact devices. Rapid assessment mortality predictor (RAMP) tests were performed on all fish to determine the level of reflex impairment and short-term survival was estimated by placing individuals into survival tanks and monitoring them for a minimum of 12 hours. Fish in the 240s air exposure treatment had significantly higher blood glucose concentrations (5.46 mmolml-1 [SD 1.58]) than those in the 10s (4.02 mmolml-1 [SD 0.97], $F_{(2,55)} = 6.60$; $p = 0.004$) and 75s (4.3 mmolml-1 [SD 1.2], $p = 0.016$) air exposure treatment. The lactate levels (8.25 mmolml-1 [SD 4.6]) of fish in the 240s air exposure treatment were also significantly higher than those in the 10s (4.61 mmolml-1 [SD 2.91], $F_{(2,59)} = 4.52$; $p = 0.018$) air exposure treatment, but not significantly different to the 75s (.68 mmolml-1 [SD 4.66], $p = 0.89$) air exposure treatment. Reflex impairment was observed for 41.6% of the individuals in the 10 s air exposure treatment, 52.3% in the 75 s and 69.5% in the 240 s treatments. Fish in the 240 s air exposure treatment were significantly more impaired than fish in the 10 s air exposure treatment (p = 0.009). However, there was no significant difference in reflex impairment between 240 s and 75 s (p = 0.299) and 10 s and 75 s air exposure treatments. The overall short-term post-release mortality was 7.35%, with more fish (8.3%) succumbing in the 75s and 240s air exposure treatments (n = 2 each). Of the five fish that died, two died the day after capture, indicating that a relatively high proportion of the mortality of released fish may be hidden.

The results of this study provide insightsinto the health and survival of *A. japonicus* following a C&R event. Although there were clear physiological and physical impacts of C&R, which were exacerbated with increased air exposure, *A. japonicus* seemed to be relatively resilient to a C&R event in the South African estuarine fishery. However, the mortality caused by hooking injury for *A. japonicus* is worrisome, particularly as the J - hooks are used extensively by estuarine anglers. Although the estimation of post-release predation was beyond the scope of this study, since estuaries in this region can be predator-rich, every attempt should be made to reduce their physiological stress and physical impairment. This includes the use of buckets while unhooking to reduce air exposure, with anglers keeping air exposures below 75 s.

Overall, the results of this study illustrate the value of studying C&R as a whole, including both human and ecological dimensions. Understanding what anglers are doing and how those specific behaviours effect the health and survival of a species leads to a fuller, more realistic picture of the effects of C&R. The structure of this research, incorporating studies on angler behaviour with the biological effects, represents the first of its kind in South Africa. A move towards inter-disciplinary studies is needed in recreational fisheries research and will lead to a better understanding of the recreational system and the effects of C&R as whole.

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CHAPTER 1

1. GENERAL INTRODUCTION

1.1 Introduction

Recreational fishing is a hugely popular pass-time the world over with an estimated 11.5% of the global population participating (Arlinghaus and Cooke 2009). Recreational fishing has been defined as fishing for aquatic animals for non-commercial purposes, usually during leisure time, with the catch not constituting an individual's primary source of income or subsistence (Arlinghaus 2005; Arlinghaus and Cooke 2009). It is a centuries-old practice, with one of the earliest known mentions of recreational fishing found in the fifteenth century manuscript *A Treatyse of Fysshinge with an Angle* attributed to Dame Juliana Berners in 1496 (Berners 1496).

While the idea of catch-and-release (C&R) angling is a more modern concept, there were harvest limiting laws, such as bag and size limits, that would have required mandatory C&R as early as the Middle Ages in Europe (Policansky 2002). It was not until 1952, however, that the concept of C&R was first publicized in the sports magazine, Sports Afield by Hazzard (1952), who termed the practice 'fishing-for-fun'. The Great Smokey Mountains National Park in North America then started implementing fishing-for-fun regulations in many of its streams, requiring anglers to release all or most of their catch, with the idea that the fish could then be caught again by another (Policansky 2002). Since then C&R has become increasingly popular, with release rate increasing from 34% in 1981 to 59% in 1999 (Bartholomew and Bohnsack 2005), and with current estimates at around 60% of recreationally-caught fish being released around the world (Cooke and Cowx 2004). However, C&R rates differ drastically among different cultures, environments, countries and even among species, with some release rates as low as 0% (Arlinghaus et al. 2007). Despite the disparity in release rates, C&R is still one of the most popular management strategies to promote sustainable angling practices in recreational fisheries, as there is a perception that once the fish is released it will survive (Bower et al. 2016). However, there is a growing evidence in the C&R literature suggesting that this may not be the case, with both lethal and sub-lethal effects being observed (e.g. Bartholomew and Bohnsack 2005; Danylchuk et al. 2014; Bower et al. 2016; Arkert et al. 2018) (see review table in Appendix 1).

Based on the research on post-release survival it appears that survival is far from guaranteed. Indeed, mortality can often be quite high. For example, Muoneke and Childress (1994) found that mortality ranged from 0-89% among an array of different species in both freshwater and marine environments. To understand when mortality can occur, one must comprehend what happens to the fish at each stage of a C&R event. Hooking is the first stage in any angling event, and it is also the most damaging stage, with hooking injuries often causing either immediate or delayed mortality (Arlinghaus et al. 2007, see Appendix 1). Hooking injury, in combination with other factors, can often be the main cause of death during angling. Indeed, Arkert et al. (2018) found in their study on *Rhabdosargus holubi* in a South African estuary, that fish who experienced mortality all showed signs of severe hooking injuries. Hook type has a huge influence on injury rates and mortality. In a comparison of circle verses "J" hooks, Prince et al. (2002) found that significantly more billfish were deep hooked (in the throat or stomach) on "J" than circle hooks in Guatemala. Having a barbed hook can also increase hook removal time, causing further injury and stress to the fish and increasing the chances of mortality.

The second stage of an angling event is the fight as the angler attempts to retrieve the fish to the shore or boat. This can often lead to exhaustion, stress and in extreme cases, mortality (Arlinghaus et al. 2007). The fight causes metabolic disturbances in the fish (e.g. lactate production, hyperglycemia) and in the cases of extended fight time and exhaustive exercise these disturbances can be pronounced (Suski et al. 2007) (see Appendix 1). Wood et al. (1983) observed a delayed mortality of 40% after exercising rainbow trout (*Oncorhynchus mykiss*) for six minutes and suggested that intracellular acidosis, caused by the intensive exercise, was the cause of death. Temperature can have a significant influence on the survival of a fish after a fight, with high temperatures often decreasing chances of survival (Brownscombe et al. 2014) (see Appendix 1). In their study on large-mouth bass (*Micropterus salmoides*), Brownscombe et al. (2014) concluded that water temperature, and not duration or intensity of the fight, was the most important predictor of the stress response. However, according to the literature, the effect of fight time and temperature on mortality seems to be species-specific (see Appendix 1), as seen in the example of Thorstad et al. (2004) where water temperatures were extremely high during capture, yet no mortalities were recorded for nembwe (*Serranochromis robustus*) or threespot tilapia (*Oreochromis andersonii*). Indeed, Braccini and Waltrick (2019) found species to be the most important predictor of mortality in sharks and rays. Not only are the metabolic and mortality effects of exhaustive exercise species-specific, research shows there is intraspecific variability among fish as well (Nelson 1990; Kieffer et al. 1994). This makes it even harder to understand the impacts and quantify the mortality caused by exhaustive fighting.

The third step in a C&R event is landing and handling the fish. Many devices used to land fish can lead to injury and delayed mortality, Colotelo and Cooke (2011) found that northern pike (*Esox Lucius*) showed extensive epithelial damage when landed with knotted nylon nets. Skaggs et al. (2017) found that black bass (*Micropterus spp.*) handled with a lip-grip after angling took longer to recover than fish held in a two-handed supportive grip. Once the fish is landed it will experience handling, this can lead to stress, injury and epithelial damage, particularly during un-hooking (Arlinghaus et al. 2007; Colotelo and Cooke 2011). Handling can lead to slime and scale removal which leaves the fish vulnerable to infection, while unhooking can exacerbate a hook injury, particularly in the case of deep hooking (Arlinghaus et al. 2007). The handling practices of an angler can also influence injury and mortality. Poor handling practices (e.g. holding the fish by the gills, dropping it on the ground, extended exposure to air) can cause the fish severe damage, while good handling practices can greatly increase a fish’s chance of survival after C&R.

Fish are often exposed to air during handling, and several studies have shown that air exposure, particularly extended air exposure, greatly increase the stress response, reflex impairment and chances of mortality in fish (Arlinghaus and Hallermann 2007; Suski et al. 2007; Lennox et al. 2015; Bower et al. 2016; Butler et al. 2017; Arkert et al. 2018). Though some studies have identified an air exposure threshold, beyond which the likelihood of mortality increases considerably (e.g. Schreer et al. 2005; Arkert et al. 2018) (see Appendix 1), it appears that this threshold is species-specific.

Once the fish is released it is not out of danger, as the sub-lethal effects of C&R can have consequences for survival (Brownscombe et al. 2017). The stress and injury inflicted during the C&R event can alter its behaviour, impair its reflexes and reduce its potential for physiological adaptation (Raby et al. 2014). This reduces the fish’s ability to evade predators and thus temporarily elevates its risk of predation (e.g. Cooke and Philipp 2004; Danylchuck et al. 2007; Raby et al. 2014; Lennox et al. 2017; Moxham et al. 2019). Injured and stressed fish can also attract predator’s due to chemical cues emitted into the water (Jenkins et al. 2004; Dallas et al. 2010). Mortality due to predation is often delayed and hidden and thus, seldom considered when estimating mortality rates of fishes that are subjected to C&R. Understanding the causes and quantifying the mortality, particularly the delayed mortality, caused by C&R angling is important as it often goes unnoticed and can thus lead to underestimates of fishing mortality (Raby et al. 2012; Raby et al. 2014).

Although mortality caused by C&R is well understood for many species, research on the sub-lethal effects, which can have long-term consequences for the fish's health and survival, is not well documented. One such sub-lethal effect is the consequences of C&R on fish growth. Stress has been shown to disrupt feeding behaviours of fish (Beitinger 1990) while physical injury caused by hooking and handling may inhibit the short-term feeding of a released fish. There are conflicting conclusions drawn from studies that have looked at the effects of C&R on growth, with some stating that growth is not affected (Pope and Wilde 2004; Pope et al. 2007; Cline et al. 2012) while others state that it is reduced (Clapp and Clark 1989; Diodati and Richards 1996; Stockwell et al. 2002; Aalbers et al. 2004; Siepker et al. 2006; Meka and Margraf 2007). In a 27-year mark-recapture study, Cline et al. (2012) found that there was a ~6-day reduction in weight of largemouth bass (*Micropterus salmoides*) after C&R, but these fish rapidly recovered to a "normal" weight after a period of compensatory growth. Stockwell et al. (2002) developed a bioenergetic model to assess growth reduction from C&R. Their model predicted a reduction in growth of up to a 30% in striped bass (*Morone saxatilis*) caught two or more times. Similarly, Meka and Margraf (2007) predicted a -164% deviation from expected growth after a debilitating hook injury and a 50% decrease in feeding potential. While it can be argued that simulations oversimplify complex natural systems and do not necessarily provide a true reflection of the effect of C&R on growth, there have been experimental studies that have obtained similar results. For example, Clapp and Clark (1989) found that smallmouth bass (*Micropterus dolomieu*) that were subjected to an experimental C&R event grew slower than wild populations. They also found that growth was significantly reduced as the number of hooking events increased. Relationships between hooking injury and growth is not uncommon. For example, Aalbers et al. (2004) found that deeply hooked juvenile seabass grew significantly slower, when compared to those that were hooked in the mouth. While it appears that the number of hooking events and the severity of hooking injury are the most important factors driving changes in fish growth, it is likely that the extent of this change may be species-specific.

The sub-lethal effect of C&R on reproduction is also not well documented. While there have been studies on the effects of chronic stress on aquaculture fish, which resulted in smaller egg size, delayed ovulation and reduced larval survival (Campbell et al. 1994), the effects of C&R on the reproduction of different species is relatively unknown. When comparing the reproductive success of largemouth bass (*M. salmoides*) and smallmouth bass (*Micropterus dolomieu*) in sites closed and open to C&R angling, Philipp et al. (1997) found that 63% of nesting males were successful in the closed sites whereas only 44% were successful in the open sites. Ostrand et al. (2004) found that largemouth bass (*M. salmoides*) that had been stressed in a simulated C&R tournament event produced age-0 offspring that were smaller and had later “swim-up” dates than those of non-stressed fish. It appears that rainbow trout (*O. mykiss*) are similarly affected by C&R. Campbell et al. (1992) repeatedly exposed fish to acute stress, applying stress at random intervals to ensure fish would not acclimate to repeated exposure, prior to their spawning. Fish that were stressed experienced a significant delay in ovulation, decreased egg size and sperm counts and a decreased survival rate for their progeny (Campbell et al. 1992). However, the effect of C&R on reproductive success, like many other aspects, appears to be species-specific, as Roth et al. (2019) found no effect of fight and air exposure on the reproductive success of Yellowstone Cutthroat Trout (*Oncorhynchus clarkii bouvieri*). Although data is scarce, and in some cases non-existent for many species, the research that has been presented suggests that C&R can have a significant sub-lethal effect on the reproductive success of fishes, which could in turn have negative consequences for the overall health of a population.

It appears that for both growth and reproduction, multiple recaptures increase the potential severity of the sub-lethal effect (Clapp and Clark 1989; Campbell et al. 1992). The same is true for increasing the likelihood of mortality after C&R. Thus, if a fish is more vulnerable to capture it will likely suffer more deleterious effects of C&R, and indeed, vulnerability to angling has been found to be a heritable trait in largemouth bass (*M. salmoides*) (Philipp et al. 2009). Fish bred for high vulnerability (HV) to angling were found likely to be caught more frequently than those with low vulnerability (LV) (Garrett 2002). It has also been found that vulnerability to angling correlates with certain behavioural and physiological phenotypes. Redpath et al. (2010) found that the metabolic rates were significantly different among HV and LV fish, with lower metabolic rates (16% lower for metabolic scope, 14% for maximal metabolic rate, and 10% for standard metabolic rate) observed in the LV fish. The stress response of LV and HV fish also appear to be different, with the blood cortisol levels of HV largemouth bass remaining lower following air exposure (Louison et al. 2017). The absolute growth rate of largemouth bass was found to be between 9% and 17% higher for LV fish, while the gonadosomatic index in LV females was lower (Redpath et al. 2009). It appears that vulnerability to angling also selects for different behavioural traits, Sutter et al. (2012) found that HV individuals were more aggressive, showed greater intensity in parental care and had higher reproductive fitness than LV largemouth bass. Vulnerability to angling is connected to a suite of physiological and behavioural traits and the selective capture and potential removal of such individuals could have severe consequences for the long-term viability of a population. Although C&R is widely believed to have little effect on the population of a targeted species, it is clear that this is not the case, and it is vital to take into account both the lethal and sub-lethal effects of C&R when managing a targeted population.

There is an emergent body of thought that is advocating moving away from C&R as a management strategy altogether on the basis of animal welfare (Arlinghaus et al. 2009). There is a growing recognition that fish have some capacity to experience pain and, to some extent, fear (Cooke and Sneddon 2007; Muir et al. 2013). In an experiment to discover the pain perception of rainbow trout, Sneddon (2003) found that trout exhibited prolonged respiratory and behavioural responses to a noxious injection into their lip. Trout were seen to perform anomalous behaviour such as rubbing the affected lip against the tank and rocking on the gravel substratum. Behaviour such as this could be taken to indicate suffering (Sneddon et al. 2003). Fish can have a profound behavioural and physiological response to a painful stimulus which may make them more conspicuous to predators in the wild (Sneddon et al. 2003; Cooke and Sneddon 2007). Research such as this influences the debate on the ethics of recreational fishing and in particular C&R. Indeed, some jurisdictions, such as Germany, have gone as far as to ban C&R altogether stating that all captured fish must be retained in accordance with animal welfare protocols (Steffens and Winkel 2002). However, a total retention of recreationally-angled fish could cause more problems than it solves and thus many are advocating the ‘selective harvest’ approach, allowing anglers to make an informed decision (guided by research, laws and ethics) as to whether or not to release a fish. Although it is a foreign thought to most anglers and managers, considering a fish’s welfare when capturing it, is likely to lead to better handling practices which will increase its chance of survival upon release. It is necessary however, to have a baseline understanding of angler handling practices and behaviour before the implementation of laws and ethics guiding angler decisions. As C&R is by nature an integrated socio-ecological system, understanding specific angler behaviour and how that effects fish will aid in deciding which behaviours need to be reformed. Thus, further study on C&R, and in particular angler behaviour and the species-specific lethal and sub-lethal effects of C&R, is needed to design optimal behavioural interventions and to aid anglers with making informed decisions.

The importance of studying the effects of C&R is clear, particularly due to the invisible nature of the lethal and sub-lethal effects which are often not considered when managing a stock. The species-specific nature of C&R survival and long-term health effects drastically complicates the management of recreational fish stocks. The wide-spread, decentralized nature of recreational fisheries also complicates management as the effects of angling and C&R on a population can often be hard to detect. Environments targeted by recreational anglers can be more vulnerable to severe overfishing than those targeted only by commercial fishers. This is because a commercial fishery is likely to stop fishing once the yield is no longer economically viable, whereas recreational fishers will often continue far beyond this point (Post et al. 2002). Indeed, despite drastic declines in catch-per-unit-effort (CPUE) from 5.6 fish/h in 1960's to 0.25 fish/h in 1980's in Puntzi Lake (Canada), angling effort more than doubled over that time period, (Post et al. 2002).

Recreational estuarine and marine fishing is very popular in South Africa with approximately 625 000 participants who spend approximately R8.9 billion (USD 596 million) on their activities annually (Saayman et al. 2017). Brouwer et al. (1997) estimated that the total effort for the South African shore-angling fishery was 3.2 million angler days-year^{-1} and a total catch of 4 519 914 fish-year^{-1}. Mandatory release is required in many circumstances for fishers to comply with the species-specific size limits, bag limits and closed season regulations. Yet voluntary C&R has also grown in popularity with many South African anglers, with C&R-only competitive angling leagues developing over the last decade (Butler et al. 2017, Mannheim et al. 2018). Despite its growing popularity, there is little research on the impact of recreational angling on South African fisheries and on the effects of C&R on South African fishes. Many South African estuaries are under heavy fishing pressure, for example the Sundays Estuary is subjected to an estimated total annual effort of 63 785 angler-hours with an annual yield of 16 214 fish (8.0 t) (Cowley et al. 2013). As estuaries are particularly important from an economic and ecological perspective, as they fulfil an important nursery role for many marine fishes, it is important to understand the impact of recreational fishing and C&R on these ecosystems. However, there is almost no data on the impact of C&R on fishes in South African estuaries. In one of the only studies on the effect of C&R on a juvenile estuarine species, Arkert et al. (2018) found that juvenile Cape stumpnose (*Rhabdosargus holubi*) experienced up to 7% mortality after an angling event, however post-release predation was not considered thus mortality is likely to be higher. The lack of data on C&R and its effects on South African fishes means that the total mortality and population impact caused by recreational fishing may be severely underestimated and this could have important implications for fish stocks as well as the people who depend on them. Many popular recreational angling species are also important to subsistence fishers and thus understanding the ‘hidden’ mortality caused by C&R will be vital for maintaining a sustainable fishery and protecting an important food source for impoverished South Africans.

The dusky kob (*Argyrosomus japonicus*) (Figure 1.1) is part of the sciaenid family and occurs in both the northern and southern hemispheres, in the southern hemisphere it occurs from the Cape of Good Hope to Mozambique and along the entire southern seaboard of Australia (Griffiths and Heemstra 1995). In the northern hemisphere it occurs from Hong Kong northward to southern Korea and Japan (Trewavas 1977). Due to their large size, *A. japonicus* is one of the most targeted species in the South African marine recreational and subsistence fisheries (Baired et al. 1996;

Brouwer et al. 1997; Childs et al. 2015). They dominate the catch numerically and by mass, accounting for up to 22.9% of the catch composition by number in the Great Fish Estuary (Cowley et al. 2004), up to 10.1% by number and 28.4% by mass in the Kowie estuary (Pradervand and Baird 2002) and 20.3% by number and 69.2% by mass in the Sundays Estuary (Pradervand and Baird 2002; Cowley et al. 2013). *Argyrosomus japonicus* are gonochoristic (Griffiths 2000) with spawning occurring during October and January in the Eastern and Western Cape and during August and November in KwaZulu-Natal (Griffiths 1996). Males reach sexual maturity at 920 mm TL (five years) and females at six years of age (Griffiths 1996). Due to their popularity, longevity (< 40 years) and slow growth (Griffiths 1996), *A. japonicus* are vulnerable to overfishing. Indeed, their stock status is currently between 2 and 5% of pristine levels and thus are considered to be collapsed (Childs and Fennessy 2013). *Argyrosomus japonicus* have been found to be highly vulnerable to recapture after release, Cowley et al. (2008) reported a 41% recapture rate within a few days or up to three years after tagging, of *A. japonicus* caught in the Great Fish Estuary while Childs et al. (2015) reported a recapture rate of 35% after an average of 429 post tagging, in the Sundays Estuary. While adults are found mostly in the near shore environment, juvenile *A. japonicus* are particularly vulnerable to recapture in estuaries as they have been found to be highly resident to specific estuaries with low levels of dispersal (Childs et al. 2015). This vulnerability to recapture means that *A. japonicus* will be more likely to experience post-release-mortality as well as being more vulnerable to the sub-lethal effects of C&R angling. *Argyrosomus japonicus* are important estuarine predators, feeding primarily on other teleosts (Griffiths 1997), cephalopods and crustaceans (Marais 1984). Thus, the observed decline in their population over the last few decades has likely had an impact on the estuarine food web. Despite their popularity in the recreational and subsistence fisheries and their vulnerability to overfishing, little research has been done on the effects of C&R on this species in South Africa. However, C&R studies on this species have been conducted in Australia (e.g. Butcher et al. 2007; Reynolds 2018). Despite this information, an understanding of the impacts of C&R of *A. japonicus* in South African estuaries is critical for its continued protection and management.

