ASSESSMENT OF THE POST-RELEASE SURVIVAL AND STRESS PHYSIOLOGY OF BARRAMUNDI (*Lates calcarifer*)

Paul de Lestang, Roland K Griffin and Quentin A Allsop

Northern Territory Government
Department of Business, Industry and Resource Development

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Project No. 2002/039

March 2004

ISBN 0 7245 4708 8
Published by the Northern Territory Government

The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a federal statutory authority jointly funded by the Australian Government and the fishing industry.

Table of Contents

List of Figures

List of Tables

List of Appendices

2002/039 Assessment of post-release survival and stress physiology of barramundi (*Lates calcarifer*)

PRINCIPAL INVESTIGATOR: Mr R.K. Griffin

ADDRESS: Fisheries Group
Department of Business, Industry and Resource Development
GPO Box 3000, Darwin 0801

OBJECTIVES:

1. To assess physiological stress imposed on barramundi caught and released by anglers.
2. To assess the survival of individual barramundi caught and released by anglers.
3. To determine the effects of different landing nets on injury and mortality to barramundi.

1 NON-TECHNICAL SUMMARY

Outcomes

Results from this study have provided a reliable assessment of the post-release survival of barramundi which supports the usefulness of catch-and-release as a management tool in the recreational fishery. The results have also highlighted the distinct seasonality in post-release survival, an outcome that should guide future management of this fishery. Furthermore, the study has provided useful information on the effects of landing nets, which will lead to improvement of fish handling practices for the recreational industry.

Barramundi is an icon species of recreational fishing in Northern Australia, with an estimated 762 000 fish caught annually. The greatest proportion of this catch is from the Northern Territory (49% of the total) and represents a significant component of the total Northern Territory recreational fin-fish harvest (15%) (Henry and Lyle, 2003; Coleman, 2004). Barramundi is also targeted in Queensland and Western Australia (40% and 19% of the total barramundi caught respectively) but these fisheries represent less than 1% of the total recreational fin-fish fisheries for the two respective states (Henry and Lyle, 2003).

The practice of catch-and-release fishing is a significant part of the barramundi fishery and is demonstrated by the high proportion (72%) of barramundi caught and released across Northern Australia annually (Henry and Lyle, 2003). The release of barramundi by recreational anglers is becoming almost expected, as fishers become more aware of fish biology and conservation values. This applies particularly to the larger barramundi (> 90 cm) that are generally female. By releasing these fish, it is hoped that barramundi stocks will remain in pristine condition, and thus excellent barramundi fishing will continue. However, studies in Australia and overseas have shown that released fish do not always survive, with post release survivals varying from as high as 98% for the common snook (*Centropomus undecimalis*) and 97% for tailor (*Pomatomus saltatrix*), and as low as 33% for striped bass (*Morone saxatilis*) (Bettoli and Osborne, 1998; Taylor et al., 2001; Ayvazian et al., 2002). Previous studies have also found a significant effect of temperature on the survival rates of released fish (Muoneke and Childress, 1994; Bettoli and Osborne, 1998).

An estimate of post-release survival is important in any fishery where catch-and-release is widely practised as it provides mortality estimates for use in stock assessment, assists fisheries managers in developing appropriate catch and size limits, and aids in developing an awareness of the role of anglers in conserving

fish stocks. Until recently, there has been no information on the survival rate of released barramundi and how this is influenced by different water temperatures.

This study has, for the first time, demonstrated the effects of angling on the physiology and survival of barramundi and has found that barramundi show a significant physiological response to capture. Knowledge gained from this study will greatly improve the reliability of barramundi management for recreational fishing and provide useful information that will lead to improved fish handling practices.

Objective 1. Assess the physiological stress imposed on barramundi caught and released by anglers.

- A series of trials were conducted, catching and playing barramundi for specified times ranging from a few seconds (controls) to five minutes. Fish were also held in pens after capture to determine how quickly they recovered from angling-induced stress.

- To determine the physiological response, a 1 mL sample of blood was drawn from each fish and analysed for changes in two commonly used stress indicators (plasma cortisol and plasma lactate).

- In total, 116 barramundi ranging in size from 38-84 cm were caught and sampled in Wildman Billabong. These fish showed a significantly elevated physiological response to capture with concentrations of both stress indicators greatest one hour after capture and decreasing over 24 hours.

- Longer landing times were shown to significantly increase lactate levels but did not affect the magnitude of the cortisol response.

- An effect of season was also found, with those fish tested in summer demonstrating significantly higher levels of plasma cortisol and plasma lactate than those tested in winter.

Objective 2. Assess the survival of individual barramundi caught and released by anglers.

- To determine the post-release survival rate of barramundi, 61 fish were caught by rod, reel and lure from a freshwater billabong and tagged with a radio-tracking transmitter. Individual fish were then followed for up to seven days, or until the transmitter was recovered.

- In the summer trial six fish died within 72 hours of release, but no mortalities were recorded in winter. This equates to an overall post-release survival rate of 90.5 %, with an 80% survival rate in summer and 100% survival rate in winter. However the sample size in this study was small and it should not be assumed that all fish released in winter will survive.

Objective 3. Determine the effects of landing nets on injury to barramundi.

- The effects of two types of landing nets on injuries to large fish were experimentally assessed at the aquarium facilities of the Territory Wildlife Park, Northern Territory. The two types of net, the knotted and knotless landing net, represented the two commonly available nets in the NT.
- Barramundi were caught and held in one of the two landing nets for 60 seconds and then released into a glass aquarium where injuries to the body and fins were visually assessed and quantified.
- All of the barramundi examined exhibited some skin abrasions and fin damage after being held in landing nets but the extent of damage was much greater for those fish held in the knotted net.
- There was no mortality observed within the 96 hour post-treatment observation period.

KEYWORDS: Barramundi; *Lates calcarifer*; Centropomidae; Angling; Stress physiology; Survival; Cortisol; Lactate; Telemetry; Mortality; Landing nets.

2 ACKNOWLEDGMENTS

The conception, design, and experimentation of this project has relied on the assistance of many people and organisations. We wish to thank the large number of very keen volunteers who assisted in the sampling, including the Amateur Fishermen's Association of the NT, the NT Fire and Rescue volunteers, Fisheries Group staff, John Harrison, Dion Wedd, Wayne Baldwin, Steve Borrmann, Michelle de Lestang, Shawn Handley, Darren Spencer, Mike Chambers and Bar Portelli. We also wish to gratefully acknowledge the assistance of the following organisations: Territory Wildlife Park, Crocodylus Park, Barramundi Fishing Park, Elizabeth Downs Station, Voyages Hotels (Wildman Resort) and Australia Barramundi Culture (Bob Richards). We are grateful to Dr John Carragher for providing valuable and methodological advice, Mark Hearnden for statistical advice, Dave Irvine of ENVIRONET for providing the knotless landing nets, Chris May for permission to use his barramundi drawing, Rob McFarlane for advice on blood analysis techniques, and Simon de Lestang and Kylie Higgins for their constructive criticism during the preparation of this report.

3 BACKGROUND

Barramundi (*Lates calcarifer*) is an icon of Northern Australia, and is the basis of significant recreational and commercial fisheries. For example, in the Northern Territory, the 25 commercial licensees take an average of around 600 tonnes of barramundi per year, with a landed value exceeding $5 million. The recreational fishery targeting barramundi is very important with 43% of all recreational effort in the NT directed toward the species (Coleman, 2004). It is a significant fishery in terms of its value to the NT economy and its potential impact on the stocks. Coleman (1998) estimated that direct expenditure on recreational fishing in the NT in 1995 was just over $30 million. In 1995 recreational barramundi fishers took 94 000 barramundi and released 135 000 (Coleman, 1998). This figure has now increased with a recent report (Coleman, 2004) estimating the 2000 barramundi harvest to be just over 100 000 fish with 300 000 released.

The recreational fishery for barramundi is regulated by a mixture of input and output controls. A minimum legal length of 55 cm applies throughout the NT and a possession limit of five barramundi also applies, except in the Mary River Management Zone where the limit is two. In Queensland a maximum size limit of 120 cm applies, while in the Ord River in Western Australia, all barramundi less than 55 cm and greater than 80 cm must be released.

Catch-and-release fishing is becoming increasingly popular as anglers become aware of barramundi biology and conservation values. Increasingly, fish that may legally be retained are being released. This particularly applies to larger fish (those over 90 cm) which are more likely to be females. The combined effect of catch-and-release practices and possession limits will lead to fewer barramundi being retained with an increased proportion being released. While the biology of barramundi is generally well known, very little is actually known about the stresses imposed by catch-and-release and the consequences for survival of released fish.

4 NEED

The recreational fishery for barramundi in the NT is formally regulated by seasonal area specific closures, minimum size and possession limits, and enhanced by the increasing practice of catch-and-release fishing. The effectiveness of such regulations and practices is to a great degree dependent on the rate of mortality of the released fish. Released fish may die directly from the stress of capture, or from injuries received while being landed, or they may be at a higher risk of predation as they recover. Post-release mortality (also called cryptic mortality) has been described for many species worldwide, but no relevant information is available for barramundi. Should recreational effort in the NT increase in line with projected population increases, there may be a need to tighten management of barramundi by further output controls. Alternatively, other arrangements could be considered such as the designation of some more popular areas for catch-and-release fishing only. To properly assess the effectiveness of such restrictions it will be necessary to estimate cryptic mortality. In situations where large catches of sub-legal size barramundi are seasonally common (such as at Shady Camp barrage, Roper Bar and Daly River Crossing) even a low rate of post-release mortality may lead to a significant increase in actual fish mortality. At Shady Camp in 1989 and 1990 it was estimated that catch-and-release of small barramundi was so high that a cryptic mortality of only 10% could have caused an increase in total deaths due to fishing of almost 70% (Griffin, 1987). A study of recreational fishing in the NT in 1995 (Coleman, 1998) found that barramundi anglers caught a total of 229 000 fish but retained only 94 000 (41%) of them. If 20% of the released fish had died the extra fishing induced deaths would amount to 27 000, an increase of 29% on the recorded fish mortality.

A recent study of line-caught striped bass *(Morone saxatilis)* in southern USA (Bettoli and Osborne, 1998) estimated post-release mortality rates to be as high as 67%. Observations during the annual *Barramundi Classic* fishing tournament at Daly River have shown a reasonably high number of caught-and-released fish collected after being fatally injured (bitten in half) by sharks. Others may have not been observed, or may well have been completely consumed by the sharks or other predators such as crocodiles or birds. During some years of the tournament around 1% of the tagged fish were recovered dead during the tournament. While this does not suggest a high rate of post-release mortality, the actual number of deaths in those instances was likely to be higher, given the abundance of predators capable of disposing of the evidence.

Information on stress physiology will also be of use to the aquaculture industry in understanding and managing stress in barramundi farm stock, but is of secondary consideration in this project.

5 OBJECTIVES

The objectives of this study were to:

1. Assess physiological stress imposed on barramundi caught and released by anglers.
2. Assess the survival of individual barramundi caught and released by anglers.
3. Determine the effects of alternative landing net designs on injury and mortality to barramundi.

Objectives 1 and 2 were stated in the initial funding application made to FRDC. While conducting the above studies it became clear that the design of the landing net used may strongly influence the results of the experiments meant to address the first two objectives, thus the effects of the landing nets became an additional objective.

6 THE PHYSIOLOGICAL STRESS IMPOSED ON BARRAMUNDI BY ANGLING

6.1. Introduction

Physiological stress in fish is defined as that environmental or biological challenge that elicits a compensating response by the fish (Wedemeyer et al., 1990). It has been well documented that angling causes an often acute physiological response (e.g. Beggs et al., 1980; Gustaveson et al., 1991; Muoneke and Childress 1994; Davis et al., 2001) and thus, by definition, is a cause of stress to the fish. The physiological responses of fish to stressful events, such as angling, include changes to blood and tissue chemistry. These changes are classified into primary, secondary and tertiary responses, depending on their temporal occurrence and the mechanisms involved (Mazeaud et al*.,* 1977; Tomasso et al*.,* 1996).

The primary stress response, stimulated at the onset of a stressful event, initiates a neuroendocrine reaction in fish (Mazeaud et al., 1977; Wedemeyer et al., 1990). This includes the activation of the hypothalamic-pituitary-interrenal (HPI) axis and sympathetico-chromaffin system resulting in the subsequent release of corticosteroids and catecholamines into the blood (Mazeaud et al., 1977; Percival, 1999; Wedemeyer et al., 1990). Cortisol, the dominant corticosteroid hormone in fish, is typically used as a measure of the physiological disturbance resulting from stress (Mazeaud et al., 1977; Mommsen et al., 1999). The abundance of information on cortisol in fish merely reflects the accuracy and simplicity of the assay procedure, and the ability to determine resting levels (Mommsen et al., 1999).

The release of corticosteriods and catecholamines as a response to stress directly affects the surrounding tissue, potentially leading to secondary effects including hyperlactacemia and hyperglycemia (Mazeaud, et al., 1977). As such, the severity and duration of the secondary response is usually described by changes in the level of plasma lactate and plasma glucose (Carragher and Rees, 1994; Wedemeyer et al., 1990), although Percival (1999) suggested that plasma glucose is not a suitable indicator for stress in barramundi. Plasma lactate is a metabolic byproduct of anaerobic activity and does not indicate stress as such, but rather, reflects situations of strenuous exercise or conditions of reduced oxygen availability (Turner et al., 1983; Wedemeyer et al., 1990). Although extreme levels of lactic acid have been implicated in post-capture mortality in a number of species (Caillouet, 1968), Wood et al. (1983) suggest that it is not an ultimate cause of stress related mortality.

Tertiary stress responses describe the longer-term effects of elevated physiological and metabolic products. These are usually deleterious sublethal effects that include impaired growth, reproduction, and immune response (Carragher, et al., 1989; Wedemeyer et al., 1990).

Studies on a range of teleost species have established a fairly typical qualitative physiological response to angling (e.g. Gustaveson et al., 1991; Tomasso et al., 1996). However, the quantitative response (magnitude and duration) may vary greatly between species and between populations (Mazeaud et al., 1977). A causative factor for this variation is season, with the higher temperatures experienced in summer often magnifying the stress response (Davis et al., 2001).

The object of this study was to quantify the magnitude and duration of the physiological response of barramundi to angling. Plasma cortisol and plasma lactate were used as physiological indicators at the playing times of <1 (control), 3 and 5 minutes. The study was conducted in summer and repeated in winter to investigate the effects of season on the physiological response.

6.2. Methods

6.2.1. Physiological parameters

Barramundi were captured by rod, line and lure in Wildman Billabong, a seasonally isolated section of the Mary River (13º46.128 S & 130º27.116 E) between 16 October and 1 November 2002 (representing summer conditions), and between 12 and 29 of August 2003 (representing winter conditions). To minimise the effect of any possible diurnal variation in basal cortisol levels, all fish were caught between 6.45 am and 11 am.

In order to investigate the effect of landing time on the physiological response of barramundi, fish were played for specified times: <1 (control), 3 and 5 minutes (maximum duration for most anglers to land barramundi). During the landing of all fish, constant pressure was maintained on the line to ensure that fish were not permitted to rest, and to minimise escapes. To evaluate delayed physiological effects and recovery times, blood was taken from the landed fish at 0, 1, 4 and 24 h recovery time. All fish, other than those sampled immediately on landing (0 hour recovery time), were individually held in 1m^3 pens (Figure 1). When required, each fish was covered with a wet cloth, lifted by hand from the pens and placed inverted in a sponge-lined cradle. A 1 mL sample of blood was aspirated from the caudal vasculature using a 22 gauge syringe within 120 seconds of handling and immediately transferred to a 1.3 mL heparinized vial (Figure 2). This time period was suggested by Percival (1999) to be sufficiently rapid to avoid any sampling induced cortisol contamination. Samples were immediately put on ice and centrifuged within 30 minutes of collection. All samples were then stored in liquid nitrogen for later determination of plasma cortisol and plasma lactate concentrations.