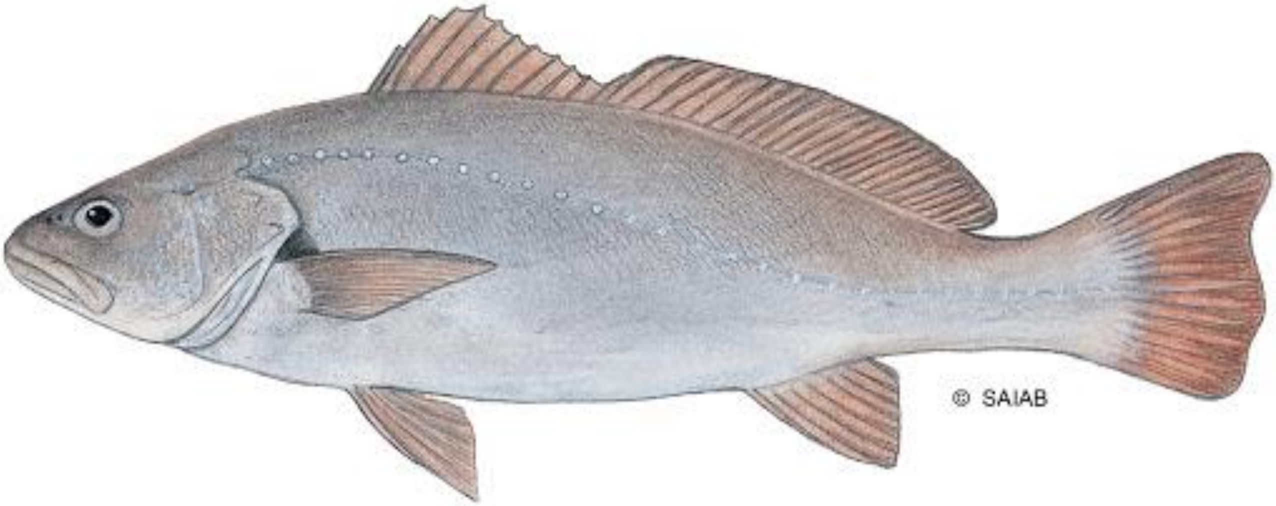

Figure 1.1: Image of study species, dusky kob (*Argyrosomus japonicus*)

The aim of this study was to evaluate the effects of C&R angling on the physiological stress response, reflex impairment and health and survival of *A. japonicus*, captured in estuaries. To do this we observed angler behaviour in order to determine real-world fight and air exposure times, we studied the time-course of the physiological stress response of *A. japonicus* following a simulated C&R event in order to determine when the peak disturbance occurs, and we examined the effects of traditional rod-and-line C&R angling on the physiological stress response, reflex impairment and short-term survival of *A. japonicus* in a South African estuary.

1.2 Thesis structure

This thesis is made up of five chapters (Figure 1.2). This chapter provides a general introduction where C&R science is discussed and placed into a global context, the study species (*A. japonicus*) is introduced and the aims of the study are discussed. Chapter 2 contains a brief study on covert angler observation, which we conducted in order to obtain baseline information on the air exposure times to which South African estuarine anglers expose their captured fish. Chapter 3 is a laboratory-based study in which *A. japonicus* were subjected to a simulated C&R event, based on the findings of Chapter 2, and the time course of the physiological stress response was examined. This was done in order to determine when the peak disturbance occurred. Chapter 4 outlines the field experiment that aimed to evaluate the physiological stress response, reflex impairment and short-term survival of angled *A. japonicus*. This experiment was designed to mimic realistic angler behaviour (obtained in Chapter 2) and to estimate the peak physiological stress response (based on the findings in Chapter 3) and used to recommend best C&R handling techniques in order to enhance the chance of survival of *A. japonicus* after a C&R event. Chapter 5 is a general discussion where the results of the previous chapters are briefly discussed and the importance of approaching C&R science as an integrated socio-ecological system is examined. Methods and recommendations on promoting pro-environmental behaviour among recreational anglers is also discussed and future studies are encouraged to combine research on angler behaviour with the physiological and environmental effects of C&R.

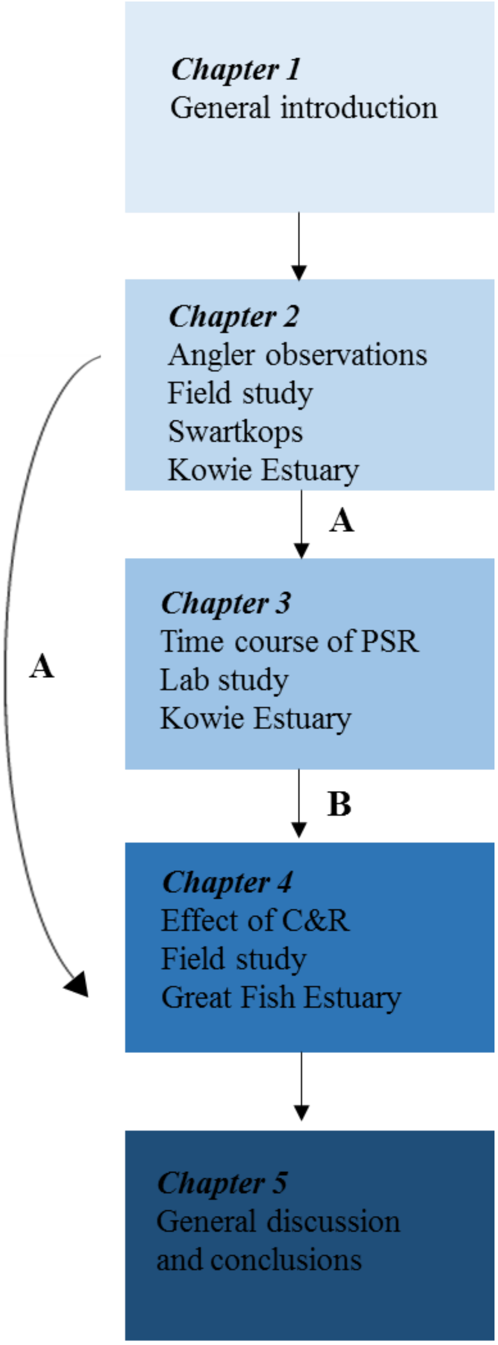

Figure 1.2: Flow diagram showing the structure of this thesis, (A) represents information from Chapter 2 and (B) represents information from Chapter 3.

CHAPTER 2

Incorporating observations of angler behaviour into catch-and-release study design

2.1. INTRODUCTION

Catch-and-release science has become a recognised field of research with many studies examining the physical effects (e.g. Hooking injury [Cooke et al. 2001], dermal abrasion [Barthel et al. 2003] and physical exhaustion/impairment [Brownscombe et al. 2013]), physiological effects (e.g. Stress response [Arends et al. 1999; Butler et al. 2017]), sub-lethal effects (e.g. Growth [Stockwell et al. 2002], reproduction [Campbel et al. 1992] and survival/fitness [Roth et al. 2019]) and mortality (e.g. Lennox et al. 2015; Bower et al. 2016) of a range of species that have been subjected to a C&R event (see Appendix 1). Some of these studies have also found clear links between the response of fishes and environmental conditions (e.g. effect of temperature on reflex impairment and survival [e.g. Thorstad et al. 2004; Brownscombe et al. 2014; Pinder et al. 2019]). While there is information on the environmental drivers on the response of fish to C&R, this is not matched by information on another primary driver of the response, angler behaviour (Brownscombe et al. 2017).

Angler behaviour represents a key link between the social and ecological systems of recreational fisheries (Arlinghaus et al. 2013). Thus, studying angler behaviour and understanding the system as a whole, rather than its individual parts, will result in greater clarity on the feedbacks between human actions and their effect on fishes (Arlinghaus et al. 2013). This will ultimately help predict changes and adaptions likely to occur in recreational fisheries and promote resilience in the fishery system (Arlinghaus et al. 2013). As C&R activities are in themselves complex socio-ecological systems within the greater system of recreational fishing, understanding angler behaviour is a critical component of predicting and understanding the outcome of a C&R event.

Although great strides have been made in understanding the human dimension of recreational fisheries (e.g. Fenichel et al, 2013; Hunt et al. 2013; Mannheim et al 2018), the lack of angler behavioural information around C&R activities is concerning as it is critical for our understanding of the impacts of C&R on fishes. There are a number of decisions by anglers that may influence the C&R behaviour of anglers. For example, their choice of angling method (Lamansky and Meyer 2016), gear choice (Twardek et al. 2019), landing net mesh type (Barthel et al. 2003), the use of live wells (Brooke et al. 2019) and hook type (circle vs J) (Prince et al. 2002) can determine the duration of the fight, hooking injury and landing injury, and ultimately influence the health and survival of released fishes (see Chapter 1 and Appendix 1).

Besides the choice of method and gear, anglers largely have control of the time a fish is exposed to air. Once a fish is captured and exposed to air, anglers may perform several actions, depending on the context, which will increase air exposure. These include unhooking, measuring/weighing and photographing the fish. As each of these activities may be extended, they will have individual and cumulative impacts on the health and survival of the fish. These impacts include an increase in physiological stress, reflex impairment and mortality (e.g. Arlinghaus and Hallermann 2007, Brownscombe et al. 2015; Bower et al. 2016; Butler et al. 2017) (see Appendix 1). Having a bassline understanding of angler behaviour in different environments and pertaining to specific species will therefore help inform and guide more realistic C&R experimental design.

Besides the value of C&R behaviour information for the design of realistic experiments, this information is also critical as a baseline from which interventions to improve angler C&R behaviour can be evaluated. This approach was used by Mannheim et al. (2018) who compared the C&R behaviour of competitive anglers exposed to a pro environmental intervention with their baseline behaviour before the intervention. In this case, the baseline information was also used to identify aspects of the angler behaviour that were concerning for fish health and survival.

Despite its clear value, only one study has covertly observed the behaviour of C&R anglers to obtain real-world air exposure times. Lamansky and Meyer (2016) observed 280 trout anglers and timed how long they exposed fish to air before releasing it. They found that anglers only exposed trout to an average of 29.4 s (range 0 - 165 s), which is substantially less than the air exposures applied by some studies (e.g. Ferguson and Tufts 1992; Schisler and Bergerson 1996). This means that C&R mortalities may have been overestimated by these studies as real-world anglers may not expose fish to the extended air exposure times found to cause high mortalities. Lamansky and Meyer's (2016) study illustrates the importance of understanding real-world angler handling behaviour, as it greatly effects the estimates of mortality caused by C&R and thus influences policy and management of recreational fish stocks. However, angler behaviour is context specific and can differ depending on sector, environment and species. For example, common carp (*Cyprinus carpio*) anglers have been found to have exceptional handling practices, using antiseptic on hook wounds and specialised mats to limit mucus abrasion when unhooking and photographing their catch (Cooke et al. 2013). However, most recreational anglers do not employ such careful handling practises when fishing. Thus, having an understanding of the behaviour of a particular sector is important when studying the effects of C&R.

Up to now, few South African studies have examined the behaviour of the angler during a C&R event. Butler et al. (2017) and Mannheim et al. (2018), both examined and recorded angler behaviour during a South African National C&R competition. Butler et al. (2017) recorded the fight and air exposure times of competitors and then evaluated the health and survival of the angled fish, while Mannheim et al. (2018) monitored the behaviour of competitors over the period of three consecutive years to determine if a pro-environmental behavioural intervention improved fish handling practices and fish heath. However, since in both cases the anglers were aware of the experiments it is possible that they may have modified their behaviour in the presence of the researchers.

The aim of this study was to obtain realistic information on selected aspects of estuarine angler C&R behaviour. To do this, angler C&R behaviour was observed (covertly) and recorded in two South African estuaries.

2.2. METHODS AND MATERIALS

2.2.1 Study site:

Angler observations took place from March to May 2018 at the Swartkops (30 and 31 March, 2 and 14 April, 5 and 6 May) and Kowie Estuaries (21, 27 and 29 April) (Figure 2.1). The Swartkops estuary is situated 8km east of Port Elizabeth (33.8603° S, 25.6199° E) and experiences high fishing pressure year-round (estimate of 2502 angling hours per year) (Pradervand and Baird 2002). The catch in the Swartkops estuary is dominated in number by *Pomadasys commersonnii* (35.9%) and *Rhabdosargus holubi* (35.5%) (Pradervand and Baird 2002). The Kowie estuary is situated in Port Alfred (33°36′06″S 26°53′58″E) and also experiences high fishing pressure (1380 angler hours) (Pradervand and Baird 2002), with the catch being dominated by *R. holubi* (33.1%) and *A. japonicus* (10.1%). *Argyrosomuc japonicus* is also one of the most targeted species in these estuaries (Baird et al. 1996). Both estuaries are in highly urbanised areas and are dominated by recreational shore and boat-based anglers (Pradervand and Baird 2002). These estuaries were selected as they offered secure areas for covert observations, excellent vantage points over high use recreational angling areas and relatively high catch rates (Pradervand and Baird 2002).

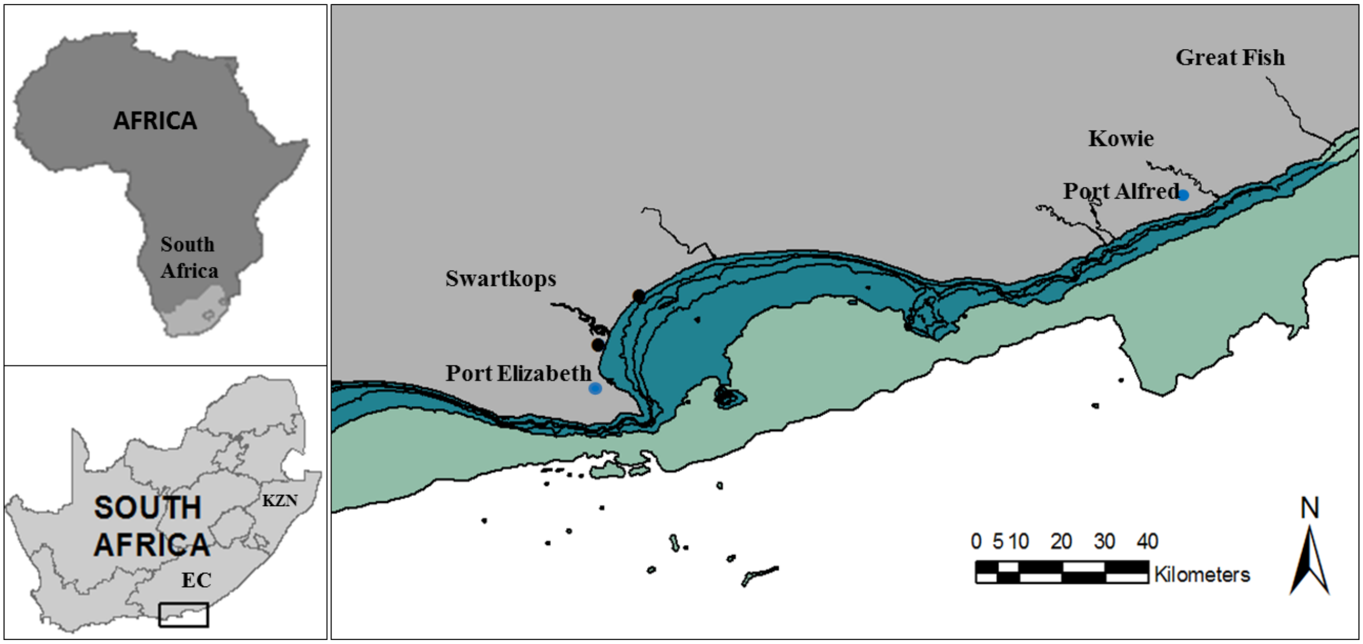

Figure 2.1: Map showing the locations of study estuaries; Swartkops Estuary (Chapter 2), Kowie Estuary (Chapter 2, Chapter 3), Great Fish Estuary (Chapter 4); coastal cities (Port Elizabeth and Port Alfred) represented by blue dots and provincial states, Eastern Cape (EC) and Kwa-Zulu Natal (KZN) mentioned in text.

2.2.2 Angler observations

This research was approved by the Rhodes University Ethics Committee - SCI2018/046 and DIFS2018.

Anglers were observed on weekends and public holidays. These observation days were chosen due to the higher number of anglers present at the locations on these days. Weather information, including temperature and cloud cover were recorded on each sampling day.

A single observer monitored the behaviour of anglers fishing from shore and boat from a closed, parked car in parking areas near the estuary banks, using binoculars (Nikon 10x42 Prostaff 7S). An observation was defined as an angler capturing and then releasing a fish. All anglers in the field of view were observed until an angler was seen to hook a fish, then the observer began to record fight time and air exposure using a stopwatch. Fight time was defined as the time from hooking until landing. If hooking was not observed, only air exposure time was recorded and was defined as the difference between the time that the fish left the water and the time that it was returned. Steps were taken to ensure that anglers were not aware that they were being observed and their actions recorded, these included sitting in a closed vehicle or pretending to watch birds, as this may have changed their behaviour and thus biased the results (Lamansky and Meyer 2016; Bova et al. 2018). If visible, the species and estimated size (small, medium or large) of the fish was recorded. A fish was classified as small if it was bellow approximately 20 cm in length, medium if it was between approximately 20 and 35 cm and large if it was above 35cm in length. The method used to land the fish (e.g. hand, net, gaff, grip) was noted and angler demographic information such as age (adult or child), gender and race were also noted. Poor handling practices (such as dragging the fish on the ground or dropping it) were noted.

2.2.3 Statistical analysis:

Data was analysed and descriptive statistics were produced using Microsoft Excel (Office 365 MSO 160.11901.20070). Student t-tests were performed to determine the difference in air exposure times between males and females, adults and youth, and land and boat-based anglers using STATISTICA 12 (StatSoft Inc.)

2.3. RESULTS

Weather on observation days ranged from cloudy to partly cloudy and cool to sunny and cool. A total of 51 observations were made between the two estuaries, with 39 C&R events observed on the Swartkops Estuary and 12 C&R events on the Kowie Estuary. Most observations (84.3%) were for shore-based anglers and the remainder (15.6%) were for boat-based anglers. Of the fish that were visible (i.e. clearly seen and not obscured by distance, an anglers' body or a boat), seven different species were observed, Pomadasys commersonni (7), *Rhabdosargus holubi* (15*), Liza richardsonii* (1), *Rhinobatos annulatus* (1), *Clarias gariepinus* (1), Ray (species not identifiable (1) and *Amblyrhynchotes honckenii* (9). Thirty-nine percent of fish were classed as small in size, 44% were classed as medium and 16% as large. Of the landings observed (including clearly visible and obscured fish), 94.11% of anglers landed their fish by hand while 5.9% landed them using a net. A total of five poor handling events were observed. These included anglers dragging fish along the ground (on sand, grass and rocks), dropping a fish onto rocks and handling a fish with a dry, rough cloth.

2.3.1 Angler demographics

The majority of C&R (82.3%) events were performed by males (Figure 2.2). The majority of anglers were white (84.3%), followed by black (11.7%) and coloured (3.9%) (Figure 2.2). Most anglers were adults (80.3%) followed equally by youth (children = 9.8%, teenagers = 9.8% (Figure 2.2).

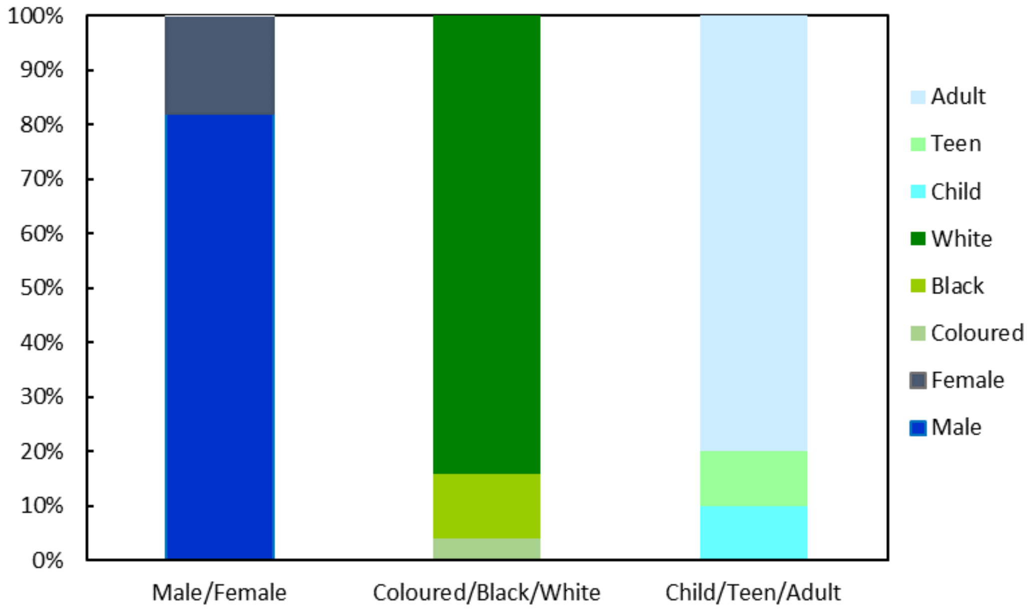

Figure 2.2: Demographics of the anglers whose catch and release behaviour was observed during surveys on the Swartkops and Kowie estuaries

2.3.2 Air exposure and fight time

The fight times of only 19 fish were observed. Mean fight time was 33.05 s ± 23.34 SD (range 8 – 92 sec). The median fight time was 21s and the mode was 60 s. Of the 51 observations made, 50 air exposure times were recorded. Mean air exposure time was 74.26 s ± 64.90 SD (range 10 – 240 sec). The median air exposure was 56.50 s and the mode was 43 s.