Figure 1. Net cages used to hold the barramundi prior to blood sampling

Figure 2. Taking blood from the caudal vasculature of an inverted barramundi

Plasma cortisol was measured by a commercial fluorescence polarisation immunoassay using the TDx analyser (Abbott Diagnostics, Illinois, USA) modified for use with fish plasma. Plasma lactate was determined enzymatically using lactate oxidase/peroxidase (dry slide) with the VITROS 950 (Ortho-Clinical Diagnostics, New York, USA).

Each fish was sampled only once. After taking blood, the lengths of all fish were measured (total length; cm) and each fish tagged (Hallprint dart tag) before being released. The water temperature and dissolved oxygen were measured each day of the experiments using a HORIBA U-10 multiparameter probe.

6.2.2. Statistical analysis

Data were analysed using a general linear model (Factorial ANOVA with covariates) (Neter et al., 1996) to determine if the main effects of season (summer and winter) and recovery period (0, 1, 4 and 24 hours), or their interaction, had any significant influence on mean lactate and cortisol levels. The total length of the fish (cm) and the time taken between hooking an individual and capturing it (landing time, in seconds) were used as covariates in the model.

Unequal cell numbers were sampled so Type III sums of squares were used to test hypotheses about differences in marginal means.

Significance levels for multiple comparison tests used to compare treatment means for the recovery period were corrected using a Bonferroni correction (Sokal and Rohlf, 1995) where $\alpha' = \alpha/k$, with k being the number of comparisons.

The interaction cell means for both lactate and cortisol data were positively correlated with their variances so empirical Box-Cox transformations were applied (Box and Cox, 1964). Values of λ for the power transformations of lactate and cortisol levels were calculated as 0.25 and –0.35 respectively.

All statistical tests were calculated at the 5% significance level (α = 0.05) using S-Plus statistical software (Insightful Corporation). The mean total length and water temperature were analysed for differences between seasons using a one-way analysis of variance (ANOVA). To satisfy the assumptions of ANOVA, the data was tested prior to ANOVA using Levene's test and all heteroscedastic data was $\log_{10}(x + 1)$ transformed.

6.3. Results

6.3.1. Physicochemical parameters

Both water temperature and concentration of dissolved oxygen differed significantly ($p < 0.001$) between seasons. Water temperature and dissolved oxygen (mean ± SE) varied from 29.5 ºC ± 0.03 and 2.28 mg/L ± 0.06 in summer to 27.1 ºC ± 0.12 and 3.65 mg/L ± 0.24 in winter.

6.3.2. Blood physiology

A total of 115 fish were caught and sampled. Fish captured in summer (n = 59) with a mean total length (± 1 S.E.) of 49 cm ± 7.83 were significantly ($p < 0.05$) smaller than those captured in winter (n = 56) 52 cm (± 8.16). Mean lactate and cortisol levels for the sampling periods and recovery time are listed in Table 1. Both the lactate and cortisol levels of fish were significantly higher during summer than winter. Levels of both also varied significantly according to recovery time. Lactate levels at recovery times of 1 and 4 hours were significantly higher than levels of fish just landed (0 hours). After 24 hours, the lactate levels had dropped to below the 0 hour treatment.

The individual cortisol levels from 37 fish were below the detection limit of the assay (< 18 mmoles/L) but for the purposes of statistical analysis were assigned the value of 18 mmoles/L.

Cortisol levels also increased significantly ($p < 0.001$) after 1 hour, but had decreased after 4 hours to a level that was still significantly higher ($p < 0.001$) than fish just landed. There was no significant interaction between season and recovery time for either variable (lactate, $F_{(3,105)}$=1.26, p = 0.2941; cortisol, $F_{(1,105)}$ = 1.67, p = 0.1790) (Figure 3).

The length of the fish had no effect on levels (lactate, $F_{1,105}$ = 2.08, p = 0.1525; cortisol, $F_{(1,105)}$ = 0.0069, p = 0.9936) however landing time significantly increased lactate levels ($F_{1,105}$ = 39.03, p < 0.0001) but not cortisol levels ($F_{(1,105)}$ = 0.708, p = 0.4021) (Figure 4). There was no observed mortality as a result of capture or handling.

Table 1. Main effect means (and standard errors) and significance test results for lactate and cortisol levels for each season and recovery time treatment level. Homogenous groups of levels within a factor are denoted with matching superscripts.

Main effect	Lactate mean (SE) (mmoles/L)		Cortisol mean (SE) (nmoles/L)	
Season				
Summer	5.19	(0.460)	68.01	(7.888)
Winter	3.96	(0.430)	41.25	(3.499)
	$F_{(1,105)}$ = 6.51, p = 0.0122		$F_{(1,105)}$ = 12.61, p = 0.0005	
Recovery Time (hours)				
0	3.62[a]	(0.386)	19.64[a]	(1.133)
1	7.55[b]	(0.473)	98.88[b]	(11.474)
4	6.47[b]	(0.541)	59.43[b,c]	(6.221)
24	0.88[c]	(0.217)	40.78[c]	(4.023)
	$F_{(3,105)}$ = 124.65, p < 0.0001		$F_{(3,105)}$ = 47.45, p < 0.0001	