The average air exposure time for males (n = 42) was 66.32 s ± 53.46 SD (range 10 – 240 sec) and females (n = 9) was 82.78 s ± 65.48 (range 23 –240). There was no significant difference in the air exposure times between males and females ($t_{(47)} = -0.8$; $p = 0.43$). The average air exposure time for youth (children and teenagers) (n= 10) was 78 s ± 68.46 (range 10 – 240 sec) and adults (n = 41) was 67.13 s ± 52.47 (range 13 –240). There was no significant difference in the air exposure times between the youth and adults ($t_{(47)} = -0.55$; $p = 0.58$). The average air exposure time for white (n= 43) was 68.36 s ± 53.2 (range 10 – 240 sec) and coloured (n = 8) was 74.37 s ± 69.98 (range 22 –240). There was no significant difference in the air exposure times between white and coloured/black ($t_{(47)} = -0.28$; $p = 0.78$).The average air exposure time for shore-based anglers (n= 43) was 65.63 s ± 50.31 SD (range 10 – 240 sec), while the average air exposure for boat-based anglers (n = 8) was 88. 37 s ± 78. 41 (range 13 –240). There was no significant difference in the air exposure times for fish captured in the shore-based and boat-based fishery t ($t_{(47)} = -1.06$; $p = 0.29$).

2.4. DISCUSSION

Although only a preliminary study, the findings suggest that the air exposure of fishes captured in the South African estuarine recreational fishery is high (mean 75 s) when compared with those of trout anglers in Lamansky and Meyer (2016) (mean 29. 4 s). While this may be attributed to a number of factors, it is most likely due to the conscientious attitudes of trout anglers (like specimen carp anglers) with regards to fish handling practices (Cooke et al 2013).

Some South African studies have looked at angler air exposure times in the marine nearshore zone; Butler et al. (2017), found that anglers exposed fish to an average of 94.3 s (SD 57.10 s, range 5-301s) air exposure, falling into the range of our results. Mannheim et al. (2018) found that air exposure times of anglers decreased after awareness interventions to improve handling over three years, declining from an average of 101.93 s ± 64.34 in 2015 to 77.37 s ± 60.52 in 2017, which is very similar to the average air exposure time observed in our study. However, these studies are not directly comparable to ours as the experiments took place within the context of a competition and required the anglers to measure and photograph the fishes in three different settings. The extreme variability in air exposure times observed during this study (range 10 – 240 s), indicate that South

African estuarine anglers are capable of limiting the time fish are exposed to air. This suggests that through pro-environmental intervention, such as education and rule enforcement, as seen in Mannheim et al. (2018), extended air exposure times could most likely be reduced.

Several C&R studies (e.g. Suski et al. 2007; Thorstad et al. 2007; Arlinghaus and Hallermann 2007) have used similar air exposure times to the mean time observed in this study. In addition, other studies that have examined the impact of what they termed "extended" air exposures of three minutes (e.g. Suski et al., 2007) also fell within the range of times observed during this study. Although this may suggest that studies on the effect of air exposure on mortality may be using realistic estimates, it is critical to note that these times are likely to be context-specific. For example, although the number of observations of C&R by boat-based anglers in this study was low (and not significant), the mean air exposure time was more than 20 s longer than the shore-based anglers.

When compared to the air exposure treatments used for estimating the impacts of C&R on estuarine fishes (Lennox et al. 2015, Arkert et al 2018), the air exposure times observed here were similar. Using an air exposure treatment of 90 s, Arkert et al. (2018) found significantly greater physiological stress and motor impairment and higher mortality rates (7%) for experimentally angled Cape stumpnose (*Rhabdosargus holubi*) when compared with the shorter air exposure treatments of 0 s and 30 s. Similarly, Lennox et al. (2015) found a mortality rate of 3% after fat snook (*Centropomus parallelus*) were exposed to air for 60 s air exposure in a Brazilian estuary. Thus although, these results were not based on measured angler behaviour, the findings of this study may suggest that they provide realistic estimates of mortality in estuarine fisheries.

From a demographic perspective, there were no significant differences in the air exposure times between males and females, adults and youth or ethnic group. Burger et al. (1999) found that there were differences in the angler knowledge, attitudes and compliance among different ethnic (White, Hispanic and Black) groups in New Jersey, America. The lack of differences among ethnic groups in this study, align with the findings of Bova et al. (2017) who found that demographics in South Africa did not influence compliance behaviour. This suggests that the norms associated with general fishing behaviour are strong. However, it is also possible that the low number of observations may have influenced the findings of this research.

Differences between the behaviour and perceptions of male and female anglers have been noted. Indeed, in their study on male and female anglers in Minnesota, America, Schroeder et al. (2006) found that men agreed more with the ethics of C&R fishing and in general were more supportive of regulations and more likely to release their catch than women. While the observed air exposure time for females in this study was about 20s longer than for males, there was no significant difference between the two genders. However, it must be acknowledged that these results are preliminary and based on low sample sizes

One might expect that in general, youth (especially young children) would have poor handling behaviour and expose fish to extended air exposures. This is because children are still developing fine-motor skills (Davis et al. 2011) and generally handle objects with less dexterity. Therefore, they will likely be more prone to dropping the fish and handling it for extended periods. This could have implications for the survival of fishes. Indeed, the observed average air exposure time for youth was over 10s longer than that observed for adults, though this was not significant. As only 9.8% of the observed anglers were children there was not a large enough sample size to determine if their air exposure time would make a significant difference to the overall air exposures experienced by South African estuarine fishes.

Ninety-four percent of the observed anglers landed fish using their hands. This may be preferable as many types of landing nets have been shown to cause epithelial damage and increase mortality rates (Colotelo and Cooke 2011). However, some poor handling behaviour was also noted, such as dragging fish along the ground and dropping them on rocks, which could have a detrimental effect on the survival of those fishes. These results highlight the importance of obtaining a baseline of angler behaviour information, as it can give an indication of the potential impacts of C&R on fish stocks, guide future research on these impacts, and used to develop (or improve) the best C&R practice guidelines.

A limitation of this study is the small sample size. As this study was only intended to be a pilot to assist with the determination of experimental air exposure treatments for assessing the survival of *A. japonicus* to the impacts of C&R, budgetary and time constraints limited the number of sampling days. In addition, the geographic distribution of sampling effort was limited, and this may have influenced the results, as estuaries in non-urbanised areas may have been characterised by anglers with contrasting demographic and possibly, behavioural characteristics. Therefore, it is certain that an extension to this study is greatly needed.

The quantification of angler behaviour has, in general, been underappreciated in recreational fisheries. However, despite the relatively low sample size, the information gained from this study has provided a realistic baseline of angler behaviour and air exposure time, which can be used to inform the experimental design of Chapter 3 and 4 on the impact of C&R in estuarine recreational fisheries. This will not only aid in providing realistic estimates of the impacts of C&R mortality but can also assist with the development of best practice handling recommendations.

CHAPTER 3

Time course of the physiological stress response of dusky kob (Argyrosomus japonicus) after a simulated catch-and-release event

3.1. INTRODUCTION

Catch-and-release (C&R) is becoming increasingly popular among recreational angling circles due to management restrictions such as bag and size limits as well as a growing concern for conservation and the protection of fishes. However, many studies have shown that releasing a fish does not guarantee its continued health and survival. Indeed, a C&R event can elicit a severe stress response and can lead to mortality in many species (e.g. Bartholomew and Bohnsack 2005; Bonefish (*Albula Vulpes*) [Suski et al. 2007]; lemon shark (*Negaprion brevirostris*) [Danylchuk et al. 2014]; Peacock bass (*Cichla ocellaris*) [Bower et al. 2016]; Cape stumpnose (*Rhabdosargus holubi*) [Arkert et al 2018]).

Almost every stage of a C&R event; the initial hooking and injury, exhaustion of the fight, handling and air exposure, can elicit a physiological stress response (PSR) in a fish (Arlinghaus et al. 2007) and there have been many studies that seek to understand and quantify this response (Suski et al. 2007; Lennox et al 2015; Butler et al. 2017; Arkert et al 2018). When these impacts are combined with stressful environmental conditions, such as high temperatures (Brownscombe et al. 2014), the PSR may be even higher (Arlinghaus et al. 2007).

The PSR in fish is controlled by the hypothalamo-pituitary-interrenal axis (HPI) (Carragher and Sumpter 1990) and takes place in two parts, a primary stress response and a secondary stress response (Mazeaud et al. 1977). The primary stress response involves a neuroendocrine cascading reaction which results in the production of cortisol and adrenaline (Barton 2002; Wendelaar Bonga 2011). These primary stress hormones increase energy expenditure of the fish and also regulate several secondary components of the PSR (Barton 2002; Lankford et al. 2003; Martinez-Porchas et al. 2009; Wendelaar Bonga 2011). The secondary stress response involves cortisol inducing the process of glycogenesis which increases the production of glucose in the cells to provide fuel for increased heart, gill and brain function and allowing the fish to respond to the stressor through burst swimming (Barton 2002; Martinez-Porchas et al. 2009; Wendelaar Bonga 2011). In the event of the fish tiring or becoming exhausted (which is often the case during the fight of a C&R event) their reserves of glycogen and adenosine triphosphate (ATP) will become depleted, this will necessitate the start of anaerobic respiration in the white muscle fibres. This will increase the blood lactate levels of the fish because lactate is the end product of anaerobic respiration (Driedzic and Hochachka 1978). Although this explanation is an oversimplification of the complex processes involved in the PSR of fish, understanding the basic primary and secondary stress responses and how they relate to each other, particularly in the case of cortisol, glucose and lactate, is important as they are the most widely used indicators of physiological stress in fishes (Cooke et al. 2013).

Many studies that evaluate the PSR of fish consider cortisol to be the most accurate and reliable indicator of acute stress (Pickering and Pottinger 1989; Pottinger and Carrick 1999). However, cortisol is expensive to analyse and is not easily measured in the field because it requires blood to be immediately centrifuged to separate red blood cells and plasma and for that plasma to be quickly frozen. Therefore, studies often opt to measure the secondary stress response using point-of-contact devices as these are cheaper and easy to use in the field (Stoot et al. 2014). Some argue that glucose is not a good indicator of PSR as it can be affected by nutrient availability (Wu et al. 2017) however, its affordability, ease of analysis and general reliability tend to override this objection and many studies have used it successfully to measure PSR (Lennox et al. 2015; Butler et al. 2017; Arkert et al 2018; Bower et al. 2016).

Blood lactate concentration, although often used as a measure of PSR, is argued not to be a stress-related metric but rather related to exhaustion and oxygen availability in a fish (Lawrence et al. 2018). However, in the case of C&R science, oxygen availability is affected by air exposure and fight time and is therefore an important component influencing the PSR to C&R. Although many studies use blood glucose and lactate concentrations to evaluate PSR in fish, understanding the relationship between the primary (cortisol) and secondary (glucose and lactate) stress response hormones is important in order to better understand and make use of glucose and lactate as reliable indicators of stress. The concentration of the primary and secondary stress hormones in the blood change over time (Cooke et al. 2013), thus understanding this change will aid in understanding the full PSR to a C&R event.

After a stressor such as a C&R event, the PSR will continue to rise until acted upon by a negative feedback loop, at which point recovery will begin (Cooke et al. 2013). Understanding the time course of the PSR helps understand when best to measure and quantify the full stress response. Studies that take blood immediately after a stressor are likely only getting baseline stress information (Lawrence et al. 2018) and are not necessarily getting a full picture of the PSR (Danylchuck et al. 2014; Butler et al. 2017).

The time at which the peak PSR can be observed also varies drastically among species, while it is recommended that blood is taken after a delay (Cooke et al. 2013; Arkert et al. 2018), the period of that delay requires species-specific research (see Appendix 2). Studies on redthroat emperor (*Lethrinus miniatus*) and green sturgeon (*Acipenser medirostris*) found that physiological stress indicators (cortisol, glucose and lactate) peaked 15 minutes after a stressor (Lankford et al. 2003;

Currey et al. 2013). Eurasian perch (*Perca fluviatilis*) blood cortisol and lactate concentrations peaked at 30 minutes post stressor (Acerete et al. 2004). While many studies have found that PSR peaks after 1-hour (Pottinger 1998; Arends et al. 1999; Frisch and Anderson 2000; Suski et al. 2007). Bracewell et al. (2004) found that chub (*Leuciscus cephalus*) PSR (glucose and lactate) peaked at 120 minutes and Girard and Milligan (1992) found that winter flounder (*Pseudopleuronectes americanus*) lactate peaked between 120-240 minutes.

Understanding the time course can also help understand the recovery of a fish after C&R and is essential for accurate interpretation of post-release movement behaviour. Recovery times vary among species, common dentex (*Dentex dentex*) took eight hours to recover after handling (Morales et al. 2005) while some fish take 12 hours to recover fully (Soivio and Oikari 1976; Milligan and Wood 1986) (see Appendix 2). Recovery time can take as long as 24 hours, which was observed in common carp (*Cyprinus carpio*) (Pottinger 1998). Thus, species-specific research on the time course of the PSR is important when evaluating the response of a species to C&R.

Argyrosomus japonicus is an important and highly targeted species in the South African estuarine and coastal fisheries (Baird et al. 1996). Given the move towards C&R as an alternative management approach, it is critical to understand the effects of C&R angling on the PSR and mortality of this species. Indeed, Reynolds (2018) found that C&R angling can cause severe hooking injury and mortality in Australian Mulloway (*A. japonicus*), thus *A. japonicus* caught in South African estuaries are likely vulnerable to C&R mortality. However, despite its popularity in almost all fishing sectors, its importance as a top predator and its high vulnerability to overfishing (Childs et al. 2015, Cowley et al. 2008, Griffiths 1997a), little research has been done on the PSR of *A. japonicus* to a C&R event.

The aim of this study was to determine the time course and peak of the PSR of *A. japonicus* following a simulated C&R event. The objectives of our study were to measure the primary and secondary stress response by assessing plasma cortisol (primary), blood lactate (secondary) and blood glucose (secondary) concentrations over time following a simulated C&R angling event. We hypothesized that plasma cortisol, blood lactate and blood glucose concentrations would change over time and that the peak PSR would occur after a delay.

3.2. MATERIALS AND METHODS

This research was approved by the Rhodes University Ethics Committee - SCI2018/046 and DIFS2018

3.2.1 Collection Methods

Collection of *A. japonicus* took place from 8 September to 12 October 2018. Fish were captured from the Kowie Estuary (33°36'08.5"S 26°54'01.2"E) (See Figure 2.1) using conventional estuarine angling tackle, graphite rods ranging from 1.8–2.0 m in length, fixed spool reels loaded with nylon or braided lines (4.5–10.0 kg breaking strain) and multiple sizes of barbed J and circle hooks were used. Upon hooking and landing, the fight time and air exposure for each individual was recorded. Fish were transported in a 1000L aerated tank from the place of capture to the DIFS Port Alfred marine laboratory where they were evenly distributed (n = 3 fish per tank) into 18, 500 L tanks, with recirculating oxygenated seawater maintained at ambient sea temperature. Fish were left to acclimatize in the tanks for a minimum of two weeks. During acclimatization fish were fed on a diet of squid (*Loligo reynaudii*).

3.2.2 Experimental procedure

After the period of acclimatization, fish were starved for 48 hours prior to the experiment. The experiment included five time treatments; 0, 30, 60 90 and 150 minutes (n = 9 fish per treatment), each treatment consisted of three replicates with three fish per replicate. All fish were exposed to a simulated C&R event. This involved chasing the fish in their tanks manually by hand (Raby et al. 2018, Pringle et al. in press) for 45s (chase time was based on the average fight time recorded during the collection of the fish). Fish were then captured using silicone mesh landing nets (capture time was recorded using stop watches) and exposed to 75s air exposure while being held in the nets (air exposure time was based on angler observation average, see Chapter 2) (See Figure 3.1). Following the simulated C&R event fish were placed back in their tanks. After the appropriate delay, either 0, 30, 60, 90 or 150 minutes, all three fish from each tank were re-captured using silicone mesh landing nets and placed upside down in foam padded cradles with a wet microfiber cloth covering their head (See Figure 3.1). Non-lethal blood samples (1.0 - 2.0 ml) were taken using 21G hypodermic needles and 5ml syringes from the caudal vasculature within 170 seconds of capture as per the recommendation of Lawrence et al. (2018). Blood glucose (mmol l -1, Accu-Chek Instant, Roche Diagnostics, Basel, Switzerland) and blood lactate (mmol l-1, Lactate-Pro 2, Arkray Inc., Kyoto, Japan) concentrations were measured using point of contact devices (Cooke et al. 2008). The remaining blood (~ 1.0-2.0 ml) was injected into heparinised tubes to prevent clotting, it was then drawn into 1.5 ml Eppendorf tubes and centrifuged at 13.3 min-1 / 17.0 x 1000 g for 20 minutes (Heraeus Pico 17 Centrifuge, Thermo Electron Corporation, Waltham, Massachusetts) to separate blood plasma from the red blood cells. The blood plasma was pippeted into 0.5 ml Eppendorf tubes and placed into a cooler box covered in ice. The plasma Eppendorfs were transported back to Rhodes University in Grahamstown and placed into a -40°C freezer before further analysis.

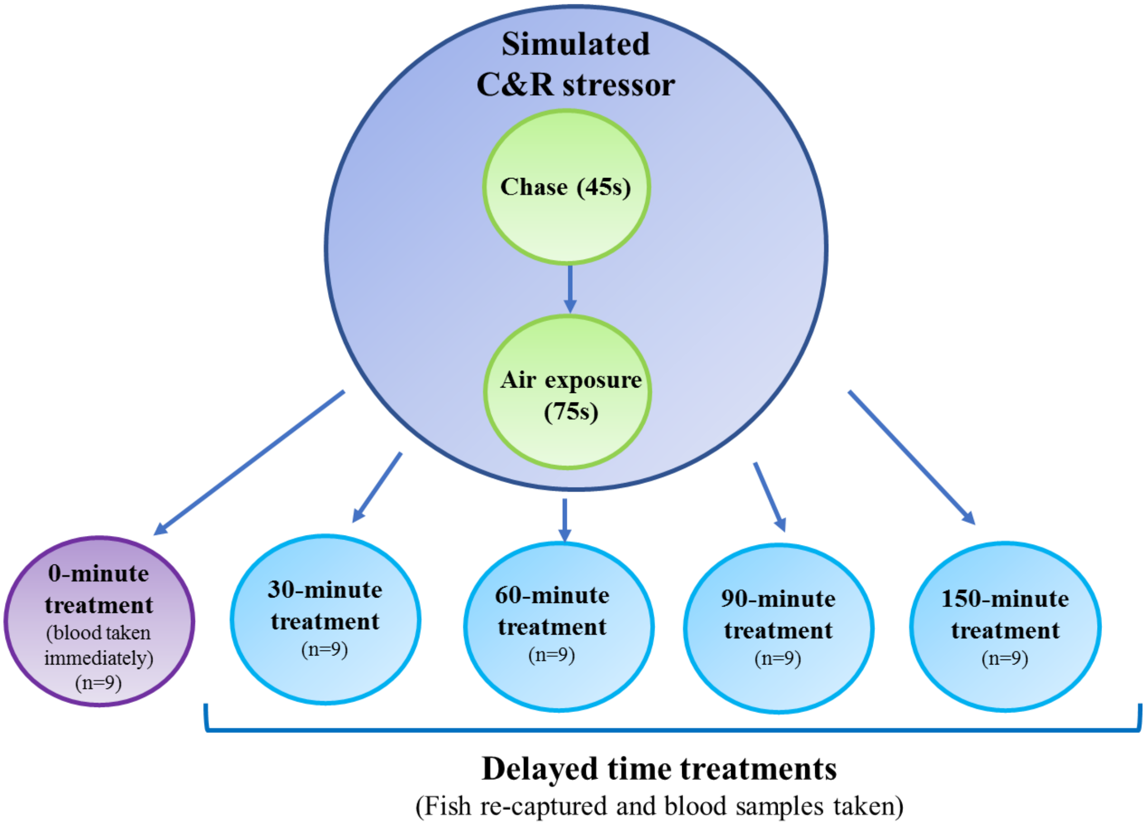

Figure 3.1: Diagram illustrating the experimental procedure

Plasma cortisol was analysed using an ELISA (Enzyme-linked immunosorbent assay) cortisol kit (Demeditec diagnostics GmbH, Kiel, Germany) (Velasco-Santamaria and Cruz-Casallas 2007). Absorbance was measured at 450 nm using a 96 well plate reader (SpectraMax ® M3, Molecular Devices, LLC, San Jose, California, United States of America). The function was calculated using a non-linear 4 parameter logistics curve fit, and the function and absorbances were used to calculate concentrations using the following equation:

$$x = c\left(\frac{a-d}{y-d} - 1\right)^{\frac{1}{b}}$$

where *x* is the cortisol concentration and *y* is the absorbance.

Water temperature, salinity, pH and dissolved oxygen were measured (AL15, Aqualytic GmBH & Co, Dortmund, Germany) in every tank after the experiment.

3.2.3 Statistical analysis

A one-way analysis of variants (ANOVA) test was conducted to determine if there was a significant difference in fish size, capture time and water quality parameters among the five treatments. The data was analysed using a Grubb's test, and outliers were removed. Blood glucose (mmol-1), blood lactate (mmol-1) and plasma cortisol concentrations were modelled as a function of time using a Generalized Additive Mixed Model (GAMM) using the mgcv package (Wood 2011) in R (version 1.1.453, R Core Team 2017). Time was included to each base model as a smoothing spline, and a random intercept for tank ID was included to account for the potential confounding effect of tank. The PSR was determined as the maximum height between the smoothing spline and the time recorded on the x-axis. Model assumptions for normality of residuals was checked using diagnostic plots, and the acf function was used to check for significant autocorrelation.

3.3. RESULTS

3.3.1 General statistics

The mean water temperature during the experiment was 21.31 ^{o}C (SD 0.53). The mean dissolved oxygen was 8.48 mg l^{-1} (SD 0.8), mean conductivity was 54.04 (SD 0.47) and pH ranged from

8.18 to 8.37. There was no significant difference among the five time treatments for water temperature (F $_{4,12)}$ = 1.32, p =0.31), conductivity (F $_{(4,13)}$ =0.29, p = 0.87), and dissolved oxygen (F $_{(4,13)}$ = 0.19, p = 0.93).

The average size of fish used in this study was 410.20 mm FL (SD 65.47), range: 285–530 mm, Table 3.1). There was no significant difference in the size of fish used in each time treatment (F $_{(4,40)}$ = 0.84, p = 0.51). The average time to capture fish from the tanks, across all treatments, was 213.13 s (SD 94.80, range: 80–386 s, Table 3.1). There was no significant difference in the catch time of fish among time treatments (F $_{(4,40)}$ = 1.85, p = 0.13).

Table 3.1: Mean fish length and capture time for dusky kob *Argyrosomus japonicus* exposed to a simulated catch-and-release angling event with blood extracted 0, 30, 60, 90 and 150 minutes after the stressor

		General statistics			
Treatment (minutes)	N	Fish length (mm)		Capture time (s)	
		Mean (SD)	Range	Mean (SD)	Range
0	9	429.33 (93.60)	285 – 530	173.66 (136.76)	80 – 356
30	9	397.77 (58.70)	340 – 500	163.66 (50.55)	112 – 227
60	9	423.33 (44.70)	350 – 470	240 (47.91)	191 – 300
90	9	419.44 (65.30)	330 – 520	219.66 (125.32)	116 – 385
150	9	381.11 (57.10)	290 – 500	268.66 (91.27)	182 – 386

3.3.2 Blood chemistry

Mean plasma cortisol concentrations among the five time treatments ranged from 94.92 ng.ml^{-1} (SD 69.38) to 338.47 ng.ml^{-1} (SD 83.15). Maximum plasma cortisol concentrations were recorded during the 30-minute time treatment with a mean of 338.47 ng.ml^{-1} (SD 83.15) (Table 3.2). However, there was a no significant effect of time on plasma cortisol concentrations ($p > 0.05$) (Table 3.3) (Figure 3.2c).

Mean blood glucose concentrations among the five time treatments ranged from 2.40 mmol.l^{-1} (SD 0.42) to 8.33 mmol.l^{-1} (SD 4.01). Maximum blood glucose concentrations were recorded during the 30-minute time treatment with a mean of 8.33 mmol.l^{-1} (SD 4.01) (Table 3.2). There was a significant effect of time on blood glucose concentrations ($p < 0.05$) (Table 3.3), the model predicted that glucose would peak between 30 and 40 minutes (Figure 3.2b)

Mean blood lactate concentrations among the five time treatments ranged from 2.27 mmol.l^{-1} (SD 1.61) to 7.46 mmol.l^{-1} (SD 3.60). Maximum blood lactate concentrations were recorded during the 30-minute time treatment with a mean of 7.46 mmol.l^{-1} (SD 3.60) (Table 3.2). There was also a significant effect of time on blood lactate concentrations ($p < 0.05$) (Table 3.3), the model predicted that lactate would peak between 30 and 40 minutes (Figure 3.2a).

Table 3.2: Mean plasma cortisol, blood glucose and blood lactate levels for dusky kob *Argyrosomus japonicus* exposed to a simulated catch-and-release angling event with blood extracted 0, 30, 60, 90 and 150 minutes after the stressor

Treatment (minutes)	N	Plasma cortisol (ng.ml-1)	Blood glucose (mmol.l-1)	Blood lactate (mmol.l-1)
		Mean±SD (Range)	Mean±SD (Range)	Mean±SD (Range)
0	9	94.92±69.38 (5.90–254.80)	2.4±0.42 (1.90–3.30)	2.27±1.61 (0.60–5.30)
30	9	338.47±83.15 (67.30–913.10)	8.33±4.01 (4.90–14.60)	7.46±3.6 (2.0–12.80)
60	9	272.49±37.70 (80.50–630.10)	6.37±0.74 (2.50–10.20)	5.78±1.81 (1.60–12.20)
90	9	172.49±98.0 (39.70–481.30)	4.43±2.45 (3.10–10.90)	5.5±3.03 (0.50–10.40)
150	9	153.19±88.30 (14.70–541.20)	3.85±1.02 (2.70–5.50)	3.51±2.15 (0.90–7.0)

Table 3.3: Summary results of the General Additive Mixed Model (GAMM) showing the relationship between plasma cortisol, blood glucose and lactate concentrations and time for dusky kob *Argyrosomus japonicus* exposed to a simulated catch-and-release angling event with blood extracted 0, 30, 60, 90 and 150 minutes after the stressor

Blood chemistry parameters	Estimate	SE	Estimated degrees of freedom (edf) for the smoother	F-value	Significance of smoother (P-value)	Deviance explained (~R^{2})
Plasma cortisol	-	-	1.83	0.45	0.57	0.04
Intercept	200.90	35.36	-	-	-	-
Blood glucose	-	-	3.50	7.57	<0.002	0.37
Intercept	4.8	0.39	-	-	-	-
Blood lactate	-	-	3	4.28	0.01	0.22
Intercept	4.79	0.44	-	-	-	-

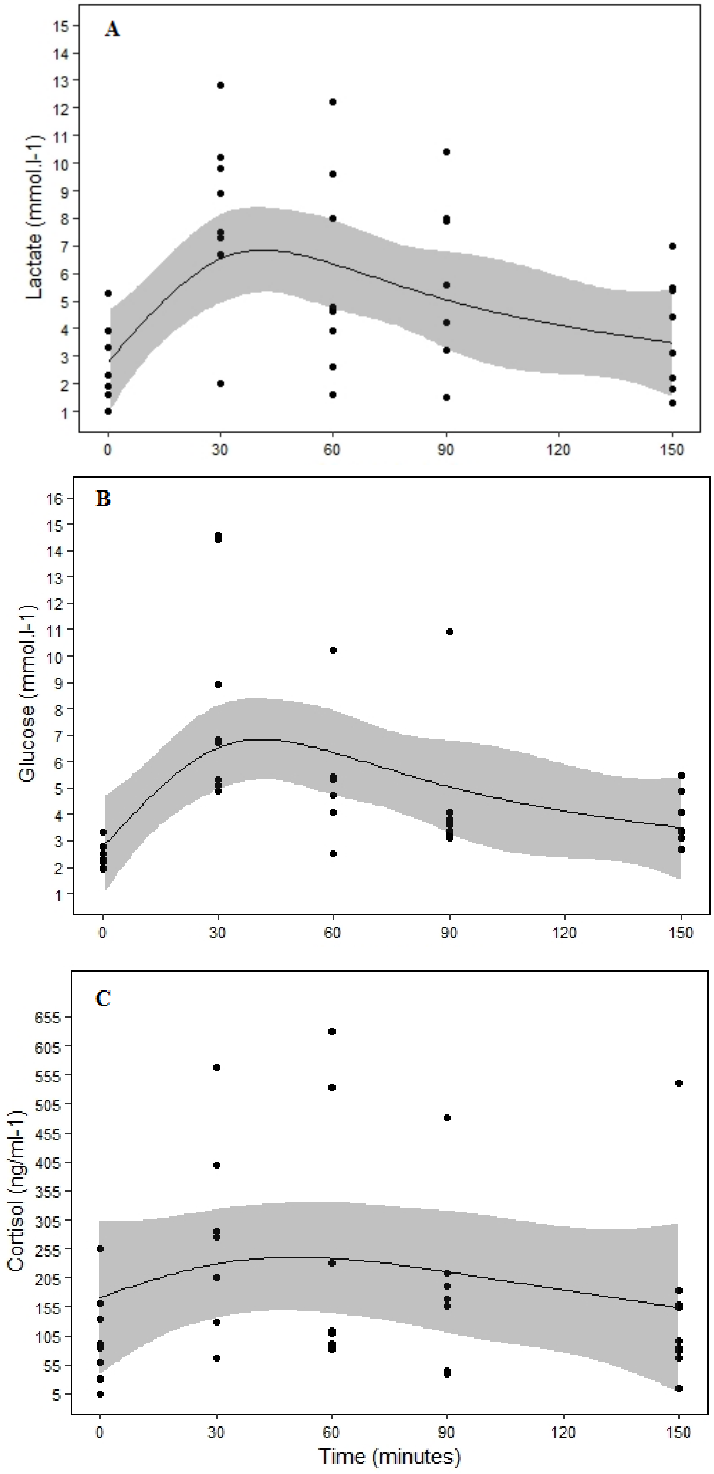

Figure 3.2: Blood lactate (a), blood glucose (b) and plasma cortisol (c) concentrations of dusky kob *Argyrosomus japonicus* exposed to a simulated catch-and-release angling event with blood extracted 0, 30, 60, 90 and 150 minutes after the stressor. A General Additive Mixed Model (GAMM) was used, where the solid line is a smoothing spline and the shaded area is a point estimate 95% confidence interval.

3.4. DISCUSSION

Despite the growing importance of C&R angling and the vast amount of studies involving C&R, there is relatively little information on the time course of the PSR of wild, South African fish, which is essential to understand the effects and sustainability of C&R on South African fish stocks. This study provides a picture of the physiological stress response (PSR) of *A. japonicus* after a simulated C&R stressor. It was evident that even a simulated C&R event had a significant effect on the PSR. However, the peak PSR was delayed and the duration of the PSR was extended in this species.

The significant effect on the PSR was not surprising as C&R events are known to elicit profound physiological changes on fishes (Cooke et al. 2013). When compared with measurements from a field study in a competitive angling event based in the marine nearshore zone, the mean lactate concentrations for *A. japonicus* (5.72 [SD 4.42]) (Butler et al. 2017) were similar to the lactate levels observed in this study in the 60 and 90-minute time treatments (Table 2). However, as Butler et al. (2017) took blood samples immediately after the C&R event, this may suggest that the laboratory-simulated stressor may have been more benign than a true field C&R event. As the average fight time (67.70 ± 59.60 s) and air exposure (101.90 ± 64.30 s) for *A. japonicus* during the competition was longer than that used in this study, it is likely that the stress response would be higher. Indeed, Suski et al. (2007) found that extended air exposure and exercise resulted in significantly higher blood lactate concentrations.

The mean blood glucose concentration at the 0-minute time treatment (2.40 [SD 0.42]) was similar to the glucose concentrations for *A. japonicus* from the 2015 RASSPL national competition (2.25 [SD 0.75]) (Butler et al. 2017). This is not surprising as Butler et al (2017) took their blood samples immediately after the C&R event, thus the glucose levels would not have had time to reach their peak concentration. This illustrates the importance of measuring blood glucose at its peak concentration, as you will likely get a fuller picture of the effect of C&R on the PSR.

In an Australian study examining the hooking mortality of *A. japonicus*, Reynolds (2018) also found that a simulated C&R event elicited a stress response. However, the recorded blood glucose concentrations (approximately 1.7 – 2.7 mmol.l-1) and plasma cortisol concentrations (approximately 4 – 13 ng/ml-1) were much lower than those observed at the peak (30 minutes) in our study. This is not all together surprising as Reynolds (2018) took blood samples immediately following the stressor. Indeed the blood glucose concentrations observed by Reynolds are similar to the mean blood glucose concentrations (2.47 [SD 0.42] mmol.l-1) that was obtained when blood was taken immediately (0 minutes time treatment).

The results of our study align with those of other studies on teleost fish, which found that the peak PSR occurs after a delay (Girard and Milligan 1992; Lankford et al. 2003; Suski et al. 2007; Currey et al, 2013, see Appendix 2). The delay in reaching their peak is attributed to the build-up of stress hormones in the blood over time and because the secondary stress response is triggered by the primary stress response (Barton 2002; Martinez-Porchas et al. 2009; Wendelaar Bonga 2011). This results in a lag between the primary and secondary stress responses and a delayed peak. However, the secondary stress response does not always peak after the primary stress response. Indeed, some studies have found the secondary stress response peaks before the primary (Rotllant and Tort 1997; Arends et al. 1999). However, in this study, it appeared that cortisol did not peak, and that time did not have a significant effect on plasma cortisol concentrations. This is unusual as many other studies have found that cortisol concentrations change with time and reach a peak after a delay (Rotllant and Tort 1997; Arends et al. 1999; Rotllant et al. 2001). A potential reason for our result could be due to the high amount of individual variation we observed within time treatments, with the standard deviation in cortisol concentrations, in one case, being as high as 98.0 (Table 2). High individual variation in cortisol concentration is not uncommon. Indeed, after employing a similar stressor, Barton (2002) found that the plasma cortisol concentrations among individuals can range at least as much as two orders of magnitude. Another reason for the results could be due to the extended period of confinement stress that the fish experienced in the tanks. This stress may have raised their cortisol levels higher than normal, thus effecting the results and potentially masking the peak PSR (Vijayan et al. 1997).

When comparing the timing of the PSR, *A. japonicus* appeared to peak sooner than other species, as most peak 60 minutes post stressor (Biron and Benfey 1994; Pottinger 1998; Arends et al. 1999; Frisch and Anderson 2000; Suski et al. 2007) (see Appendix 2). Indeed, in a very similar study (to this MSc) on bronze bream (*Pachymetopon grande*), Pringle et al. (in press) found a peak in blood glucose levels after 75 minutes and a delayed peak (> 125 minutes) in the blood lactate levels. Many studies similarly used wild caught fish and a simulated C&R stressor, however the time at which the peak PSR occurred differed greatly between the different species used in these studies (see Appendix 2). Only one species, the Eurasian perch (*Perca fluviatilis*) showed a similar time course to *A. japonicus*, with blood cortisol and lactate concentrations peaking 30 minutes post stressor (Acerete et al. 2004). However, Acerete et al. (2004) used aquaculture fish in their study. Due to the nature of aquaculture, with frequent handling stress and disturbances, the results yielded from these fish may differ to wild fish.

While the peak PSR occurred earlier for *A. japonicus* than for many other species, there is no data on the time course of the PSR of other sciaenid's with which to compare our results (see Appendix 2). The findings of studies done on sparids, which are within the same superfamily (Percoidea) as *A. japonicus*, also do not align with our results, with peak PSR occurring 60 to 120 minutes post stressor (Rotllant and Tort 1997; Morales et al. 2005, Pringle et al. in press). As there are innate differences in the stress response of fish (Fevolden et al. 1993; Demers and Bayne 1997; Barton 2002) which will affect the time course of the PSR, this difference is not altogether unexpected. Regardless, the variation between this and other studies (Appendix 2), exemplifies the species- and context-specific nature of the time course of the PSR.

It appears that *A. japonicus* recovers relatively quickly after a C&R event, and when exposed to an average of 75 s air exposure. Indeed, besides declines in the means blood lactate and glucose concentrations after the peak, there was also a decline in the variability (SD) with the lowest and similar values observed in the 0-minute and 150-minute time treatments (Figure 3.2). These findings suggest that *A. japonicus* were almost fully recovered from the physiological stress induced by the simulated C&R event within 150 minutes. This rapid recovery is unusual as Kieffer (2000) suggested that it takes up to 12 hours for most fish to recover from a stress event. Indeed, recovery was considerably longer (up to 24 hours, Rotllant and Tort 1997; Pottinger 1998; Rotllant et al. 2003) in some studies (see Appendix 2). Therefore, when compared with other fishes, these findings may suggest that this species and possibly other Sciaenids may recover relatively quickly from the effects of a C&R event. A reason for this quick recovery could be due to the estuarine environment in which *A. japonicus* are adapted to live. Estuarine environments are characterised by rapid fluctuations in temperature, salinity and turbidity on a daily basis (Wallace et al. 1984). Thus, it is possible that *A. japonicus*, who are adapted to deal with these rapid fluctuations in their environment, may be better able to withstand, and recover quickly from, acute stressors, such as a C&R event. However, it must be acknowledged that true baseline values were not obtained in this study, thus it is possible that recovery time for *A. japonicus* is longer than 150 minutes.

Although *A. japonicus* showed a fast physiological recovery from C&R they still experience a PSR for more than 150 minutes after capture. Therefore, particularly within the first 30-40 minutes after capture, they will be highly vulnerable to predation, as stressed fish emit chemical cues into the water which attract predators (Arlinghaus et al. 2007; Jenkins et al. 2004; Dallas et al. 2010). Indeed, lemon shark (*Negaprion brevirostris*) have been found to detect olfactory cues released by fish after a C&R event (Dallas et al. 2010). In addition, fish that have been subjected to extended fight times and air exposure generally exhibit high blood lactate concentrations and are also more likely to have an impaired escape response and thus be susceptible to post-release mortality (Arlinghaus et al. 2007; Brownscombe et al. 2015; Arkert et al. 2018).

A potential limitation of our study is that the C&R event was simulated and likely less rigorous than a real-life C&R event as it did not involve hooking, had a non-conventional fight and relatively good handling practices. Therefore, it is possible that the nominal stress response is underrepresented and that the values presented in our study may be lower than would be experienced in a real-life C&R scenario. Nevertheless, the chase and air exposure represent the main stressors experienced during a C&R event and the results of our study did fulfil our aim, which was to determine when the peak PSR of *A. japonicus* occurs. Also, true baseline values were likely not obtained in this study as fish were subjected to a C&R stressor before blood sampling took place and handling is likely to have caused immediate stress (Lawrence et al. 2018). The holding period in the tanks likely also caused confinement stress, which would have affected baseline values. Therefore, having a control group, which was not subjected to a C&R scenario, may have given more insight into the change of the stress response between baseline and peak physiological stress. However, true control (with no stress) is not likely and careful thought should be placed into how to treat the control fish in such an experiment.

It is expected that baseline plasma cortisol levels will range between 2 and 30 ng ml-1 for both wild and captive fishes (Barton 2002, Pankhurst 2011; Lawrence et al. 2018). However, in our 0-minute time treatment we observed plasma cortisol concentrations ranging between 5.9 and 254.8 ng ml-1, which far exceeds the expected range. The range we recorded in elevated plasma cortisol levels (e.g. 67.30 to 913.10 ng ml-1) also exceeded the expected levels of 40 to 600 ng ml-1 (Suski et al. 2003; Cook et al. 2012; Pullen et al. 2017; Lawrence et al. 2018). This high variability in cortisol levels highlight another caveat of the study, which was a low sample size, and is likely the reason we did not observe clear patterns in plasma cortisol concentrations. To reduce the bias of inter-individual variability, it is recommended that future PSR studies on this species maintain a larger sample size.

In conclusion, the findings of this study, give insight into the physiological effects of C&R on *A. japonicus*. The findings suggest that the PSR is significant even during a simulated C&R event in the laboratory and thus provides motivation for a field-based study. Based on these findings, the true PSR in the field should be measured 30−40 minutes after the C&R event (see Chapter 4). Finally, the results suggest that from a physiological perspective, this species may be able to recover quickly, when compared to other estuarine and marine species, from the stressors associated with C&R.

CHAPTER 4

Consequences of catch-and-release angling on the reflex impairment, physiology and short-term survival of Argyrosomus japonicus in an estuarine environment

4.1. INTRODUCTION

Recreational fishing is a hugely popular pastime the world over, with Cooke and Cowx (2004) suggesting that global recreational catch could be as high as 47.1 billion fish per year. Although global overfishing is largely blamed on commercial fisheries, the potential of recreational fisheries to deplete fish populations was recognized as early as the Middle Ages in Europe, as indicated by the implementation of size limits and other harvest limiting rules (Policansky 2002). In response, anglers began adopting catch and release (C&R) behaviour initially only due to minimum size limits and other harvest limiting laws, however as it grew in popularity conservation-conscious anglers began voluntarily releasing their catch. It has been estimated that more than half of global recreationally caught fish are released Cooke and Cowx (2004) and it is thought that the popularity of C&R is based mainly on the belief that a released fish will live to be caught another day. However, it has been found that post-release mortalities can be high for some species (Bartholomew and Bohnsack 2005; Suski et al. 2007; Danylchuk et al. 2014; Bower et al. 2016; Arkert et al 2018).