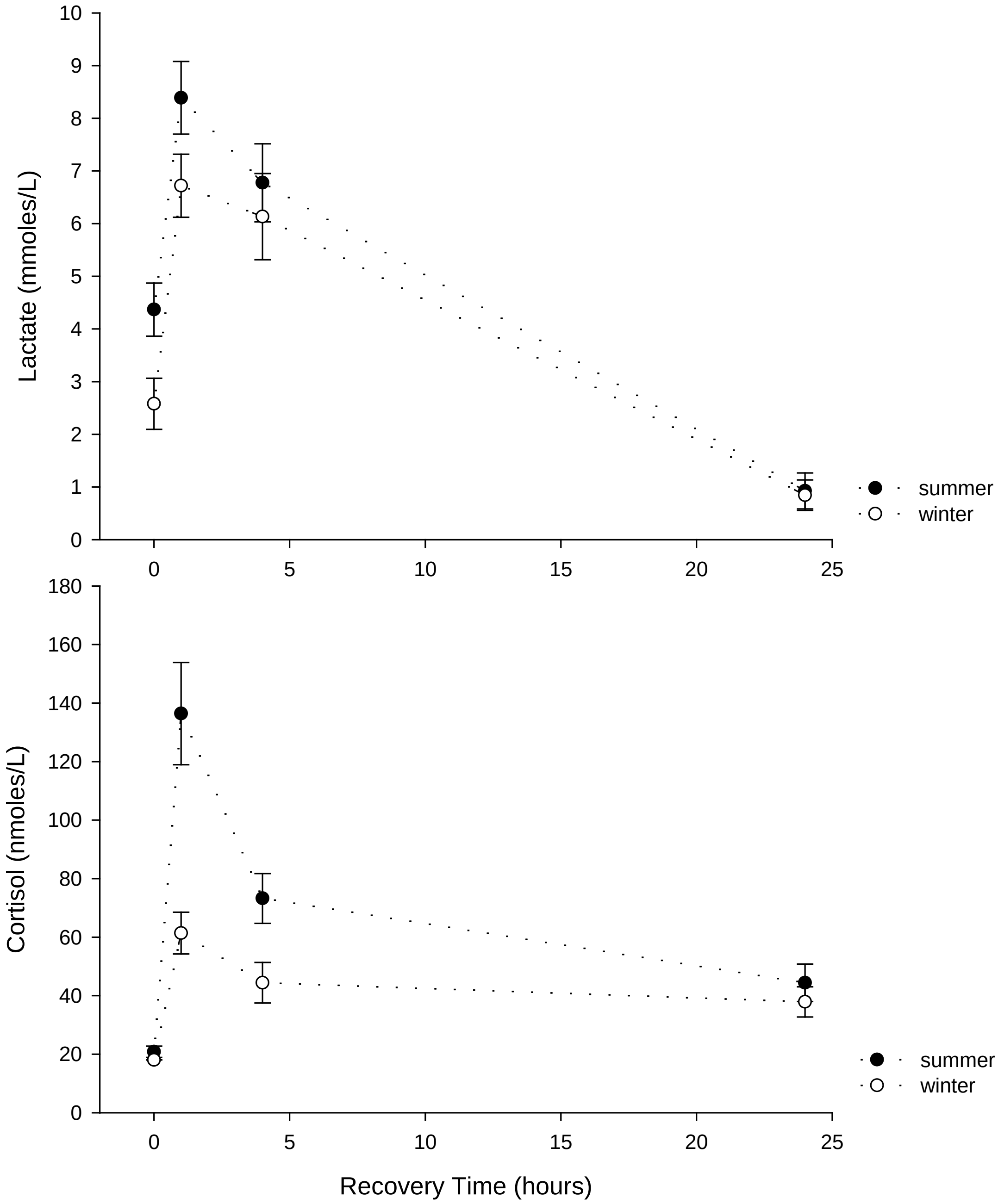

Figure 3. Interaction means (± 1 SE) for lactate (top) and cortisol (bottom) levels for each recovery period during summer (solid circles) and winter (open circles)

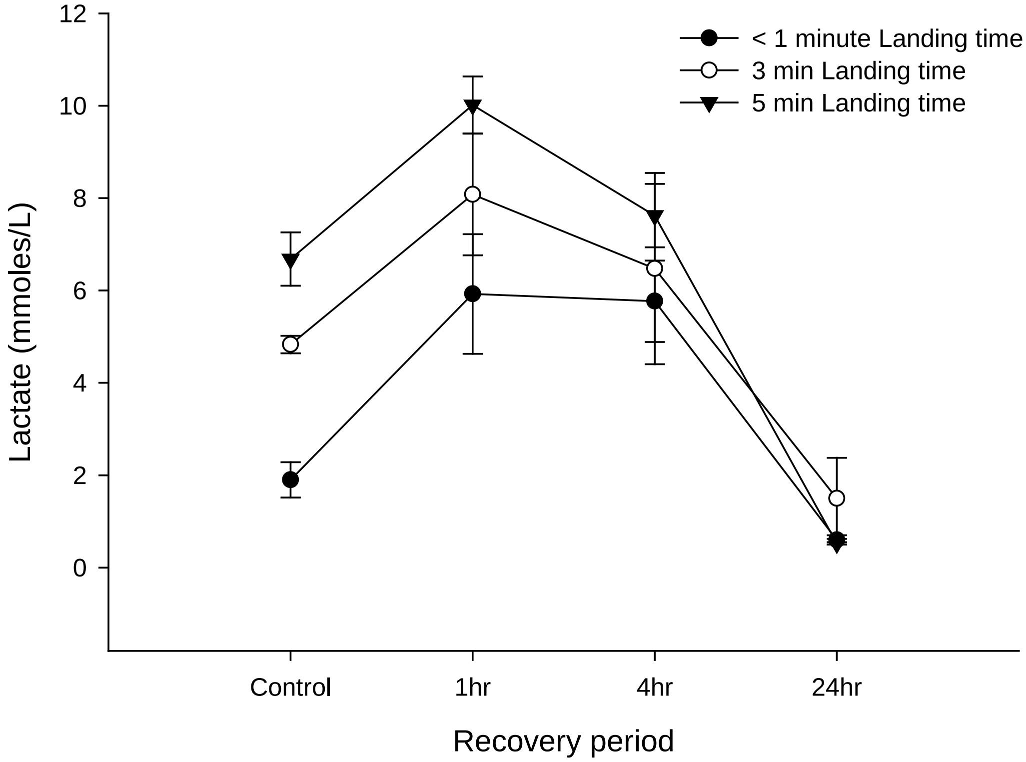

Figure 4. Mean lacate levels (± 1 SE) at each recovery period for the landing periods, control (solid circles), 3 minutes (open circles) and 5 minutes (solid triangle)

6.4. Discussion

This study quantified the effect of angling on the physiological response of barramundi. The results found that hooking and landing barramundi caused significantly elevated levels of plasma cortisol and plasma lactate. These chemical alterations were more pronounced in summer than winter and in general were judged to be within physiological tolerance levels for those fish played for five minutes or less.

The change in the concentration of plasma cortisol, the main corticosteroid in fish, is used as a measure of stress (Mommsen et al., 1999). This study found that barramundi responded to angler capture with a fairly typical plasma cortisol response, with concentrations quickly increasing immediately after the stressor (angler capture) followed by a gradual decrease over a longer period of time (Mommsen et al., 1999). The mean cortisol concentration recorded for control fish (19.64 nmoles/L ± 1.133) in this study was higher than the resting concentration reported for barramundi (< 10 nmoles/L) by Percival (1999) and for other species such as the golden perch *(Macquaria ambigua*) (Carragher and Rees, 1994) and carp (*Cyprinus carpio*) (Pottinger, 1998). However, in this study, the cortisol concentration in 10 of the 12 control fish were below the detection limit of the assay, *i.e*. 18 nmoles/L, but for statistical analysis were given the value of 18nmoles/L. Thus the mean concentration recorded immediately on landing in this study does not represent the basal cortisol level for barramundi but rather is an indicator of the magnitude of increase in plasma cortisol over the recovery times.

Barramundi showed a mean peak level of plasma cortisol one hour after capture of *ca*. 100 nmoles/L with several samples as high as 240 nmoles/L. These levels were similar to those described in other species, such as black bream (*Acanthopagrus butcheri*) (Haddy and Pankhurst, 1999) and chinook salmon (*Oncorhynchus tshawytscha*) (Barton and Schreck, 1987), but were under the maximal level expected in a severely stressed barramundi (*ca.* 490 nmoles/L) (Percival, 1999).

The results describe a decrease in mean cortisol levels at four and 24 hours but, at 24 hours, the level was still twice that recorded at capture. Elevated levels of cortisol, 24 hours after a stressful event, have been described for other species, such as chinook salmon (Jepsen et al., 2001). However, retaining the barramundi in holding nets during this study may have been a further (and continual) stressor masking the actual recovery period. This phenomenon was described by Gustaveson et al. (1991), who investigated the effects of angling on the physiological responses of largemouth bass (*Micropterus salmoides*). On the other hand, Pottinger (1998) clearly demonstrated that the retention of carp (*Cyprinus carpio*) after capture did not cause an additional stress to the fish.

Variation in landing time did not significantly affect the magnitude of plasma cortisol response, but rather appeared to elicit a similar response in terms of magnitude and temporal recovery. Thus, in barramundi, a significant elevation of cortisol levels will occur irrespective of time taken to capture the fish.

The accumulation of lactate in fish occurs as a result of anaerobic metabolism in the white muscle fibres and is described as a secondary response to stress (Reubush and Heath, 1997; Clements et al., 2002). The concentration of plasma lactate in barramundi during this study showed a similar trend over time to plasma cortisol, with levels significantly elevated after one hour and decreasing thereafter until 24 hours. At 24 hours, plasma lactate was significantly lower than at initial capture. The minimum and maximum levels of plasma lactate recorded in this study (0.88 – 7.55 mmole/L) were elevated compared with those reported by Percival (1999) (0.1 – 4 mmole/L) for hatchery reared barramundi, but were similar to other species such as wild populations of rainbow trout (*Oncorhynchus mykiss*) (1.37-7.15 mmoles/L) (Pankhurst and Dedual, 1994). The higher resting and elevated levels of plasma lactate in this study compared with that described by Percival (1999) could be related to the initial fitness and physical activity between the two test populations, and the differences in the severity of the exercise between the two studies. Love (1970) suggests that physically conditioned fish typically have higher levels of plasma lactate than unconditioned fish.