Fishes are subjected to considerable stress during a catch and release event and their fate is dependent on a range of different factors. These include biotic factors, such as environmental conditions (e.g. water temperature and quality) and ecological conditions (e.g. predator density) (Brownscombe et al. 2017), and the behaviour of anglers (e.g. gear choice and handling practices) (Brownscombe et al. 2017). These behaviours can affect the health and potential survival of a fish in a number of ways, for example, the choice of hook type is known to have an impact on hooking injury (Prince et al. 2002) and this is often the leading cause of mortality in C&R (e.g. Muoneke and Childress 1994; Prince et al. 2002; Arkert et al. 2018) as fish are often hooked in sensitive areas (near the heart or in the gills). The choice of angling gear is related to the fight time, with extended fights leading to exhaustion, reflex impairment and blood acidosis (Wood et al. 1983; Suski et al. 2007; Danylchuck et al. 2014; Butler et al 2017) and these may increase the vulnerability of fishes to predation (Raby et al. 2014). The behaviour of anglers between landing and releasing a fish determines their exposure to air. Increased air exposure has led to reflex impairment (Butler et al. 2017; Arkert et al. 2018) and has been identified as a cause of increased C&R mortality in several studies (e.g. Schreer et al 2005; Arlinghaus and Hallermann 2007; Suski et al. 2007; Brownscombe et al 2013; Bower et al 2016; Arkert et al. 2018) (see Appendix 1). Although this has been attributed to the physiological impacts associated with hypoxia (Pollock et al. 2007), there appears to be a species-specific threshold where the impacts of air exposure are negligible. For example, Schreer et al. (2005) found that brook trout (*Salvelinus fontinalis*) could withstand air exposures time of up to 60s with little physiological and physical impairment. Therefore, knowing the air exposure threshold of fish has important implications for implementing appropriate management strategies to minimise the effects of C&R.

Research on the effects of C&R has gained increasing popularity over the past decade and studies have been conducted on a range of different species in different environments (see Appendix 2), for example; peacock bass (*Cichla ocellaris*) (Bower et al. 2016), largemouth bass (*Micropterus salmoides*) (Brownscombe et al. 2014), smallmouth yellowfish (*Labeobarbus aeneus*) (Smit et al. 2016) and bluegill (*Lepomis macrochirus*) (Gingerich et al. 2007) in freshwater environments; bonefish (*Albula vulpes*) (Danylchuck et al. 2007; Suski et al. 2007; Cooke and Philipp 2004) in marine nearshore environments; atlantic cod (*Gadus morhua*) (Ferter et al. 2015) in marine offshore environments and fat snook (*Centropomus parallelus*) (Lennox et al 2015) and Cape stumpnose (*Rhabdosargus holubi*) (Arkert et al. 2018) in estuarine environments. Each species responded differently to C&R, for example; Bower et al. (2016) reported a post-release mortality rate of 5% for peacock bass, while Cooke and Philipp (2004) reported 0% mortality for angled bonefish in low predation areas (see Appendix 2).

The fate of a released fish is primarily dependent on angler behaviour, such as gear choice and handling practices (Twardek et al. 2019). Anglers that are unprepared for C&R will often increase the stress and mortality experienced by released fish (Brownscombe et al. 2017). This unpreparedness is often a result of a lack of awareness of the drivers of increased C&R mortality and poor knowledge on the best handling practices. Therefore, creating awareness on the best tools and techniques of C&R angling will allow anglers to mitigate the harmful effects of C&R and improve fish health. However, the optimal practices and thus strategies for preparedness are dependent on the target species and the habitat where the angling occurs. For example, species captured from deep water off a boat will experience different stressors (e.g. barotrauma) (Kerwath et al. 2013) than those captured from shallow water from the shore (Butler et al. 2017), and thus will require different handling practices to improve fish health. The predator density of a certain habitat can also influence post-release mortality caused by predation (Cooke and Philipp 2004). Therefore, when developing knowledge on best handling practice, it is necessary to provide best practice guidelines for habitat specific responses to C&R angling. The importance of understanding the effects of C&R for specific species in different environments is thus critical for the development of best practice guidelines and the sustainability of C&R angling.

The environment in which C&R takes place has been shown to affect the outcome of the C&R event (e.g. Danylchuck et al. 2007; Suski et al. 2007; Brownscombe et al. 2014; Bower et al. 2016;

Butler et al 2017), however, comparatively little research has been done on estuarine environments and only one study has been conducted in an estuary in South Africa (Arkert et al. 2018). Unlike temporarily open-closed estuaries (TOCE), permanently open estuaries represent unique aquatic environments with rapidly fluctuating environmental conditions such as temperature, salinity and turbidity (Wallace et al. 1984; Whitfield 2019). Fishes either respond to the rapid environmental fluctuations through behavioural adaptations, such as movement (e.g. Childs et al. 2008; Næsje et al. 2012) or through physiological adaptation (e.g. Huey and Bennet 1990). However, since C&R is known to result in motor impairment (e.g. Bower et al. 2016; Arkert et al. 2018) and negatively impact physiological processes (e.g. Butler et al. 2017, Chapter 3), it is likely that the response of fishes to release in estuaries may be different to more stable environments.

South African estuaries are subjected to high fishing pressures (e.g. 30 952 and 63 785 angler-hour per year on the Kowie and Sundays estuaries, respectively, [Cowley et al. 2004, 2013]) and the stocks of many estuarine dependent species are overexploited (Griffiths 2000, Whitfield and Cowley 2010). Many popular recreational angling species such as spotted grunter (*Pomadasys commersonnii*) and dusky kob (*Argyrosomus japonicus*) utilize estuaries as nursery grounds (Cowley et al 2013; Whitfield 2019). This nursery function means that many estuarine dependent fishes are particularly vulnerable to growth overfishing, as large proportions of fish caught in estuaries are undersized (e.g. 90% on the west coast) (Whitfield and Cowley 2010).

There are multiple methods to assess the health and survival of a fish after a C&R event, most studies monitor the reflex impairment, physiological stress, behavioural response and post-release mortality of a fish (Bartholomew and Bohnsack 2005; Arlinghaus et al. 2007; Lennox et al. 2015; Bower et al. 2016). Monitoring the reflex impairment of a captured fish, such as the presence of a startle response or the ability of a fish to regain equilibrium, is a useful tool in C&R science because it is non-invasive and easy to perform. Reflex impairment is also a reliable predictor of post-release mortality and gives a good picture of the general health of the animal after capture (Davis 2010).

Examining the physiological stress response by collecting and analysing blood samples is also a popular method for evaluating the effects of C&R. It is known that extended air exposure, handling, exhaustion and confinement can increase the blood concentrations of cortisol (primary stress response), lactate and glucose (secondary stress response) (Arends et al. 1999; Kieffer 2000). While cortisol is a reliable indicator of the primary stress response, it is expensive and difficult to examine in the field. Therefore, many studies prefer to examine the secondary stress response (lactate and glucose) as they are cheap and easy to study in the field using point-of-care devices (Bower et al. 2016; Pinder et al. 2019). Studies have also examined other physiological alterations associated with stress response, such as haemoglobin characteristics or ionic and acid-base status (Cooke et al. 2013). Regardless of the indicators, the time at which blood samples are taken must be optimized, because, as we have shown in Chapter 3, the peak physiological disturbance only occurs after a delay.

Measuring post-release mortality in a C&R study is important as it reveals the hidden mortality caused by C&R, which is often not taken into account when managing recreational fish stocks such as *A. japonicus*. Post-release mortality is often monitored by placing angled fish into a recovery tank/pen for a defined period of time (usually 12-48 hours) and recording the deaths that occur (Lennox et al. 2015; Butler et al. 2017; Arkert et al 2018). This method is favoured due to its ease and inexpensiveness; however, two drawbacks are, its inability to take into account post-release predation (Raby et al. 2014) and the confinement stress it may cause. In order to account for post-release predation some studies (e.g. Danylchuk et al. 2014, McLean et al. 2019) have used biotelemetry to track fish after release. While this method is effective it is cost prohibitive and thus not feasible for many studies.

Argyrosomus japonicus are an important and valuable species in both the subsistence and recreational fishing sectors. They dominate the catch by weight and represent a very important source of food for subsistence fishers (Cowley et al. 2004). *Argyrosomus japonicus* populations have been severely depleted over the decades and in their recent study Mirimim et al. (2015) found signs of genetic bottlenecking and low and declining trends of effective population size. *Argyrosomus japonicus* are also particularly vulnerable to growth overfishing due to their use of estuaries as nursery grounds. Many *A. japonicus* angled from this environment are immature (size limit of 1100 mm) and below the legal-size limit. For example, Cowley et al. (2004) found that almost 50% of *A. japonicus* caught in the Great Fish Estuary were below the legal-size limit. This means that mandatory release is required in many cases. However, Childs et al. (2015) also reported high rates of recapture in estuaries for *A. japonicus* (see Chapter 1), highlighting the increased vulnerability of this species to injury and mortality caused by C&R in estuaries. The high recapture rate in this study, however, also indicate that *A. japonicus* can be resilient to C&R when handled optimally, as was done during acoustic-tagging by Childs et al. (2015). Despite their value in both recreational and subsistence sectors and their vulnerability, no research has been done on the effect of C&R on *A. japonicus* in South African estuaries.

The aim of this study was to examine the effects of recreational rod-and-line C&R angling on the health and survival of *A. japonicus.* In order to do this, we used information obtained from previous chapters (Chapter 2) to design the C&R event (Figure 1.1) and examined the reflex impairment, peak physiological stress response (based on the findings of Chapter 3) and short-term survival of angled fish. We hypothesized that angling, severe hooking injury and extended air exposure would have a significant negative effect on the reflex impairment, physiological stress response and short-term survival of angled fish. The results of this study will contribute to the management and protection of this important fishery species by informing best practice handling guidelines for this species and providing estimates of ‘hidden’ mortality caused by C&R to be incorporated into stock assessment and management.

4.2. MATERIAL AND METHODS

4.2.1 Study site

The study took place on the Great Fish Estuary (GFE) which is situated approximately 28 km east of Port Alfred in the Eastern Cape, South Africa (33°28'53.8"S 27°06'29.9"E). The GFE is a 15-km long, permanently open estuary and is relatively shallow (1-2 m depth) and wide (30-200 m width) (James and Harrison 2010; Cowley and Daniel 2001). Water temperature in the lower reaches of the estuary range seasonally between 13 and 21^{o}C and between 11 and 26^{o}C in the upper reaches, (Allanson and Read 1987). There is a high level of freshwater input into the estuary with oligohaline conditions often extending into the lower reaches and a strong vertical salinity gradient (of up to 20 ppm) between the lower and middle reaches (James and Harrison 2010; Cowley et al. 2004). The GFE is located in a rural area, and is subject to relatively high fishing pressure, predominantly from the subsistence sector (59%), but also from the recreational sector (Cowley et al. 2004, Potts et al. 2005).

4.2.2 Research approach

Sampling was conducted on three angler outings in February (15th), March (7 to 9th) and April (3rd) 2019. Water temperature (^{o}C), salinity and dissolved oxygen (mg/l) was recorded (AL15, Aqualytic GmBH & Co, Dortmund, Germany) on each tide (high, low, incoming or outgoing). Angling took place from boats on the estuary. Fish were captured using traditional estuary fishing tackle, graphite rods ranging from 1.8–2.0 m in length, fixed spool reels loaded with nylon or braided lines (4.5–10.0 kg breaking strain) and multiple sizes of barbed J and circle hooks were used. Sand prawn (*Callichirus kraussi*), mud prawn (*Upogebia africana*) and pilchards (*Sardinops sagax*) were used as bait during the experiment as this is the conventional method for catching *A. japonicus*. When a fish was hooked, fight time (time from hooking to landing) was recorded using stop watches, once landed fish were held using bare hands to simulate a real-life angling event and were exposed to one of three air exposure treatments; 10 s, 75 s or 240 s. The time of air exposure was based on the minimum, average and maximum air exposure times observed for estuarine anglers (see Chapter 2). During air exposure, the fish were measured, the location of hooking was recorded, and the hook was removed. Fish were then placed into a black plastic container (100 cm x 50 cm x 40 cm) containing fresh estuary water and a reflex action mortality predictor (RAMP) test was performed (Davis 2010). The reflex indicators were; 'tail grab' (the ability of a fish to employ burst swimming action when its tail is grabbed), 'body flex' (the ability of the fish to flex its torso when held flat on your hand out of the water), 'head complex' (the presence of steady opercular beats) and 'equilibrium' (the ability of the fish to right itself after being flipped upside-down). These indicators were previously validated by Raby et al. (2012) and Arkert et al. (2018). In order to generate RAMP score, a binary system was employed, where a score of zero was given if the reflex was present and a score of one if the reflex was absent.

Fish were transported to the shore where they were housed in black plastic containers (100 cm x 50 cm x 40 cm) for 30-40 minutes (based on the time delay results from Chapter 3) after the C&R event. Non-lethal blood samples (< 1 ml) were taken from the caudal vasculature of all fish (n =

68) and blood lactate (mmol.l-1, Lactate-Pro 2, Arkray Inc., Kyoto, Japan) and glucose (mmol.l-1, Accu-Chek Instant, Roche Diagnostics, Basel, Switzerland) concentrations were measured using point-of-contact devices. Blood samples were taken within 120 s, as per the recommendations of Lawrence et al. (2018). Blood samples that took longer than 120 to extract were excluded from the analysis (n = 5).

After blood samples were taken, fish were placed into one of three survival tanks (diameter 220 cm, depth 90 cm, volume 3 425 l), corresponding to air exposure treatment, that were located on the banks of the estuary. Water was pumped into the tanks with a BVP5000 submersible water pump (Leader Pumps, Italy), powered by a 6 kVA petrol generator at a flow rate of 3 450 l/h (> 1 replacement per hour). Fish were maintained in these tanks for between 12 and 36 hours and dead fish were removed, measured and examined for injury. After the experiment, the tanks were drained, and the surviving fish were released back into the estuary.

4.2.3 Statistical analysis

A one-way ANOVA and Tukey HSD post hoc test was conducted to determine if there was a significant difference in fish size, fight time and duration of blood taking among the three air exposure treatments. Blood chemistry was tested using a one-way ANOVA and Tukey HSD post hoc test to determine if there was a significant effect of air exposure time on blood glucose and lactate concentrations. As RAMP score is an ordinal categorical multinomial response variable (Agresti 2002), an ordinal regression cumulative link model was used to determine if there was a significant effect of air exposure time on reflex impairment of fish, using the *clm* function in the '*ordinal*' package in R (Christensen 2015). Model assumptions of normality and homogeneity of variance were tested using Shapiro-Wilk and Levene tests, respectively, and if assumptions were not met, non-parametric analyses were conducted. All data was analysed using STATISTICA 12 (StatSoft Inc.) or in R (version 1.1.453, R Core Team 2017).

4.3. RESULTS

Weather patterns over sampling days ranged from partly cloudy with wind to heavy rains with air temperature ranging between 18 and 25^oC and water temperatures ranged from 20.5 to 23.3^oC. Most fish were caught on the outgoing tide (56.4%), while 37.0% were caught on the incoming tide and 3.2% were caught at high and low tide. Water temperature in the survival tanks ranged from 20.2 to 25.6^oC, the salinity ranged from 15 to 35 ppm and dissolved oxygen ranged between 14.3 and 21.3 mg/l.

4.3.1 General statistics

The average size of fish caught in this study was 283 mm FL (SD 75.9, range: 190–645 mm, Table 4.1) and there was no significant difference in the size of fish caught between the three air exposure treatments ($F_{(2,63)} = 0.12$, $p = 0.31$). The average fight time was 28.46 s (SD 31.36, range: 8–240 s, Table 4.1) and this was not significantly different between the treatments ($F_{(2,64)} = 2.37$, $p = 0.10$). The average time taken to extract blood from the fish was 47.03 s (SD 25.02, range: 15–120 s) (Table 4.1) and this was not significant different between treatments ($F_{(2,58)} = 0.89$, $p = 0.41$). The majority of fish were hooked in the corner of their mouths (36.6%), while 28.3% swallowed the hook, 20.0% were hooked in their upper lip and 8.3% were hooked in their lower lip and 5.0% were foul hooked. Two thirds of the hooks that were swallowed were J- type and the remaining third were circle-type hooks.

Table 4.1: Mean fish length, fight time and duration of blood taking for dusky kob *Argyrosomus japonicus* exposed to a catch-and-release angling event and air exposure treatments (10s, 75s, 240s)

General statistics							
Air exposure treatment (s)	n	Fish length (mm)		Fight time (s)		Blood time (s)	
		Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
10	24	275.86 (56.98)	210 – 440	19.37(12.66)	8 – 60	53.30 (20.60)	30 – 100
75	21	270.90 (48.78)	210 – 435	24.66 (16.87)	9 – 60	45 (25.10)	15 – 90
240	23	303.59 (107.33)	190 – 645	42 (48.40)	10 – 240	43.20 (28.40)	18 – 120

4.3.2 Blood Chemistry

Blood extraction was successful (within the 120 s window) for 62 fish. The mean blood glucose concentration in the 240 s treatment (5.46 mmolml-1 [SD 1.58]) was significantly higher than the 75 s (4.3 mmolml-1 [SD 1.2], $F_{(2,55)} = 6.60$; $p = 0.02$) and 10 s (4.02 mmolml-1 [SD 0.97], $p = 0.004$) treatments (Table 4.2, Figure 4.1). There was no significant difference in the mean glucose concentration between 10 s and 75 s ($p = 0.79$) (Figure 4.1).

Mean blood lactate concentration in the 240 s treatment (8.25 mmolml-1 [SD 4.6]) was significantly higher than 10 s (4.61 mmolml-1 [SD 2.91], $F_{(2,59)} = 4.52$; $p = 0.02$) (Table 4.2, Figure 4.1), however it was not significantly different from the 75 s (7.68 mmolml-1 [SD 4.66], $p = 0.89$) (Table 4.2, Figure 4.1). There was no significant difference between 10 s and 75 s treatment ($p = 0.05$) (Table 4.2).

Table 4.2: Mean blood glucose and lactate concentration of dusky kob *Argyrosomus japonicus*, after being subjected to different air exposure treatments (10, 75 and 240 seconds), after a catch and release event

		Blood Chemistry			
		Blood glucose (mmol.1-1)		Blood lactate (mmol.1-1)	
Treatment	N	Mean (SD)	Range	Mean (SD)	Range
10	20	4.02 (0.97)	2.10 – 5.0	4.61 (2.91)	2.20 – 12.80
75	21	4.30 (1.21)	1.80 – 6.40	7.68 (4.66)	2.70 – 20.30
240	21	5.46 (1.58)	2.10 – 8.20	8.25 (4.60)	2.10 – 21.60

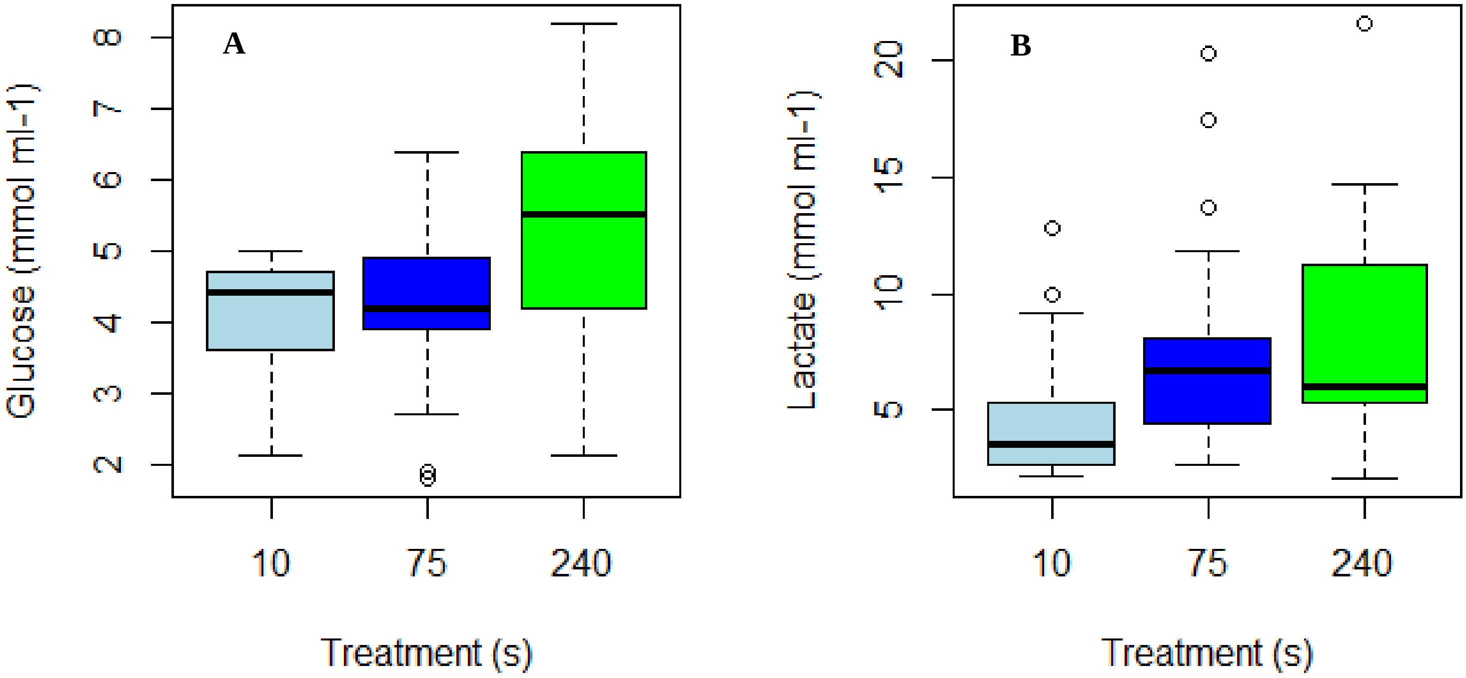

Figure 4.1: Mean blood glucose (A) and lactate (B) concentration of dusky kob *Argyrosomus japonicus* after being subjected to different air exposure treatments (10, 75 and 240 seconds) after a catch and release event. Error bars denote standard deviation

4.3.3 Rapid assessment mortality predictor (RAMP)

Reflex impairment was observed for 41.6% (*n* = 10) of the individuals in the 10 s treatment, 52.3% (*n* = 11) in the 75 s and 69.5% (*n* = 16) in the 240 s treatments (Table 4.3). Fish in the 240 s (mean RAMP score: 0.3 [SD 0.29]) (Figure 4.2) treatment were significantly more impaired than fish in the 10 s (mean RAMP score: 0.10 [SD 0.13]) (Figure 4.2) treatment ($p < 0.01$)(Table 4.4), and there was no significant difference in reflex impairment between 240 s and 75 s (mean RAMP score: 0.19 [SD 0.25]) (Figure 4.2) ($p = 0.30$) (Table 4.4) or between the 10 s and 75 s treatments (Figure 4.2) (Table 4.4). Body flex was the most sensitive of the RAMP indicators, with 50.0% of individuals not responding to this indicator, tail grab was the next most sensitive indicator with 13.4% of individuals impaired, followed by equilibrium (11.8% fish impaired) and head complex (4.5% fish impaired).