The duration of elevated plasma lactate concentrations for barramundi described in this study is consistent with that described for other species such as rainbow trout (Pankhurst and Dedual, 1994), carp (Pottinger, 1998), and striped bass (Reubush and Heath, 1997), with complete recovery occurring in 24 hours. The effect of landing time was also found to elicit a similar response to that described for other species such as largemouth bass and striped bass (Gustaveson et al., 1991; Tomasso et al., 1996). In those studies, the duration of the stressor (i.e. landing time) was proportional to the magnitude of plasma lactate response.

Season was found to greatly affect the plasma cortisol and plasma lactate response in barramundi. The physicochemical water variables in summer were characterised by significantly higher water temperature and lower levels of dissolved oxygen relative to that recorded in winter. The effect of poor water quality (i.e. high temperatures and lower dissolved oxygen) on the degree of a stress-induced response is well described (*i.e*. Tomasso et al., 1981; Kieffer et al., 1994; Davis et al., 2001). The increased level of both plasma cortisol and plasma lactate recorded in summer demonstrated a similar temporal recovery trend to those variables recorded in winter, with no significant difference in the corresponding samples after 24 hours. Thus, in barramundi, environmental stress increases the extent but not the duration of the physiological and metabolic response to a stressor.

In the present study, no mortalities were observed during or post sampling. However, short-term post-release moribund or dead fish may have been removed or disposed of unobserved by the large number of scavengers (raptors and crocodiles) in the area.

6.5. Conclusion

The physiological response of barramundi to capture during this study was found to be within the tolerance limits, and did not appear to directly cause any short term mortalities. Furthermore, the present study demonstrates that barramundi respond in a similar way to that typically described for many fish species. However, the sublethal effects of elevated physiological and metabolic responses on the growth and reproduction of barramundi are yet to be described. Adverse effects associated with stress can include reduced and delayed reproductive capacity, increased susceptibility to infection and decreased growth rates (Pickering and Pottinger, 1985; Carragher et al., 1989; Campbell et al., 1992; Haddy and Pankhurst, 1999). It is suggested that these factors need to be investigated before the effects of recreational angling on barramundi can be fully understood.

7 THE POST RELEASE SURVIVAL OF BARRAMUNDI CAUGHT WITH RECREATIONAL FISHING TACKLE

7.1. Introduction

Barramundi is an icon of Northern Australia, attracting anglers from across Australia and overseas. This fish is the basis of a significant recreational fishery with an estimated annual recreational catch of more than 762 000 fish across the top end (Henry and Lyle, 2003). The greatest proportion of this catch is from the Northern Territory (49%) followed by Queensland (40%) and Western Australia (10%) (Henry and Lyle, 2003). The practice of catch-and-release fishing is a significant part of this fishery and is demonstrated by the high proportion (72%) of barramundi caught and released across Northern Australia annually (Henry and Lyle, 2003). The trend toward catch-and-release fishing is due to management controls, such as possession limits and minimum size restrictions, and to the general increase in angler conservation awareness (Muoneke and Childress, 1994; Lyman, 2002). Catch-and-release fishing is a growing trend world wide, partly driven by an increasing demand on depleting stocks, and partly by a greater education, awareness and understanding of fishery sustainability (Radonski, 2002).

The success of catch-and-release fishing is based ultimately on the survival of the released fish, and knowledge of the short and longer-term survival rates is required not only for stock assessment analysis but also to determine the success of management controls (Muoneke and Childress, 1994; Nelson, 2002). Mortality associated with angler capture is often classified into initial and delayed mortality (Muoneke and Childress, 1994). Initial mortality refers to those fish that are dead or so severely injured on landing that they are judged not able to survive (Muoneke and Childress, 1994). The period of time suggested for delayed or short-term mortality varies with species, but is generally within 72 hours of release (Harrell, 1988; Muoneke and Childress, 1994).

Reviews such as Mouneke and Childress (1994) describe the survival rate of many species and identify the large variation in survival rate which exists between and within species. They also suggest a number of factors which contribute to post-release survival, including environmental conditions (primarily temperature and oxygen) and hook position. Although most, if not all, species exhibit some post-release mortality, Mouneke and Childress (1994) suggest that survival rates must be below 80% before being considered excessive and requiring management intervention.

There have been several different methods employed in previous studies to determine post-release mortality. Generally during studies fish have been caught using standard angling methods and are held for a period of time in observation tanks (e.g.Taylor et al., 2001; Ayvazian et al., 2002). These methods may introduce stresses that are not found in the natural environment (captivity and transport) as well as insulating the fish from possible interactions (predator) in the natural environment (Carmichael et al., 1994; Barnett and Pankhurst, 1998). Telemetry is another method employed as a means of observing the fate of fish (e.g. Bettoli and Osbourne, 1998; Isely et al., 2002). This methodology allows fish to be caught and released back into the natural environment with minimal extra stress and has recently been successfully used in studies on the post-release mortality of striped bass in the United States (Osborne and Bettoli, 1995; Bettoli and Osborne, 1998). However, no radio tracking studies on the post-release survival of barramundi have been conducted.

The objective of this study was to describe the short-term (within 72 hours) mortality of barramundi using a retrievable radio transmitting tag. A further aim was to investigate the effect of season (summer and winter) on the mortality of barramundi.

7.2. Methods

To investigate the survival rate, barramundi were captured by normal angling methods in Mission Billabong, a seasonally closed section of Elizabeth Creek, which is a tributary of the Daly River (S13º46.128; E130º27.116) (Figure 5). Since mortality rates in previous studies varied significantly with season (Muoneke and Childress, 1994; Bettoli and Osborne, 1998) this study was conducted in both summer (14-24 October 2002) and repeated in winter (22-9 August 2003) using the same methodology.

Figure 5. Fishing for barramundi in Mission Billabong

During the field trips, volunteer anglers recruited to simulate typical fishing conditions were encouraged to handle fish in a manner consistent with their normal practices. All fish were captured using conventional fishing tackle (rods and reels) and artificial lures with either single or treble hooks. Participating anglers were separated into teams of two people per boat. Each boat was provided with stop watches to record playing time, a knotted landing net and an air horn to signal the tagging boat. The tagging equipment was kept in the research boat, which maintained visual contact with the other anglers. When a lure was struck, the second angler of the capture boat started recording the time and then signalled the research boat. This initial 'landing time' was the time between hooking the fish until it was brought to the side of the boat and captured in the landing net. The fish was then lifted into the capture boat using the landing net and the hooks were removed by the angler as per normal practice. The time between capturing the fish in the landing net and handing the fish to the tagging boat is referred to as the handling time. After unhooking, the fish was immediately handed to the research boat, wrapped in soft wet material and restrained in a sponge-lined cradle. After measuring the fish's total length to the nearest centimetre, a Hallprint dart tag and a radio transmitter tag were attached to each fish externally (described below) and the fish was immediately released (Figure 6). The time taken for this part of the process is referred to as the tagging time. Other recorded measurements included location of capture, number of hooks on the lure and hooking location. The hooking location was recorded as mouth, throat, gills or foul-hooked (i.e. hooked to an exterior location such as the operculum, cheek or eye area).

Figure 6. A 100cm radio tagged barramundi just before release

Each fish was located on a daily basis for at least three consecutive days after release (Figure 7). About 75% of the fish were located each day for at least seven consecutive days after release. When a fish was located, the tag number, location, pulse interval and water temperature (surface, middle and bottom) was recorded. Using the pulse rate and temperature calibration curves, the temperature of the tag's surrounding environment was estimated and then compared with that temperature recorded in the field. Some fish were actually seen when located but most were not due to poor visibility (< 1 m). Physicochemical variables of the water, i.e. temperature and dissolved oxygen, were measured on each day of the experiment using a HORIBA U-10 multi-parameter probe.