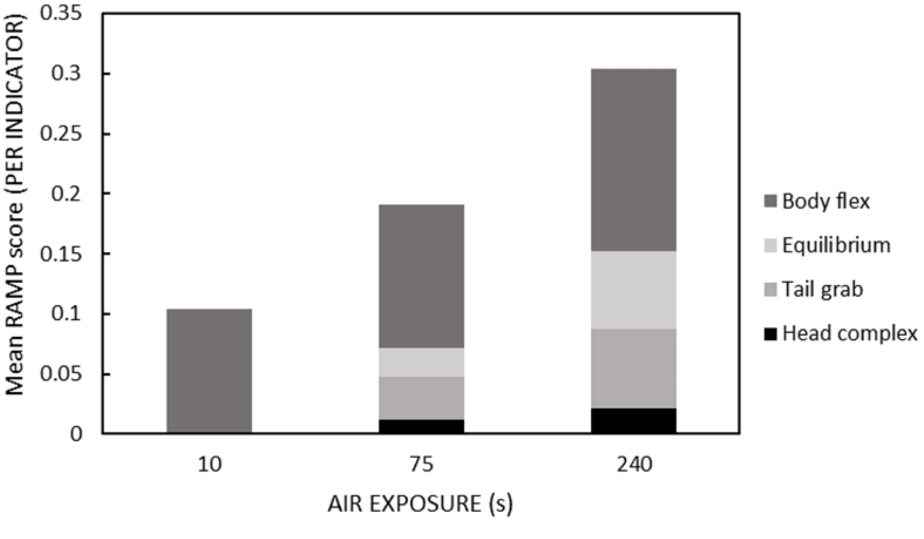

Figure 4.2: Mean RAMP scores per indicator of dusky kob *Argyrosomus japonicus*, after being subjected to different air exposure treatments (10, 75 and 240 seconds), after a catch and release event

Table 4.3: Mean RAMP ordinal scores and percentage impairment per RAMP indicator for dusky kob *Argyrosomus japonicus*, after being subjected to different air exposure treatments (10, 75 and 240 seconds) after a catch and release event

		RAMP					
Treatment	n	HC%	TG%	EQ%	BF%	Impaired%	RAMP mean (SD)
10	24	0	0	0	100	41.6	0.10 (0.12)
75	21	6.2	18.7	12.5	62.5	52.3	0.19 (0.24)
240	23	7.1	21.4	21.4	50	69.5	0.30 (0.29)

Table 4.4: Summary results of the Cumulative Link Model (CLM) describing the relationship between RAMP and air exposure for dusky kob *Argyrosomus japonicus*, after being subjected to different air exposure treatments (10, 75 and 240 seconds), after a catch and release event

Variables	*Estimate* (β_i)	*SE*	*z value*	*P-value*
Air exposure (75 s)	0.60	0.58	1.04	0.29
Air exposure (240 s)	1.51	0.58	2.60	**0.009***
Threshold coefficients	*Estimate* ($\theta_{\hat{j}}$)	*SE*	*z value*	
0|1	0.46	0.40	1.16	
1|2	2.56	0.52	4.96	
2|3	3.39	0.62	5.51	
3|4	4.39	0.823	5.29	
AIC	162.36			
Log-likelihood	-75.18			

4.3.4 Short-term survival

Post-release mortality was low (7.4%), with the highest mortality seen in the 240 s (8.3%, *n* = 2) and 75 s (8.3%, *n* = 2) air exposure treatments and only 4.1% (*n* = 1) in the 10 s air exposure treatment. Sixty percent of the deaths were observed on the day of capture, while the remaining 40.0% died the following day. Twenty percent of the fish that swallowed the hook or were foul hooked died.

4.4. DISCUSSION

The results of the study suggest that *A. japonicus*, experience significant physiological and motor impairment as a result of a C&R event. Although it appeared that survival in this experiment was influenced by hooking injury, fish subjected to extended air exposure exhibited greater physiological stress and motor impairment. Thus, in environments that are predator rich (e.g. the Breede Estuary, McCord and Lamberth 2009), it is likely that extended air exposure will negatively influence survival. Indeed, Zambezi sharks (*Carcharhinus leucas*) have been observed orienting themselves around angling activity in South African estuaries where they most likely opportunistically feed on released fishes (McCord and Lamberth 2009). Thus, the findings of this study suggest that post release mortality of fishes may be reduced by reducing the air exposure of released *A. japonicus.*

Many studies have shown that air exposure can significantly influence the response of fishes to C&R (e.g. Bower et al. 2016; Butler et al 2017; Arkert et al. 2018). In our study we found a significant positive relationship between blood glucose concentrations and air exposure time. Studies attribute a rise in glucose levels to the fight, where glucose is released into the bloodstream to provide energy to the muscles (Martinez-Porchas et al. 2009, Wendelaar Bonga 2011). Indeed, Suski et al. (2007) found a significant positive correlation between fight time and blood glucose levels. However, as the fight times were similar among all air exposure treatments the significantly higher glucose concentration observed in the 240 s air exposure treatment may be due to increased stress caused by extended air exposure. This is because adrenalin and cortisol regulate the production of glucose by stimulating glycogenolysis and gluconeogenesis, causing an increase in blood glucose during a stress event (Reid et al.1998, Wendelaar Bonga 2011). There was no significant difference in blood glucose levels between the 10 s and 75 s air exposure treatments, likely because these air exposures did not cause the fish greater stress. This may indicate that *A. japonicus* are able to withstand up to 75 s air exposure without experiencing significantly elevated blood glucose levels.

Similarly, blood lactate concentrations were positively correlated with air exposure time. This relationship is not uncommon, as many studies have found that extended air exposures result in increased blood lactate levels (Suski et al. 2007; Bower et al. 2016, Arkert et al. 2018). Air exposure influences lactate levels as oxygen acts as the terminal electron receptor in adenosine triphosphate (ATP) production (Wang and Richards 2011). When oxygen is limited, as experienced during extended air exposure, the mitochondrion’s capacity to produce ATP is reduced. In order to maintain energy requirements anaerobic metabolism is initiated and the end product of this process is lactate (Wang and Richards 2011; Butler et al. 2017). Indeed, while the lactate levels of fish in the 75s air exposure treatment were not significantly different to those in fish from the 240 s or 10 s air exposure treatments, 75 s air exposure did cause an elevation in lactate levels, with lactate levels in the 75 s treatment being closer to the levels of fish in the 240 s treatment (p = 0.89) than those in the 10 s treatment (p = 0.05). This is likely because 75 s air exposure was sufficient to initiate anaerobic metabolism.

Air exposure appears to be the main influencing factor in blood lactate concentrations, for this study as other factors, such as fight time, hooking and handling, which have been found to influence concentrations, were similar among all fish. This was evident in the comparison of two studies on sparids, Arends et al. (1999) looked solely at the effect of air exposure on gilthead seabream (*Sparus aurata*) in aquaculture conditions, while Arkert et al, (2018) looked at the effects of air exposure on Cape stumpnose (*Rhabdosargus holubi*) subjected to a simulated C&R event. Arkert et al. (2018) recorded blood lactate concentrations more than five times higher than those observed by Arends et al. (1999). Indeed, Suski et al. (2007) found that bonefish (*Albula vulpes*) which had been exercised for one-minute had lactate concentrations almost three times higher than control levels. Thus, it is likely that the cumulative effects of the fight and air exposure drive the elevated blood lactate concentrations. However, with the relatively short fight times for the majority of fishes (including juvenile *A. japonicus*) captured in South African estuarine fisheries (see Chapter 2), it is likely that the biggest driver of elevated blood lactate will be air exposure.

The results of this study appear to indicate that blood glucose levels were affected more by the stress of the C&R event and in particular, extended air exposure, as all fish had increased glucose levels however, fish in the 240 s treatment had significantly higher concentrations. While lactate levels appear to be more directly affected by air exposure, due to the initiation of anaerobic respiration which produces lactate during hypoxia (Wang and Richards, 2011). Glucose levels are influenced by stress hormones, such as adrenaline and cortisol, which are released during a stress event, such as extended air exposure (Barton 2002; Martinez-Porchas et al. 2009; Wendelaar Bonga 2011). Indeed, Van Raaij et al. (1996) found a similar trend in rainbow trout (*Oncorhynchus* *mykiss*) with hypoxic conditions affecting the two indicators (glucose and lactate) differently. Fish exposed to hypoxic conditions experienced a peak in glucose levels directly correlated with a peak in adrenaline and cortisol levels, with glucose levels quickly returning to normal with the decrease in these stress hormones, even while still experiencing hypoxia. Whereas lactate levels began to increase with hypoxic conditions and remained elevated during the entire hypoxic period.

When comparing the blood physiology results of Chapter 3 with this chapter, there is agreement in the blood lactate concentrations. The peak mean lactate level (blood taken at 30 minutes) in Chapter 3 was 7.46 ± 3.60 (2.0–12.80), which is very similar to the lactate level in the 75 s air exposure treatment, 7.68 ± 4.66 (2.70–20.30) of the current chapter. This similarity is likely due to the fact that fish in both the experimental laboratory study (Chapter 3) and fish in the 75 s air exposure treatment of the field experimental study (this chapter) were exposed to the same air exposure times and similar fight times. The results of the blood glucose, however, do not agree, peak mean glucose levels (blood taken at 30 minutes) in Chapter 3 were 8.33 ± 4.01 (4.90–14.60), this is much higher than the glucose levels seen in the 75 s air exposure treatment in the current chapter (4.30 ± 1.20 [1.80–6.40]). A reason for this disparity could be that the combination of confinement and the simulated C&R event experienced by fish in Chapter 3 resulted in a greater stress response, than that experienced by fish subjected solely to the C&R event in this chapter. Another reason for the disparity could be because blood glucose levels change in relation to feeding and nutrition (stress-independent factors) (Wu et al. 2017). Thus, while lab fish were fed a regular diet and were starved 48 hours prior to experimentation, field fish may have eaten just prior to being caught or weeks before, causing disparity in the blood glucose levels.When combined, the blood physiology results of this chapter suggest that fish subjected to 240 s of air exposure suffer a significantly higher PSR. Lactate concentrations in the 75 s air treatment were not significantly different to the concentrations in either the 10 s or 240 s air exposure treatments. Confirming the results of blood glucose, that 75s air exposure, while still having an impact, is more less harmful as any air exposure above this level could result in *A. japonicus* experiencing greater physiological impairment, while reducing air exposure below this level could result in a reduced physiological stress response. Indeed, many studies recommend reducing air exposure to mitigate the effects of C&R (Schreer et al. 2005; Suski et al. 2007, Lennox et al. 2015, Bower et al. 2016, Butler et al. 2017; Arkert et al. 2018). With some of them (e.g. Schreer et al. 2005; Arkert et al. 2018) suggesting that air exposure is kept below a particular threshold for each species.

Although the results of the RAMP tests show that *A. japonicus*, across all air exposure treatments, experienced some physical impairment, fish in the 240 s treatment were significantly more impaired than those in the 10 s treatment (Table 4.4, Figure 4.2). These findings suggest that a combination of angling and air exposure contributes to motor impairment in this species. Interestingly, there were some fish in every air exposure treatment that showed no signs of reflex impairment and as there were no differences in the size or fight time between impaired and unimpaired fish, this could indicate that *A. japonicus* are fairly resilient to C&R. Indeed, in a similar study on the effects of C&R on Cape stumpnose (*Rhabdosargus holubi*), Arkert et al. (2018) found that 100% of fish exposed to extended air exposure (90 s) showed signs of reflex impairment. In this study only 69.5% of *A. japonicus* in the 240 s air exposure treatment were physically impaired. This could be due to species-specific variation or could be attributed to habitat. In this experiment, *A. japonicus* were captured in the GFE which is a permanently open estuary, while *R. holubi* were captured in the non-tidal, temporarily open closed (TOCE) West Kleinemonde Estuary (WKE, Arkert et al. 2018). It is possible that the exposure of *A. japonicus* to strong tidal currents in the GFE provides them with a physical advantage, and thus better able to tolerate exhaustion, over the *R. holubi* in the WKE. Rosenfeld and Boss (2001) found that juvenile cutthroat trout (*Oncorhynchus clarki*) occupying strong water flow sections of rivers, known as riffles, expended more energy than fish in the low flow, ‘pool’ sections of a river. Thus, *A. japonicus* may be used to high energy expenditure while swimming and therefore less impacted by the energy required during a C&R event. Indeed, the low mean RAMP score observed across treatments showed that while there was a relatively high percent of impairment for angled fish, the severity of the impairment was low.

There was agreement between the RAMP tests and the blood physiology results, with fish in the 240 s air exposure treatment significantly more impaired (Figure 4.2). This confirms the hypothesis that extended air exposure results in increased physiological and physical impairment and is similar to the result of other studies (Brownscombe et al. 2015; Bower et al. 2016; Butler et al. 2017, Arkert et al, 2018; Pinder et al. 2019). Again, there was no significant difference in the physical impairment of fish in the 75 s treatment compared to those in the e 10 s or the 240 s treatments. However, with a p-value of 0.07, fish in the 75 s air exposure treatment were close to being significantly less impaired than fish in the 240 s air exposure treatment. Suggesting that 75 s could be within the threshold of air exposure for this species. This is important as 62.0% of anglers observed in Chapter 2 had air exposure times between 10s and 75s, thus the air exposure time *A. japonicus* are likely to experience will not more severely impact their health and survival after C&R.

The ‘body flex’ indicator was responsible for the highest percent of impairment (up to 100% in the 10 s treatment), followed by the ‘tail grab’ (up to 21.4% in the 240 s treatment) and ‘equilibrium’ (up to 21.4% in the 240 s treatment) indicators. It has been suggested that ‘body flex’ and ‘tail grab’ impairment is linked to physical exhaustion (Raby et al. 2012) and indeed, ‘body flex', 'equilibrium' and 'tail grab' are indicative of a fish's ability to evade predation (Brownscombe et al. 2017). Thus, the high percent of impairment observed for these indicators suggests a reduced ability for *A. japonicus* to take evasive action after C&R and thus greatly increase the possibility of post-release predation, particularly after extended air exposure. Previous studies on bonefish (*Albula vulpes*) found that a loss of equilibrium after C&R resulted, within 30 minutes, in an increase in post-release predation (Danylchuck et al. 2007). When motor impairment is combined with the release of chemical cues as a result of stress (Arlinghaus et al. 2007; Jenkins et al. 2004, Dallas et al. 2010), it is likely that post-release mortality could be high in predator rich environments. Since some South African estuaries are known to be rich in shark predators (e.g. the Breede estuary, McCord and Lamberth 2009) and large adult *A. japonicus*, which are known to feed on their juveniles (Griffiths 1997), it is likely that this species is vulnerable to predation after C&R in estuaries.

Short-term survival for this species was high (92.6%), suggesting *A. japonicus* is relatively resilient to C&R. However, as survival was monitored in tanks, which did not include predators, it is likely that mortality was underestimated and in reality, is far higher due to post-release predation. Post-release predation was not included in this study as acoustic telemetry was not within the scope of this research, however, it is recommended that future studies should aim to include post-release predation into their mortality estimates through the use of acoustic telemetry or other methods.

Another caveat of our study is that angling, and experimentation took place over multiple non-consecutive days. This was done as it was not possible to capture the number of fish required for our study in one day. However, as fish were randomly assigned to one of the three air exposure treatments on each day of angling and water quality parameters and water temperatures were similar among the days, we do not consider this a critical limitation. The confinement stress experience by fish during the 30-40 minutes prior to blood taking is also a limitation of this study, however as confinement area and time were the same among all fish, we do not consider this to be a confounding limitation. Despite these limitations we feel the experimental design gave valid results and is useful in evaluating the health and survival of other species to C&R events.

Survival in this experiment was primarily influenced by hooking injury as the majority of fish that died in this study (80.0%) either swallowed the hook or had other visible injuries, such as bite marks or foul hooking injuries. These fish were all of similar size and evenly distributed among air exposure treatments thus suggesting that hooking mortality is a concern for *A. japonicus*. Indeed, in their study on the effect of hook location on short-term mortality of *A. japonicus*, Butcher et al. (2007) observed an overall mortality rate of 26.9% in one of their experiments. In fact, hooking mortality has been found to be the leading cause of death in many C&R studies (Prince et al, 2002; Bartholomew and Bohnsack 2005; Danylchuck et al. 2014; Arkert et al. 2018) (see Appendix 1). The only fish to die without any visible hooking injury was in the 240 s air exposure treatment. This suggests that extended air exposure and extreme stress can cause mortality in this species and supports our hypothesis that extended air exposure will increase the likelihood of post-release mortality.

Catch and release mortality is often delayed and therefore invisible to anglers and fisheries managers. Indeed, 40.0% of mortalities in this study occurred 12 hours after capture. Similarly, Butcher et al. (2007) found a significant delay in mortality of caught and released *A. japonicus*, with 59.3% experiencing mortality during the first 24 hours after release. This result is important for the management of *A. japonicus* stocks as, due to the invisible nature of C&R mortality, it is often not known and therefore not included when modelling the mortalities in the recreational fisheries. This delayed mortality is also likely to be greater if post-release predation is taken into account. Indeed, as it takes up to 150 minutes for *A. japonicus* to recover from a C&R stressor (see Chapter 3), post-release predation will likely be high for released fish as stressed and injured fish attract predators (Arlinghaus et al. 2007; Jenkins et al. 2004, Dallas et al. 2010).

The results of this study have implications for the management of *A. japonicus*. Due to the harm caused by hooking injury it is suggested that anglers use barbless circle hooks which decrease the likelihood of hooking injury (Prince et al. 2002; Cooke et al. 2012). The significantly higher physiological and physical impairment caused by 240 s air exposure suggests that fisheries managers should implement best practice guidelines that aim to reduce air exposure below 75 s. To do this, the mandatory use of buckets filled with estuarine water, which is changed frequently, to reduce air exposure time while de-hooking is recommended (see Butler et al. 2017; Mannheim et al. 2018). Indeed, buckets could be sold with fishing licences and legislation could be implemented which would result in a fine if an angler is caught fishing without a bucket. Public awareness campaigns on the effects of C&R and best handling recommendations will also be important in gaining awareness and support for best practice C&R. Ultimately these steps may reduce post-release mortality in *A. japonicus* and aid in the protection of South African estuarine biodiversity as well as protect an important food source for impoverished South Africans.

CHAPTER 5

5.1 GENERAL DISCUSSION

This thesis provides much needed insight into the health and survival of juvenile *A. japonicus* following a C&R event in an estuarine environment. Research of this nature is becoming increasingly important given the overexploited nature of estuarine and coastal fishes, particularly in South Africa, and the expanding non-traditional recreational management measures such as voluntary C&R behaviour (Cooke et al. 2013). Although C&R science is well-established globally (see review table, Appendix 1), it has only recently begun to gain momentum in southern Africa. The results of this study indicate that juvenile *A. japonicus* appear to be relatively resilient to a C&R event and will likely recover fairly quickly (Chapter 3) when exposed to the average air exposure and fight times observed for estuarine C&R (Chapters 2). Physiological and motor impairment was not significantly worse when fish were exposed to the average air exposure time (75 s) of recreational anglers. This suggests that the current practices of estuarine anglers in South Africa may be less harmful for this species. However, the significant physiological and motor impairment observed when fish were subjected to longer air exposures (240 s), suggests that an intervention to reduce these times is needed. However, the mortality caused by hooking injury for *A. japonicus* is concerning, particularly as the hooks used in our experiments were similar to those used by most estuarine anglers.