Figure 7. Radio tracking barramundi in Mission Billabong

Prior to radio tracking, experimental trials were conducted to test the effects of two potential complicating factors:

i) the consumption of tagged fish by estuarine crocodiles *(Crocodylus porosus)*; and,
ii) the effects of tagging on the fish itself.

The first experiment tested whether a radio tag could survive ingestion by a crocodile and if so, whether a signal could still be received. This experiment was conducted at the Crocodylus Nature Park with the assistance of the park staff. One radio tag was inserted into a 1kg piece of meat and the meat (plus tag) was fed to a 2 m female estuarine crocodile. Over the following five days the tag signal was checked. On the sixth day, the crocodile was anaesthetised and its jaws tied open. A volunteer then inserted his hand through the mouth of the crocodile and retrieved the tag (Figure 8). At the time of retrieval the tag was still transmitting and on examination, both the tag and crocodile showed no visible signs of damage.

Figure 8. NT Government Minister for Business, Industry and Resource Development (the Hon Paul Henderson MLA) retrieving the radio transmitting tag from an anaesthetised estuarine crocodile

The second preliminary experiment investigated the possible effect of the radio tag and the tagging procedure itself on barramundi mortality. On 3 October 2002, 12 fish with a mean length of 47.4 cm $\pm$ 0.85 cm were landed in a mean time of 45s $\pm$ 0.15 by rod and reel from an artificial pond at the *Australia Barramundi Culture* aquaculture farm. On landing, each fish was wrapped in soft wet material and restrained in a sponge-lined cradle. Six of the fish were tagged with a dummy radio tracking tag as described in Section 7.2.1. The tagging process took 65 s $\pm$ 0.11. Immediately after tagging the fish were weighed and placed in one of two 1.2 m^3 floating mesh nets. The other six fish (control) went through the same handling process, although no tag was actually inserted into the fish. After the handling time of 65 s (determined from the mean handling time of the first six fish) the control fish were placed in the second mesh holding net.

After seven days the cages were removed from the water. No mortalities were recorded in either the control or tagged barramundi and all of the dummy tags had released as planned. Each fish was removed from the cage and examined for injuries associated with the tags. Small red lesions were seen on and around the attachment wounds on two of the experimental fish. The other tagged barramundi showed only signs of new scarring with no inflammation.

7.2.1. Transmitter tag assembly

Radio transmitters were used to track barramundi over a period of nine days. The transmitter tag assembly design was modelled on that of Osborne and Bettoli (1995). The transmitters (Advanced Telemetry Systems Model # F2030) were a cylindrical shaped tag 15 mm in diameter, 60 mm long and weighed 9.5 g (Figure 9). Each antenna was fitted with a cylindrical float positioned immediately behind the tag. The floats were constructed of polymer foam coated with epoxy resin and attached to the tag with wire. The total length of the assembly, including the antenna, was 360 mm with a cross-section of 15 mm. The tag and float assembly weighed about 15 g out of the water and never exceeded 2% of the animal’s weight. Once submerged, the float exerted a slight positive buoyancy.

All tags were attached to the fish using a straight triangular cutting needle (size 3) and absorbable chromic gut suture #1 (Ethicon). Attachment was through the musculature on the mid-dorsal region of the back, at the base of the dorsal fin. Once attached, liquid antiseptic (Betadine; Faulding Pharmaceuticals) was applied to all puncture wounds and the suture knots were secured with fast acting glue. The suture material decomposed after approximately nine days and the tag was released to float up to the surface where it could be located and retrieved. Tags were located using a 2 Mhz radio frequency receiver (Advanced Telemetry Systems Receiver, Model # R2000).

Each transmitter was coded with a unique frequency and equipped with mortality and temperature sensor functions. The mortality function would double the pulse rate if the tag did not move for a period of nine hours. The temperature function varied the pulse rate in accordance to the surrounding water temperature and the temperature/pulse rate relationship was modelled for each tag.

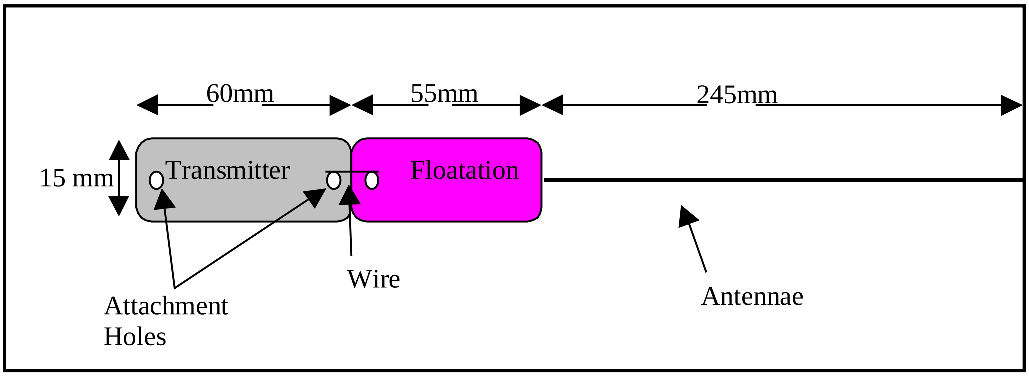

Figure 9. Diagram of the transmitter tag and float assembly used to track barramundi in Mission Billabong

7.2.2. Statistical analysis

Water temperature and levels of dissolved oxygen were analysed for differences between season using ANOVA. To satisfy the assumptions of ANOVA, the data were tested prior to ANOVA using Levene's test, and all heteroscedastic data was $\log_{10}(x + 1)$ transformed. Logistic regression was used to test the relationship between survival rate and either water temperature, landing time, handling time, tagging time, or fish length. A Student's *t*-test was used to compare the mean lengths of fish between the two sampling times.

7.3. Results

7.3.1. Physiochemical parameters

Water temperature and dissolved oxygen levels were found to be significantly different ($p < 0.001$) between the two periods of sampling. Mean water temperatures for summer and winter were 31.9 ºC ± 0.10 and 24.3 ºC ± 0.05, respectively. Mean concentrations of dissolved oxygen for summer and winter were 6.65 mg/L, ±0.15 and 7.65 mg/L, ± 0.067, respectively.

7.3.2. Tagging

A total of 61 barramundi (29 in summer and 32 in winter) were caught, tagged and tracked in the Mission Billabong. Each fish was tracked for a minimum of three days with tracking continuing for seven days for *ca* 75% of the fish. The mean times associated with the landing, handling and tagging of the fish are shown in Table 2. The time taken to land and handle the fish were ($p < 0.001$) longer in winter, while tagging time during this period was significantly ($p < 0.001$) shorter.

The tagged fish ranged in size from 42 cm to 100 cm with the mean total length of those fish caught in summer (53.6 cm ± 1.4) being significantly (p <0.001) smaller than those fish caught in winter (61.8 cm ± 2). The mean length of all fish caught in both sampling periods was found to be significantly correlated (r^2 = 0.7327; p < 0.001) with landing times.

Table 2. Mean (± 1 SE) length, landing time, handling time and tagging time of barramundi caught and released in Mission Billabong between the 14 and 24 of October 2002 (summer), and between 22 July – 9 August 2003 (winter)

Time Period	*n*	Mean length (cm)	Landing time (s)	Handling time (s)	Tagging time (s)
Summer	29	53.6 (± 13.7)	36 (± 3.49)	40.28(± 3.55)	92.78(± 4.31)
Winter	32	61.8 (± 19.0)	66.12(± 6.68)	73.45(± 8.32)	72.2(± 3.53)

The majority of fish caught in the study were hooked only in the mouth (56 fish). The other fish were hooked in either multiple positions (mouth and eye; 2 fish), in the gills (2 fish), throat (1 fish) or outer jaw (1 fish). Overall, short-term mortality occurred in 9.6 % (6 fish) of all fish tested with all of the mortalities occurring in the summer period. Four of the six dead fish were recovered floating with the tags still attached, the other two tags were found surrounded by scales on the river bank (Figure 10). There were no apparent injuries caused either during or after capture and release (marks, cuts or lesions) to any of the four dead fish found floating. In the other two cases where the tags were found on the river bank (< 1 m from the water edge), each amongst scattered barramundi scales, it appeared that the carcass of the dead barramundi had been dragged from the water, most probably by a resident white-bellied sea eagle (*Haliaeetus leucogaster).* The tag must have then been detached from the carcass prior to its consumption, either by the bird or by a crocodile. One further tag was found floating close to its release location 23 hours after release. The suture material (still attached to the float) was broken and the float was covered in small scratches or bites. As there was no evidence of a carcass, the fate of that fish could not be determined and it is therefore not included as a mortality. It is possible in this case that the tag was bitten off by another fish.

Figure 10. One of the four dead fish located during the summer phase of the radio tracking experiment

Of the six fish that died, four, (TL 62, 60, 56 and 55 cm) were hooked in the mouth; one (TL 56 cm) in the mouth and eye; and one (TL 48 cm) in the gills. Only the fish hooked in the gills was bleeding noticeably on release. In terms of behaviour on release, two of the fish were observed to sink when released while the other four appeared to quickly swim away. Those six barramundi travelled distances in the initial 24 hours after release of 23, 67, 126, 299, 454 and 1000 m, respectively, before dying. The measured variables of landing time, holding time and tagging time were found not to have any significant effect on mortality rates ($p > 0.2$).

During the study, fish movement in a 24 hour period varied from <10 m to just under 3 000 m. The mean daily distance travelled in the winter period (504 m/day $\pm$ 43.36) was significantly greater ($p < 0.05$) than during the summer period (183 m/day $\pm$ 24.81).

Although no short term mortality was found during the winter phase, one fish was found floating dead seven days after release. This fish had been previously hooked in the gills and was bleeding freely on release. In the period before dying, the fish moved an average of 781m/24 hours $\pm$474.6 with a maximum distance of 2 903 m/24 hours. The cause of its death could not be determined.

7.4. Discussion

This study has, for the first time, investigated the survival rate of recreational angler caught and released barramundi in a freshwater environment. In total, over 90.5% of the barramundi caught and released during the study survived for 72 hours. It is acknowledged that the tagging process may have accounted for a proportion of the mortality and as such, the survival rate shown in this study reflects the combined effect of catching and tagging. Furthermore, the effect of the transmitter tag may also have inhibited performance of the fish and thus increased the chance of mortality through predation or starvation (Lewis and Muntz, 1984; Thorstad et al., 2000). However, the actual effect of the tag is considered to be very small and has minimal impact on the actual mortality of the barramundi. This contention is based on several facts. Firstly, the experiment conducted prior to this study recorded no mortality in either the control (non-tagged) or tagged fish. Secondly, the difference in mortalities recorded in winter (nil) to summer (20%) suggest the mortality is not an artefact of the tagging process. Lastly, studies such as Osborne and Bettoli (1995) and Bettoli and Osborne (1998) have described only a minimal effect of the tags on the striped bass using a larger and a much heavier tag-float assembly (42 g, 290 mm x 16 mm). To demonstrate the minimal impact one study actually re-caught six tagged fish, one within two hours after tagging (Osborne and Bettoli, 1995).

The mortality of six fish in our study was attributed to the capture process. The carcasses of four of these fish were located within 48 hours of release, and upon visual examination showed no external injuries to suggest another cause of mortality. Only the tags of the other two fish were recovered, and the fish were considered deceased due to the location of the tags (up a bank) and the large number of scales found surrounding them. Crocodiles (*Crocodylus spp*.) are the main terrestrial predator of barramundi in the Northern Territory (Figure 11). However, it would be highly unusual for a crocodile to leave remains such as those found on the banks, in the short time period, and with no physical or chemical (acidic) damage to the tags (S.C. Manolis, pers. comm. Wildlife Management International, Darwin).

Raptors such as the white bellied sea eagle are another large predator in the Northern Territory that prey upon fish (Cupper and Cupper, 1981). It is unlikely that the raptors in this location will capture and remove live fish (> 54 cm) from the water (Barnes, pers. comm.). More realistically, it is suggested that the fish with tag was taken to the bank by a large raptor, when floating dead on the surface. Such behaviour by the white bellied sea eagle has previously been observed by the authors. These raptors tear and rip at food such as carrion, when feeding, (Allsop, pers. comm.), an action that could easily separate the tag from the carcass. Furthermore, it would also result in the large number of dislodged scales found on the bank surrounding the tag. Although the cause of the mortality of these fish can only be speculation, the location of the tags and associated scales suggest that scavenging by raptors is the most likely explanation. The tags were located within 72 hours of release indicating that the fish had perished and floated prior to this. This time period is consistent with the other four fish, which were found floating dead, within 48 hours of release. The location of the two tags, associated fish remains, and short time period after release are considered compelling evidence that the deaths of the two fish were due to the catch-and-release process.

Figure 11. A small (about 3 m) estuarine crocodile on the banks of Mission Billabong

The high survival rate recorded for barramundi in this study is comparable to the common snook, (98%) (Taylor et al., 2001), another member of the Family Centropomidae. However, it is much higher than that recorded for fish from other families such as striped bass (58%) (Bettoli and Osborne, 1998) and large mouth bass (75%) (Steeger et al., 1994). This high survival rate demonstrates the resilience of this family, specifically this species, to a stressful event such as angler capture. However, a survival rate of 90.5%, as indicated by this study, suggests that recreational fishing in the Northern Territory could still account for about 28 000 post-release mortalities. This number equates to 30% of the estimated recreational barramundi harvest (Coleman, 2004).

The short-term survival of barramundi was found to vary significantly between seasons, with a survival rate of 80% recorded in the warmer summer conditions compared with 100% in winter. Reduced survival rates as ambient temperature increases has been described in other studies (Muoneke and Childress, 1994; Bettoli and Osborne, 1998; Davis, et al., 2001). The increased survival rates in cooler periods are believed to be associated with lower metabolic rates and physical activity (Muoneke and Childress, 1994). This was consistent with the barramundi physiology results, which found significantly lower levels of both lactate and cortisol associated with the winter phase of the sampling.

The results did not identify any relationship between the survival rate and any of the recorded times (landing, handling or tagging), hook position, length or distance travelled/day. The lack of any relationship between measured times and fish length on survival rates has been reported by other researchers (Muoneke and Childress, 1994; Doidati and Richards, 1996; Bettoli and Osborne, 1998; Taylor et al., 2001). However, hooking location is described as a significant variable affecting the survival of many species, including the common snook (Taylor et al., 2001), striped bass (Diodati and Richards, 1996), and tailor (Ayvazian et al., 2002). The fact that no relationship was identified in this study was primarily due to the type of gear used and the small sample size. Fish in this study were predominantly caught with treble hooked lures which tended to hook the fish on the extremities, rather than internally (gills / stomach). Studies on other species, for example the small mouth bass and bluegill (Clapp and Clarke, 1989; Siewert and Cave, 1990), have demonstrated a significant increase in mortality rates in those fish hooked with baits compared with those caught on artificial lures. It is suggested that the post release survival of barramundi caught using other methods such as live baits may be significantly lower than that estimated in this study. Bait fishing for barramundi accounts for less than 15% of the total barramundi caught and released in the Northern Territory (Coleman, pers. comm.) and at those levels the significance of any increased mortality would probably be inconsequential to the management of the fishery.

This study did find a significant effect of season on the measured times and distance travelled. Mean landing and handling times were much greater in winter, while the mean tagging time was greater in summer. The longer times (landing and handling) recorded in the winter sampling merely reflect the greater size of fish caught during this period, which was positively correlated with landing times. The shorter tagging period in winter possibly reflects the increase in experience and ability of the research officers, who had previously conducted the summer phase. The difference in mean distance travelled in 24 hours between the summer and winter samples merely represents the available area at that time. In summer, the lower water levels effectively cut off a 2500 m section of downstream billabong to the fish, which, during the winter phase was available.