The ability to interpret C&R research results in the context of the resource and its user is critical for improving our understanding of the complex interactions between angler behaviour and fish health and survival. Although a move towards inter-disciplinary studies is needed in recreational fisheries research worldwide, it is sorely needed in South Africa and will ultimately lead to an improved understanding of the recreational fishery system and the effects of C&R as a whole.

However, the structure of this research, including the incorporation of research on angler behaviour with the biological effects of C&R is an important step in understanding this coupled social-ecological system (SES) (Berkes et al. 2008; Liu et al. 2007; Ostrom et al. 2009).

Recreational fisheries and C&R are, by their very nature, SES, with human behaviour directly influencing the natural environment and vice versa (see Figure 5.1) (Arlinghaus et al. 2017). Socio-ecological systems are characterised by interactions between humans and natural components and these form complex feedback loops (Berkes et al. 2008; Liu et al. 2007; Ostrom et al. 2009). While there are many studies that examine the social or ecological aspects of systems in isolation, this separation has resulted in a lack of understanding of the complex processes and patterns of SES (Berkes et al. 2008; Liu et al. 2007). This is particularly relevant for C&R systems.

Angler handling behaviour has been found to be the main factor influencing the health and survival of released fish in a C&R system (Brownscombe et al. 2017). Several studies have provided insights into the science of C&R and have examined the effects of capture, handling, gear type and air exposure on the health and survival of released fish (Figure 5.1) (e.g. Dempson et al. 2002; Barthel et al. 2003; Alberts et al. 2004; Suski et al. 2007; Colotelo and Cooke 2011; Pinder et al. 2019; Roth et al. 2019, see Appendix 1). However, since their primary focus has been on the biological and physical effects of C&R on fish without incorporating empirical prior knowledge of how anglers behave and handle fish in the real-world (represented by social systems circle of Figure 5.1), they may lack realism. This could lead to over- or under-estimations of the mortality caused by C&R, because, as discussed in Chapter 2, assumptions made in C&R experiments (e.g. air exposure times) may not be based on reality and thus may not be giving accurate estimates of mortality.

Not fully understanding all aspects of the C&R system, in this case, angler behaviour, can lead to ineffective or even harmful management and conservation policies (Liu et al. 2007; Arlinghaus et al. 2013). This highlights the importance of approaching the management of SES rather than managing humans and nature as separate entities (e.g. Granek et al. 2008) and has been recommended to be a central approach when managing recreational fisheries (Cooke et al. 2019). To inform optimal strategies for recreational fisheries management, it is critical to move toward interdisciplinary research, which will likely lead to enhanced recreational fisheries management (Fenichel et al. 2013; Hyder et al. 2018; Cooke et al. 2019). However, up to now, there is limited interdisciplinary research being conducted in recreational fisheries science (Fenichel et al. 2013).

In terms of C&R science, improving angler behaviour and handling practices is integral to ensuring better health and survival of captured fish and will be a central requirement for better recreational fisheries management. However, the process of changing human environmental behaviour is complex (Steg and Vlek 2009) and effective behavioural change requires managers to be equipped with knowledge on current behavioural norms and what effect each behaviour has on the fish (Figure 5.1). This is also necessary if we are to move towards constructing and implementing more appropriate and effective management strategies that will benefit both the fish and the fishers. Without this knowledge, managers may attempt to implement strategies that are unnecessary. For example, Lamansky and Meyer (2016) observed the behaviour of 280 trout anglers and found that anglers only exposed trout to an average of 29 s air exposure before releasing them. This is well below the lethal limit for trout (Schreer et al. 2005), indicating that trout fishery management will not need to implement strategies to reduce the air exposure time and can instead focus their efforts on changing other, more harmful, angler behaviours.

In this study, the average air exposure time for estuarine anglers (75 s) did not result in significantly poorer health and survival than a 10 s air exposure time. Although this study did not take into account post-release predation, this finding may suggest that the C&R behaviour by the average angler may be relatively benevolent for the species. However, the range of air exposure time was high, with extended (> average) air exposures occurring frequently (30.6% of the time). Thus, it is recommended that steps are taken to reduce air exposure times, and in so doing, reduce the likelihood of post-release predation. Besides reducing air exposure, the findings from this study also highlight that hooking injury can also play a considerable role in post-release mortality of *A. japonicus* and thus any intervention to reduce air exposure should ideally also attempt to reduce poor hooking.

In order to improve C&R behaviour, one needs to understand current behavioural norms and the motivation behind them. There are few examples of studies that have examined methods for improving angler C&R behaviour. While education approaches have been found to play a vital role in changing social behaviour, a multiple-method approach is more effective (Steg and Vlek 2009, Mannheim et al. 2018). Steg and Vlek (2009) provide a comprehensive framework with which to change social norms and promote pro-environmental behaviour. This framework suggests first identifying the behaviours which need to be changed. In the context of C&R, this can be done by monitoring angler behaviour and determining the effect that behaviour has on fish (see Figure 5.1). They then suggest identifying the factors which determine this behaviour such as the perceived costs and benefits to certain behaviours (social system circle of Figure 5.1). Next, appropriate interventions to encourage pro-environmental behaviour must be identified and implemented. These interventions could include informational strategies (e.g. awareness, education, role models and social support) and structural strategies (e.g. legal regulations, availability of products and financial strategies). Finally, the effectiveness of the intervention must be evaluated, with C&R science monitoring both the social system, to determine if the intervention successfully changed angler behaviour, and the resource, to determine if the changed behaviour positively effects fish populations (Figure 5.1). This framework highlights the importance of approaching C&R as an integrated SES in order to promote pro-environmental behaviour (Figure 5.1). While this framework has been used for several environmental behavioural interventions (e.g. Frederikset al. 2015; Gifford 2011), only one (Mannheim et al. 2018) has implemented this in a C&R context. In this study, Mannheim et al. (2018) worked with an exclusively C&R fishing competition over a period of four years. Through negotiations with the leadership of the league, they implemented rule changes, conducted extensive awareness and knowledge campaigns and developed a penalty and reward systems for good and bad handling practices. They found that over time there was a significant improvement in angler handling practices and as a result, improvement in the health of released fish.

The use of conservation-minded fishing gears (i.e. gear which has been shown to cause less harm to captured fish e.g. barbless circle hooks) also represents one of the most common and wide-spread voluntary pro-environmental actions by anglers (Cooke et al. 2013). In Germany for example, there is a social norm of ‘Weidgerechtigkei’ which is a term that promotes ethical behaviour of fair chase with fish (Cooke et al. 2013). This social norm promotes the voluntary limitation of fishing gears, making capture of fish harder and thus protecting recreational fish stocks (Cooke et al. 2013). ear restrictions are one of the most popular tools used by fisheries managers to control the size and species of fish being caught (Cooke et al. 2013). Indeed, a change in gear type is needed in South Africa as hooking mortality was high for *A. japonicus*, this can be done through structural strategies such as legislation requiring barbless, circle hooks, as these have been found to reduce the amount of hooking mortality (Prince et al. 2002; Arkert et al. 2018). However, Bova et al. (2018) found high rates of non-compliance to fishing legislations in South Africa, therefore it is likely that a legislation such as this would not be widely adhered to. Anglers tend to choose gear that is cheaper and more affordable, thus when trying to change angler preference to gear type making the preferred gear more affordable is likely a good way to facilitate this change (Steg and Vlek 2009). Introducing a government subsidy on less harmful fishing gears may represent a step in the right direction and may result in an increased usage of recommended gear types. However, there is a need for a change in the social conscious and behavioural norms with regard to gear choice, which structural strategies alone cannot change (Steg and Vlek 2009). Therefore, the implementation of informational strategies such as education, role models and peer-pressure will also be needed (Steg and Vlek 2009).

Besides issues with air exposure, several harmful angler handling practices were observed during this study (see Chapter 2). These included dragging fish along the ground (on sand, grass and rocks) and are likely to reduce the health and increase the post-release mortality of a released fish (Brownscombe et al.2017, Figure 5.1). Thus, improvements in handling practices that will minimise air exposure, and reduce harmful handling must be encouraged among anglers. Structural strategies, such as legislation requiring anglers to carry buckets filled with water to use when de-hooking fish, may be effective in reducing air exposure times. However, informational strategies will likely be more effective in reducing harmful handling practices. Education on the effect of certain bad handling practices, such as dragging fish along the ground and extended air exposure, and the high potential mortality caused by these practices will be a good starting point (Burgess et al. 1998; Mannheim et al. 2018). Role models can also have an important part to play in changing angler handling behaviour (Mannheim et al. 2018). Competitive anglers or anglers with a high social status among recreational anglers can set trends in good handling practices which may encourage other anglers to do the same (Mannheim et al. 2018). Angling clubs and competitions are also a good launching pad to promote a change in C&R handling (Cooke et al. 2013; Mannheim et al. 2018). If clubs and competitions change their rules to require good handling practices, such as the use of a bucket, this may result in anglers who are members of these clubs adopting such handling practices in their own personal fishing (Cooke et al. 2013; Mannheim et al. 2018). Changing social norms with regard to good handling in C&R is important as peer-pressure can be a strong motivator, with rule-breakers at risk of tarnishing their reputations which? can also have the potential to make C&R fisheries self-regulating (Ostrom 1994; Cooke et al. 2013).

Changing angler behaviour is often a difficult, long process and there are sometimes external challenges (Steg and Vlek 2009) which need to be overcome before any real progress can be made. A lack of trust between scientists, management and recreational anglers represents a great challenge to changing angler behaviour (Dudual et al 2013, Mannheim et al. 2018) (restricting the flow between C&R science and the social system Figure 5.1). This lack of trust is often propagated by scientists and managers themselves, as humans were considered as non-natural disturbances and thus excluded from the development of conservation plans (Patterson 2006; Arlinghaus et al. 2007; Cowx et al. 2010). This can lead to anger, conflict and ultimately a disintegration of dialogue between parties (Arlinghaus 2005; Cowx et al. 2010). Recreational anglers thus tend to mistrust scientists, blaming them for the increase in regulations and believing them to be arrogant and out of touch with the real-world (Bower et al. 2017; Danylchuck et al. 2017; Mannheim et al. 2018). Thus, building trust and relationships between scientists and recreational anglers is a vital step to changing social norms. Indeed, Mannheim et al. (2018) suggested that the development of a relationship of trust between the scientists and competition anglers was vital to the success of their project.

Another challenge that can often limit the success of changing angler behaviour is poor communication between scientists and stakeholders (Dedual et al. 2013). Scientists mainly publish their work in scientific journals and there are few people who are willing to attempt to bridge the gap between scientific research and communicating the information to the public (Dedual et al. 2013). This communication is vital for anglers to understand the need for behavioural changes and without it change in social norms is far less likely. Good communication is also important for scientists and management as information on anglers' reactions and opinions to regulation changes can help direct research and design regulations that will better achieve management and conservation goals of pro-environmental behaviour (Hunt et al. 2013) (Figure 5.1).

Generally, there is a lack of awareness within the social system (Figure 5.1) of the impact of recreational anglers on fish stocks, this may be one of the first obstacles that needs to be overcome when changing the environmental attitudes of recreational anglers. Studies have found that recreational anglers have a large impact on fish stocks, in some cases even larger than commercial fisheries (Cooke and Cowx 2004, 2006, Dedual et al. 2013). However, recreational anglers will often dispute this fact and do not see themselves as a problem (Dedual et al. 2013). Accordingly, an effective strategy for recreational anglers to change this attitude could be through raising awareness and knowledge (Steg and Vlek 2009) of the negative impact they may have on fish populations (Figure 5.1). Indeed, Dorow et al. (2010) suggested that knowledge of the condition of the resource may change the anglers' attitude towards current management regulations (and the social norms surrounding those regulations) and thus promote pro-environmental behaviour (van Poorten et al. 2011; Hunt et al. 2013) (Figure 5.1).

Instilling a sense of pride and ownership of recreational fish stocks in angling communities could also lead to a greater drive in conservation efforts and to better handling norms. *Argyrosomus japonicus* have been found to be resident to their home estuaries during their prolonged juvenile phase (when they are most vulnerable to capture) (Childs et al. 2015), this knowledge could be disseminated to locals in such a way as to inspire a sense of ownership and protection of resident stocks. This could hopefully lead to a similar situation as described by Cooke et al. (2013) where residents in Ontario Canada, took responsibility for enforcing fishing restrictions and protecting 'their' fish. Ultimately a change in mind set is needed for South African recreational anglers, as many of them do not see themselves as causing harm to fish stocks, therefore they do not see a need to change their behaviour. Disseminating information, such as that gained from this research, will be important in changing this mind set. We therefore recommend educational drives to disseminate this information through various means, such as through angling clubs and competitions, social media, radio shows and angler magazines.

Going forward, it is important to recognise the caveats of this study and identify knowledge gaps for future research. One of the limitations to our study was the lack of angler C&R behavioural information for *A. japonicus*. As the species grows larger than many of the other estuarine species, fight times and air exposure times may differ. In addition, anglers may be more likely to measure the size of *A. japonicus* as the size limits larger than most other estuarine fishery species. This will increase both the handling and air exposure for the species. A study to estimate angler C&R behaviour for *A. japonicus* would not only be beneficial but could also provide additional information (above that collected in Chapter 2) for all estuarine species. However, as the aim of the observations in this study were to get an estimate of angler behaviour, to be used in our laboratory and field experiments, and not to do an exhaustive study on angler C&R behaviour, the methods and sample size are deemed sufficient for this purpose. Another limitation is that observations were also only made at two estuaries in the Eastern Cape. While for this study, these estuaries were deemed sufficient, particularly as they represent very popular fishing areas situated in highly urbanised regions, having a wider range of observation regions would also have strengthened our results. Although we initially used angler observations to provide realism to our study and inform our field design, we have come to realise that this is a critical component of C&R studies and should be incorporated (at a much more detailed and extensive level) in all future studies. A final limitation of our study is that we did not look at the effects of C&R on *A. japonicus* over different environmental contexts (e.g. coastal zone; marine boat fishery), seasons or during a wider range of temperatures and salinities. As coastal zones represent high energy environments (Butler et al. 2017), the impact of C&R on *A. japonicus* in this context may differ to that seen in estuaries. Temperature too has been found to greatly affect the health and survival of captured fish (Muoneke and Childress 1994; Dempson et al, 2002; Thorstad et al. 2003), and the need for osmoregulation may decrease the energy available for recovery for *A. japonicus*. Therefore, conducting experiments in different environments and during different seasons would likely give a fuller picture of the effect of C&R on this species.

Despite the limitations, this study represents the first to combine empirical research on angler behaviour with the biological effects of that behaviour on a species of fish. This structure of study leads to a fuller and more practical understanding of the effects of C&R and can lead to more appropriate management recommendations. With the global population rapidly reaching the eight billion mark, we can no longer afford to be as exclusive in science as we have in the past, excluding human activity from biological research and vice versa. It is our hope that this study will be one of the first steps to greater interdisciplinary work in C&R science and that research such as this may be conducted on other important recreational species. For science to be effective and truly reach its goal of understanding and bettering society it needs to be inclusive of that society. Working towards greater communication and co-operation with recreational anglers will ultimately lead to the production of better C&R science and greater protection for fishes.

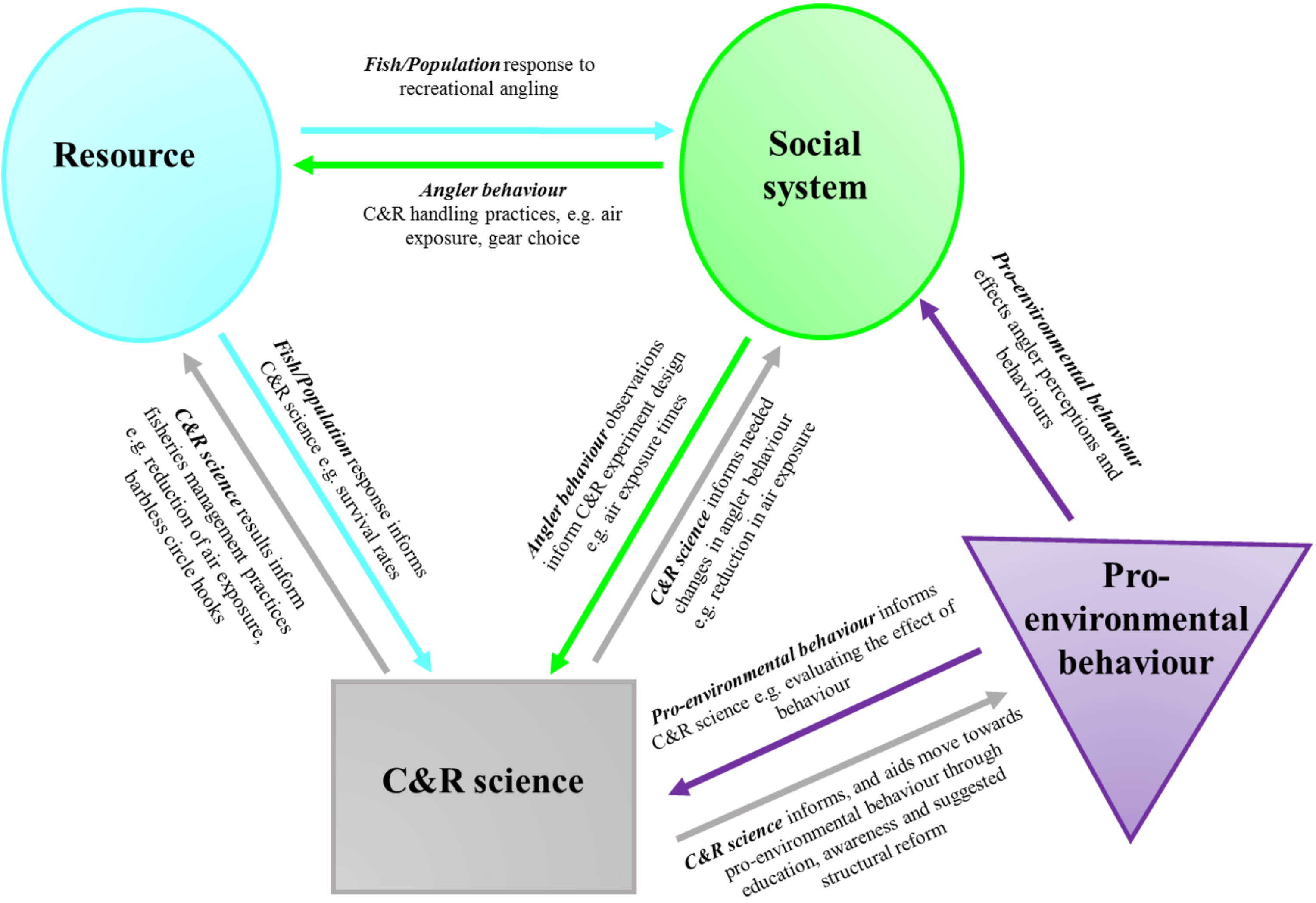

Figure 5.1: Conceptual diagram illustrating the relationship among science, the resource and angler behaviour and their move towards pro-environmental behaviour in recreational fisheries

Appendix 1:

Catch-and-release literature review table:

Authors	Species	Country	Habitat	Aim of paper	Findings
Aalbers et al. 2004	Juvenile White Seabass (*Atractoscion nobilis*)	United States of America	Marine	To examine the effect of **hooking injury** and location on survival and growth rates	Circle and 'J' hooks resulted in same mortality rate (10%), all mortalities were caused by deep hooking events. Deeply hooked fish grew at a significantly reduced rate (likely due to a reduction in feeding and food intake). Survival was better when deep hooks were left in the fish.
Arends et al 1999	Gilthead sea bream *(Sparus aurata)*	Spain	Marine	Investigate the endocrine responses to **air exposure** and **confinement**. Exposed fish to 0s and 180s air exposure	Air exposure induced a strong and rapid increase in both glucose and lactate concentrations
Braccini and Waltrick 2019	Sharks and rays	Australia	Marine	To evaluate the at vessel **mortality** (AVM) of elasmobranch species and to assess the effect of body size, sex, soak time, bottom depth and latitude on the mortality of a number of different species.	Found that species was the most important predictor of AVM as some species were more susceptible to gear injury than other species.
Brownscombe et al. 2013	Bonefish *(Albula Vulpes)*	The Bahamas	Marine	Evaluated the usefulness of **recovery bags** on **impairment.** Exposed fish to 0, 120, 240 or 360s air exposure.	Found that fish that were allowed to recover showed less locomotory impairment than fish released immediately. However, suggest that recovery bags don't accelerate recovery but provide protection from predation during recovery and thus reduce post-release mortality
Brownscombe et al. 2015	Bonefish *(Albula Vulpes)*	Puerto Rico	Marine	Evaluate the **stress response** and **reflex impairment** of experimentally angled	Found that extended air exposure and water temperature were the most important factors in

				fish. Exposed fish to 0s or 120s air exposure	determining post-release mortality
Butler et al. 2017	Multiple species	South Africa	Surf zone, marine	To evaluate the effect of C&R angling on the **stress response** and **reflex impairment** of multiple species caught during a South African competitive angling competition. Fish exposed to average of 94.3s air exposure.	Found that fight time was a significant predictor of blood glucose concentration and air exposure was a significant predictor of blood lactate concentration in teleosts. 9% of the teleost's suffered some form of reflex impairment with fight time and hook removal identified as the best predictors of reflex impairment. Mortality was only observed in one family, the Ariidae (38.5%).
Butcher et al. 2007	Yellowfin bream (*Acanthopagrus australis*) and Mulloway (*Argyrosomus japonicus*)	Australia	Marine	To quantify the **mortality** of yellowfin bream and mulloway after being hooked in the mouth or ingesting hooks and then released by different methods, either removing the hook, cutting the line and leaving the hook in the fish, or cutting the line underwater to ensure 0s air exposure.	Found that for both species that had their ingested hooks removed experienced the greatest mortalities (87.5% bream) and 72.7% mulloway). Mortality rates of bream and mulloway were significantly decreased to 1.7 and 16%, respectively, when they were released with their lines cut, few mortalities occurred mulloway when it was released with no air exposure. Suggest that anglers should cut the line from hook-ingested fish but remove the hook from mouth-hooked individuals.
Butcher et al. 2008	Yellowfin bream (*Acanthopagrus australis*)	Australia	Marine	To test the relationship between anatomical **hooking location** and different designs and sizes of hooks and terminal rigs and then to identify strategies to minimise hook ingestion.	Found that fewer fish (16.6 and 8.5%, respectively) ingested hooks than those hooked in the mouth (82.1 and 88.6%). More J hooks were ingested than circle hooks or J hooks modified with a 15-mm horizontal bar. Increasing hook weight and decreasing fish size resulted in lower rate of ingestion irrespective of hook type. Encourage anglers targeting this species to use circle or

					modified J hooks and, the largest hook size possible attached to short traces or a sinker only
Danylchuck et al. 2014	Juvenile lemon shark *(Negaprion brevirostris)*	The Bahamas	Marine	To evaluate the effect of C&R on the **hooking injury physiological response** and **short-term survival** of experimentally angled fish	Reported 12.5% mortality within the first 15 minutes after release. Found that hooking damage was an important predictor of mortality and that temperature exacerbated the stress response
Edwards 1998	Tarpon *(Megalops atlanticus)*	United States of America	Marine	Examined effects of C&R of angled Tarpon, by monitoring **survival** using tracking devise for 1-14hrs	Found high survival rate, with only one fish experiencing mortality due to air exposure. Some of the tarpon exhibited strange behaviour immediately after release but seemed to recover quickly. The high survival rate was attributed to the good handling practices of the guides and anglers.
Lennox et al. 2017	Bonefish *(Albula glossodonta)*	French Polynesia	Marine	To quantify **post-release predation** (PRP) of bonefish after C&R and examine the impacts of **handling (air exposure)** and release practices (retention for a short period vs immediate release) on PRP	Found that extended air exposure did increase the fish's susceptibility to PRP. Also found that retaining fish for 30 min prior to release resulted in higher PRP as it gave predators greater time to aggregate in the area. Therefore, authors suggest that air exposure time is limited, and that fish are released immediately after angling.
Moxham et al. 2019	Bonefish (Genus *Albula)*	Seychelles	Marine	To analyse bonefish movements by first analysing the occurrence of **post-release predation** bias when using acoustic telemetry.	Found that only 10% of tagged bonefish were detected for longer than two-weeks and suggested that at least 43% of tagged fished experienced post-release predation mortality. Due to the high post-release mortality they observed they suggest that C&R could represent a danger to these fishes and suggest that

					management and policy should be adjusted accordingly.
Prince et al. 2002	Billfish	Guatemala	Marine	To compare circle hook and "J" hook performance in C&R and evaluate the **damage caused by different hook** types	Found that circle hooks minimized deep hooking, foul hooking and bleeding, and recommend the use of circle hooks for promoting the live release of billfish
Reynolds 2018	Yellowfin bream (*Acanthopagrus australis*) and Mulloway (*Argyrosomus japonicus*)	Australia	Marine, Aquaria facility	To identify the negative hooking, handling and release practices that effect **post-release survival** of fish and find ways to maximise survival.	Found post-release survival rates between 89 and 100% for yellowfin bream and 27 and 96% for mulloway. Most deaths occurred within the first 24 hours. Fish with several hooking injury were found to be more likely to die. Hooked yellowfins were able to withstand up to 30 s of exercise and 5 min of air exposure with few negative short-term impacts.
Suski et al. 2007	Bonefish *(Albula Vulpes)*	The Bahamas	Marine	To determine the **physiological disturbance** and **recovery dynamics** of bonefish, in response to variable exercise and exposure to air. Exposed fish to either 0, 60 or 180s air exposure.	Found that longer angling and air exposure times resulted in significantly higher stress response
Arkert et al. 2018	Cape stumpnose *(Rhabdosargus holubi)*	South Africa	Estuarine	To evaluate the **health** and **survival** of angled fish to C&R, exposed fish to 0s, 30s and 90s air exposure	Found that fish exposed to extended air exposure times (90s) experienced greater stress response, reflex impairment and short-term mortality. It appears that 30s air exposure is a threshold at which minimal harm is done to the fish.
Butcher et al. 2006	Sand whiting (*Sillago ciliate)*	Australia	Estuarine	To assess the **post-release mortality** of captured sand whiting and to identify and quantify the key contributing factors to mortality.	Experienced a mortality rate of 6% for captured fish and found that hook location (oesophagus-ingested hooks) and bait type (beach worms) were significant predictors of mortality

Lennox et al. 2015	Fat snook *(Centropomus parallelus)*	Brazil	Estuarine	Evaluate the effects of C&R angling on the **mortality** and **stress response** of fat snook in an estuary. Exposed fish to 0s and 60s air exposure.	Found that fish exposed to extended air exposure and handling experienced a significantly higher stress response and reflex impairment. Experienced low mortality rates but mortality was attributed to hooking injury not air exposure.
Anderson et al. 1998	Atlantic salmon *(Salmo salar)*	Canada	Riverine, freshwater	To measure the heart rate of fish during simulated angling event and **monitor recovery**	Found that fish survival was only 20% for fish angled in high temp (20C), while there was no mortality for fish at 8C or 16C. Mean resting heart rate was higher for fish in high temp and post angling HR increased after angling for all fish (by 1.2 fold in 8C, 1.3 fold in 16C and 1.15 fold in 20C).
Arlinghaus and Hallermann 2007	Pikeperch *(Sander lucioperca)*	Germany	Freshwater	Investigate the effects of **air exposure** on **mortality** and **growth**. Exposed fish to 0, 60, 120 and 240s air exposure	Found higher mortality rates for fish exposed to air than those not exposed to air and that there was no difference in growth rates between air exposure treatments
Bartel et al. 2003	Bluegill *(Lepomis macrochirus)*	Canada	Lake, freshwater	To test the effect of different mesh types on **injury** and **mortality** of bluegill. Exposed fish to 30s air exposure.	Found that course knotted nets were worst and caused most skin damage (10%mortality), followed by fine knotted nets (14% mortality) Other mesh types also experienced mortality; knotless mesh (6% mortality) and rubber mesh (4% mortality). Only control fish (not held with net) had 0% mortality. All mesh types also caused injury and abrasion to skin and fins, resulting in negative sublethal effects (e.g., infection, reduced predator avoidance, reduce ability to capture prey etc).
Bower et al. 2016	Peacock bass *(Cichla ocellaris)*	Puerto Rico	Freshwater	To evaluate the **effect of C&R** angling on Peacock bass. Exposed fish to 0s or 30s air exposure.	High survival rates, with mortality only associated with extended handling and air exposure treatment

Brobbel et al. 1996	Atlantic salmon *(Salmo salar)*	Canada	Riverine, freshwater	To compare and evaluate the **effects of C&R** on starved salmon on their way downstream to healthy salmon on their way up stream	Found that there was a higher physiological response and mortality (12%) in bright (healthy) salmon compared with kelts (starved salmon) (0% mortality). Also took blood at intervals to monitor recovery, found that lactated peaked 2hrs after angling and only returned to normal levels after 12 hrs.
Brownscombe et al. 2014	Largemouth bass *(Micropterus salmoides)*	Canada	Lake, freshwater	To evaluate the influence of water temperature and fight intensity on the **physiological stress** response and **reflex impairment** of angled fish	Water temperature was the most important predictor of stress response, with colder temperatures resulting in a greater stress response and reflex impairment than warm temperatures
Clapp and Clark 1989	Smallmouth bass *(Micropterus dolomieu)*	United States of America	Freshwater	To determine the effect of **hooking injury** on **mortality** and **growth rate**	Found that some fish were susceptible to multiple recaptures, while others were not caught at all. Found that there was a general decrease in growth for all fish and that there was a significant regression of growth vs number of hooking events
Colotelo and Cooke 2011	Northern Pike (*Esox lucius*) and largemouth bass (*Micropterus salmoides)*	Canada	Lake, freshwater	To evaluate the sources of angling induced **epithelial damage** of capture fish	Tested the epithelial damage caused by different handling techniques (i.e landing net types, boat floor surfaces and tournament procedures). Northern pike exhibited extensive epithelial damage after exposure to several treatments (worst being, knotted nylon nets, carpeted boat surfaces and line rolling). Largemouth bass didn't show any significant damage to any of the treatments.
Cooke et al. 2001	Rock Bass *(Ambloplites rupestris)*	United States of America	Freshwater	To examine the effect of hook type and bait on **injury** and **mortality** as well as the effect of C&R on **cardiac disturbance**. Exposed fish to 30s or 180s air exposure.	Found that fish caught using worm bait were hooked more deeply than fish caught on jigs. Fish caught on barbless jigs were unhooked faster than other tackle type and experience an average of 20s

					air exposure, other tackle types caused longer air exposure times. Fish in lab studies were chased to simulate C&R and exposed to 30s or 180s air exposure, during chasing cardiac output increased greatly and was slightly arrhythmic, then during air exposure it fell drastically. Fish exposed to 180s required double amount of time to recover (4h) to those exposed to 30s.
Cooke et al. 2005	Bluegill *(Lepomis macrochirus)*	Canada	Lake, freshwater	To evaluate the effect of circle **hook size** on **hooking efficiency**, **injury** and size selectivity.	Found that the largest hook size had low hooking and capture efficiency but selected larger fish, small hooks also had low hooking efficiency and selected smaller fish sizes. Jaw hooking increased with decreasing hook size. Gullet hooking only occurred with the smallest hook sizes.
Dempson et al. 2002	Atlantic salmon *(Salmo salar)*	Canada	Riverine, freshwater	To evaluate the **effects of C&R** on Atlantic Salmon. Fish exposed to an average of 22.2s (air exposure times were not controlled)	Reported an 8.2% mortality rate, but 12% died among salmon angled in high water temps (>17.9C), no mortalities occurred in salmon caught in cool water temps. Of the mortalities, all but one occurred within 4hrs of capture, one died a week after capture
Fobert et al. 2009	Bluegill *(Lepomis macrochirus)*	Canada	Lake, freshwater	Investigated whether removing deeply swallowed **hooks** or leaving them in was better for **survival**	Overall found it was better to cut the line and leave the hook in rather than remove it.
Klefoth et al. 2008	Northern Pike *(Esox Lucius)*	Germany	Lake, freshwater	Examined the impact of C&R angling on the **short-term behaviour** and habitat choice of northern pike. Exposed fish to 30s air exposure.	Reported a 7.4% mortality rate due to hooking mortality. Also found that minimum displacement per hour (movement) and distance to shore were significantly lower upon 1st post-release tracking compared to baseline tracking (before C&R). However, on

					2nd tracking behaviour appeared to be back to normal, showing that behavioural/movement change after C&R was temporary and pike recovered after C&R.
Lindsay et al. 2004	Chinook Salmon *(Oncorhynchus tshawytscha)*	United States of America	Riverine, freshwater	To examine the effect of **hooking location** on fish **mortality**	Found that mortality was lowest for fish hooked in jaw (2.3%) and highest for those hooked in the gills (81%) and in the oesophagus-stomach (67%). Concluded that mortality was largely dependent on hooking location.
McLean et al. 2016	White sturgeon (*Acipenser Transmontanus)*	United States of America	Freshwater	To validate a **reflex impairment** protocol by exposing sturgeon to simulated C&R event during summer and winter and then linking the resulting reflex impairment to **stress physiology** and recovery times.	Found that all fish experienced a physiological stress response when exposed to the C&R event, with the magnitude of the response linked to the duration of the stressor. Reflex impairment was more pronounced during summer temperatures. Also found that reflex impairment was also correlated with lactate concentrations (e.g. physiological stress related to exhaustive exercise)
Philipp et al. 1997	Small (*Micropterus dolomieu*) and largemouth bass (*Micropterus salmoides)*	Canada	Lake, freshwater	Examined the effects of C&R stress on the **reproductive success** of bass. Exposed fish to 60s to 180s air exposure.	Found than increased handling time and air exposure resulted in a stronger likelihood of nest abandonment and that bass in areas of higher exploitation has lower reproductive success rates.
Pope et al. 2007	Rainbow trout *(Oncorhynchus mykiss)*	United States of America	Freshwater	To examine the effects of C&R angling on **growth** and **survival** of rainbow trout	Found that survival rates were very high for this species (96%), but this was likely due to the fact that fish were purposefully hooked in mouth with no deep hooking. but has been found in other studies that this species has a high C&R survival rate (even in wild). Also found that there was no effect on growth rate,

					even for fish caught multiple times (4X).
Pope and Wilde 2004	Largemouth bass *(Micropterus salmoides)*	United States of America	Freshwater	To examine the **effects of C&R** angling on **growth** of largemouth bass. Exposed fish to 25s air exposure.	Found that there was no difference in mortality rates between caught and control fish. There was no difference in growth rate between caught and uncaught largemouth bass (however one fish was hooked through the eye which could cause significant feeding problems in wild). Almost all fish in this study were caught in non-lethal locations (which probably accounts for the very high survival rate).
Schreer et al. 2005	Brook trout *(Salvelinus fontinalis)*	United States of America	Freshwater	Examined the effect of different **air exposures** on the **swimming performance** of Brook Trout. Exposed fish to either 0, 30, 60 or 120s air exposure.	Found that fish exposed to 30 and 60s air exposure showed little difference in swimming performance to control fish (0s). However, fish exposed to 120s air exposure showed a dramatic decrease in swimming performance (~75%) and in some cases were unwilling or unable to swim at all.
Siepker et al. 2006	Largemouth bass *(Micropterus salmoides)*	United States of America	Freshwater	To examine the effects of angling on the **feeding** and **growth rate** of bass. Exposed fish to 120s air exposure.	Found that angling treatment had a significant effect on the delay until first feeding of fish compared to control fish. Statistical modelling predicted lower growth rates for fish that experienced reduced feeding associated with angling events, growth was even more reduced if fish were captured more than once.
Smit et al. 2009	Tigerfish *(Hydrocynus vittatus)*	Botswana	Freshwater	To test **blood lactate** for use as a biomarker for angling induced stress in tigerfish and to test the relationship between angling time and blood lactate levels.	A significant elevation in blood lactate levels after angling were observed regardless of angling time. Suggest that angling time increases physiological stress and that this may have an impact on breading success and mortality for this species.

Smit et al. 2016	Smallmouth yellowfish (*Labeobarbus aeneus)*	South Africa	Freshwater	To investigate the **response** of Orange-Vaal smallmouth yellowfish, to catch-and-release angling. Fish were collected using fly-fishing techniques, anaesthetised and had blood drawn from the caudal vasculature. Fish were then weighed, measured and finally released.	Found that overall C&R caused a physiological stress response in fish, with glucose levels affected by water temperature and a few fish experiencing increases in plasma cortisol levels. For fish exposed to extended capture times (>1min) lactate levels increased significantly. The authors suggest that future studies on this species include handling and air exposure of angled fish.
Sutter et al. 2012	Largemouth bass *(Micropterus salmoides)*	United States of America	Freshwater	To determine if recreational fishing **selectively captures** individuals with the highest fitness potential	Selectively bread male Largemouth bass for high vulnerability of low vulnerability to angling, found that HV correlates with aggression, intensity of parental care and reproductive fitness. HV males were more reproductively fit, therefore study showed that angling selectively captures individuals with the highest potential for reproductive fitness. This removal of fittest individuals could have population impacts in the long term.
Stockwell et al. 2002	Striped bass *(Morone saxatilis)*	United States of America	Freshwater	To determine if C&R fishing could constrain striped bass **growth**	Statistical modelling showed that multiple hooking events, that resulted in a day or 2 of feeding cessation, could result in a decrease in growth rate from 13-30%>. Concluded that due to the large magnitude of the C&R fishery in Massachusetts (the study area) that C&R could be contributing to the declines in the overall health of striped bass stocks.
Thorstad et al. 2003	Atlantic salmon *(Salmo salar)*	Norway	Riverine, freshwater	To evaluate the effects of C&R on Atlantic salmon by looking at **mortality** and **behaviour after**	Found high survival rate (97%) at temps of 10-14C, seemed that behaviour after C&R was affected, with

				release. Exposed fish to 180s air exposure.	downstream movement observed in a high proportion of fish (>80%). Hooking in the throat occurred in only 7% of cases, with hooking in the maxillary and upper jaw occurring most often
Thorstad et al. 2004	Nembwe (*Serranochromis robustus*) and threespot tilapia (*Oreochromis andersonii*)	Namibia	Riverine, freshwater	To evaluate the **effect of C&R** angling on two cichlid species. Exposed fish to an average of 15s air exposure (not controlled).	Found that no immediate mortality occurred (even in very high temperatures). Had one confirmed predation of released fish by a fish eagle. Movement behaviour directly following release seemed to be different to that observed a few months after release.
Thorstad et al. 2007	Atlantic salmon *(Salmo salar)*	Norway	Riverine, freshwater	To examine **survival** and **migration behaviour** after C&R of salmon downstream from spawning grounds. Exposed fish to 30 or 60s air exposure.	Found no mortalities and that C&R may result in a delay in upstream migration (which may have unknown negative effects) some fish also showed unusual downstream movement after C&R.
Whoriskey et al. 2000	Atlantic salmon *(Salmo salar)*	Russia	Riverine, freshwater	To evaluate the **effects of C&R** angling on the Atlantic Salmon	Found that fish had high rates of survival and had an 11% recapture rate. Also kept 62 captured fish for 24hrs, only one fish died (and it was heavily scarred by gill nets). Seemed that the behaviour of the fish was little altered by the angling event.

Appendix 2:

Time course of physiological stress response literature review table:

Species	**Family**	**Stressor**	**Wild or farm fish**	**Country**	**Peak time of PSR***	**Recovery time**	**Habitat**	**Authors**
Gilthead sea bream (*Sparus aurata L.*)	Sparidae	Air exposure and confinement	Farm	Spain	60 min	2 hrs	Marine	Arends et al. 1999
Common dentex (*Dentex dentex*)	Sparidae	Handling	Farm	Spain	Between 90 – 120	8 hrs	Marine	Morales et al. 2005
Bronze bream (*Pachymetopon grande*)	Sparidae	Simulated C&R	Wild	South Africa	Between 65 – 86	130 min	Marine	Pringle et al. in press
Red porgy (*Pagrus pagrus*)	Sparidae	Handling	Farm	Spain	Between 60 – 120	24 hrs	Marine	Rotllant and Tort 1997
Carp (*Cyprinus carpio*)	Cyprinidae	Angling	Farm	UK	60 min	24 hrs	Freshwater	Pottinger 1998
Chub (*Leuciscus cephalus*)	Cyprinidae	Handling and electrofishing	Farm	UK	120 min	8 hrs	Freshwater	Bracewell et al 2004
Bonefish (*Albula vulpes*)	Albulidae	Simulated C&R	Wild	The Bahamas	60 min	2- 4 hrs	Marine	Suski et al. 2007
Bonefish (*Albula vulpes*)	Albulidae	Angling, C&R	Wild	Puerto Rico	60min	-	Marine	Brownscombe et al. 2015
Pikeperch (*Sander lucioperca*)	Percidae	Simulated C&R	Wild	USA	60 min	-	Marine	Arlinghaus et al. 2007
Eurasian perch (*Perca fluviatilis, L*)	Percidae	Transport and handling	Farm	Spain	30 min	4 hrs	Freshwater	Acrete et al. 2004
Northern pike (*Esox Lucius*)	Esocidae	Angling	Wild	Canada	180 min	96 hrs	Freshwater	Schwalme and Mackay 1985
Green sturgeon (*Acipenser medirostris*)	Acipenseridae	Air exposure	Farm	USA	15 min	2 hrs	Marine, coastal	Lankford et al. 2003

Redthroat emperor (*Lethrinus miniatus*)	Lethrinidae	Angling and air exposure	Wild	Australia	15 min	-	Marine, reefs	Currey et al. 2013
Brook trout (*Salvelinus fontinalis Mitchill*)	Salmonidae	Handling and confinement	Farm	Canada	Between 60 – 120	2 hrs	Freshwater	Biron and Benfey 1994
Winter Flounder (*Pseudopleuronectes americanus*)	Pleuronectidae	Strenuous exercise	Wild	USA	Between 120 – 240	-	Marine	Girard and Milligan 1992
Coral trout (*Plectropomus leopardus*)	Serranidae	Capture and handling	Wild	Australia	60 min	4 hrs	Marine	Frisch and Anderson 2000
Sea bass (*Dicentrarchus labrax*)	Moronidae	Confinement	Farm	Spain	60 min	24 hrs	Marine	Rotllant et al. 2003

*Physiological stress response

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