The high survival rate of barramundi shown in this study supports the Northern Territory management strategies of possession limits and minimum size restrictions. It also supports the growing culture among recreational anglers to fish on a predominantly catch-and-release basis. However, we have only investigated those fish in a freshwater environment, and this study highlights the effect of angling only on the short-term mortality of barramundi. Angling stress may lead to longer-term mortality, and sublethal effects such as impaired reproductive capabilities, reduced growth, and a lowered immune response (Muoneke and Childress, 1994; Wedemeyer et al., 1990; Pickering et al., 1987). We recommend further research into the sublethal effects of catch-and-release fishing, especially on the larger, mature barramundi (>100 cm) that are increasingly targeted as trophy fish.

7.5. Conclusion

Recreational fishing harvest is often perceived to be that portion of the fish caught and kept, with little regard given to that portion of the catch that was released but subsequently died due to the effects of capture. Knowledge of post-release mortality is important for the management of any fishery in which catch-and-release fishing is practised or enforced through regulations. The overall mortality rate of sampled barramundi was found to be 9.5% and thus considered unlikely to warrant management concern. However, seasonality was found to be a significant factor in the post-release mortality of barramundi and should be considered in future management strategies.

8 THE EFFECTS OF LANDING NETS ON BARRAMUNDI

8.1. Introduction

Landing nets, one of many tools used by recreational fishers to aid in the capture of fish, allow a fish to be held and lifted out of the water without stressing the line or rod (Barthel et al., 2003). They also offer a safer means of retrieving fish out of waters that are inhabited by dangerous aquatic organisms such as the estuarine crocodile (*Crocodylus porosus*). Landing nets are considered relatively friendly to the captured fish and are thus considered preferable to other landing aids, e.g. gaffs and jaw clamps, which often cause obvious damage to the fish. Therefore, it is generally assumed that the use of a landing net increases the chances of survival of a fish to be released, which with the growing trend in many recreational fisheries to practise catch-and-release fishing, is extremely important. Since the success of a catch-and-release fishery relies inherently on the survival of released fish there have been a number of studies on this subject (eg. Pottinger, 1998; Gustaveson et al., 1991; Ayvazian et al., 2001; Taylor et al., 2001). However, many of these studies have focused on hook mortality, handling time and length of "fight" and there has been little research on how landing nets may impact on the survival of released fish, especially on larger species. On small species, a study by Barthel et al. (2003) quantified the injuries of bluegill (*Lepomis macrochirus*) (<14 cm TL) that had been held in several types of landing net mesh. The results described injuries caused by all nets and found that the severity of the injuries was related to mesh type.

In the Northern Territory, landing nets are more commonly used to hold much larger fish than those described by Barthel et al. (2003). An example is the barramundi, which is commonly caught up to 1.2 m total length. In 2000, it was estimated that 417 000 barramundi were caught in the NT and an estimated 76% of these were released (Coleman, 2004). It is quite reasonable to assume that a large proportion of those released fish were handled in a landing net, and thus, any injuries could have detrimental consequences for the barramundi involved.

Landing nets come in a variety of shapes, sizes, and mesh types. In the Northern Territory the more commonly used landing nets are made of an open large-meshed knotted polypropylene material. However, some suppliers in the Northern Territory are currently marketing new types of 'fish-friendly' landing nets. These nets are often larger and are made from knotless nylon or rubber material. The manufacturers claim that the shape and material reduce the incidence and severity of injuries to fish, thus increasing the post-release survival.

From the above it follows that the aims of this study were to quantify the effects of the commonly used knotted landing net on barramundi and compare these with those effects produced from landing fish with "fish friendly" landing nets.

8.2. Methods

All barramundi used for this experiment were captured from the Adelaide River (12º 39S and 131º20E) using monofilament gillnets (stretched mesh 127 mm). The captured fish ranged in size from 45-65 cm. These fish were held in a 50 000 L tank with recirculating fresh water for a period of 12 weeks, at the end of which all injuries caused by capture and transport had healed.

At the start of each experiment, the water flow into the holding tank was stopped and the water depth was lowered to 20 cm. One randomly-selected fish was then caught in one of two landing nets and held out of water for *ca* 60 s. This time is just greater than the mean handling time (58 ± 5.2 seconds) recorded for barramundi in the post release survival survey (Chapter 7). During this holding time, each fish was weighed to the nearest 1 g and tagged (Hallprint dart tag) while still being held in the landing net. The fish was then released into a 1000 L glass recovery aquarium. In each sampling period, four fish were randomly-selected and caught using one of the two landing nets, with half of fish being caught with each trial net. This number was constrained by the size of the recovery aquarium. The two landing nets used were:

1. A coarse knotted polypropylene landing net, representative of the type commonly used by recreational anglers in the Northern Territory. This net has a twine diameter of 1.5 mm, knot diameter of 7 mm and a stretched mesh measurement of 50 mm. The net was roughly cylindrical in shape with a net mouth of 590 mm by 600 mm and depth of 750 mm (Figure 12a).

2. A PVC coated nylon welded mesh with a twine diameter of 0.5mm and rectangular mesh measurement of 1x 2 mm. The net was triangular with a flat bottom and measured 590 mm by 680 mm with a depth of 560 mm (Figure 12 b).

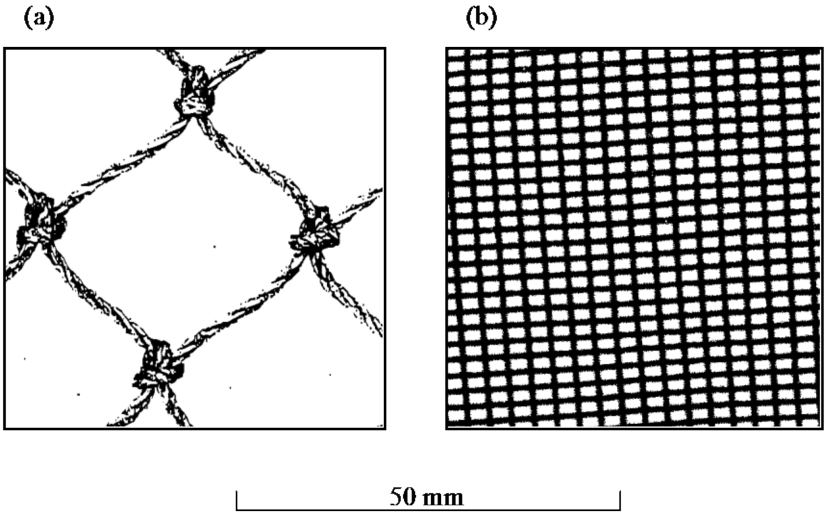

Figure 12. Illustration of the knotted (a) and knotless (b) landing net mesh used in the experiment

The condition of the treated fish was visually assessed prior to, immediately after, and four days after release (note: any injuries recorded prior to the experiment were excluded from the post treatment assessment). There was no significant difference ($p > 0.9$) between the total injury scores immediately after handling and four days after handling. As such, only the data scores determined immediately after release were used.

The damage exhibited by each fish was assessed using two different sets of criteria. The first assessed the fins of each fish for tears. Tears were scored on a scale of 0 for no tear, 0.5 for a tear that did not reach the proximal edge of the fin and 1.0 for a tear that reached from the distal tip to the proximal edge of a fin. The second set of criteria, which assessed body abrasions, subdivided each side of the fish into three sections (Figure 13). The first section of the body was defined as that area anterior to the opercular membrane; the second section from the opercular membrane to the posterior edge of the first dorsal fin base; and the third section from the posterior edge of the first dorsal fin base to the posterior edge of the caudal peduncle. Each section was ranked on a scale from 1 to 3, depending on the amount of dermal abrasions. A score of 1 represented minor dermal abrasions such as mucus loss, whereas 3 represented major abrasions including multiple scale and mucus loss. The capture, holding and release process was recorded using a digital video camera. This footage was used to determine the amount of movement of each fish whilst being held in the landing nets and was expressed as a percentage of time held in the net.

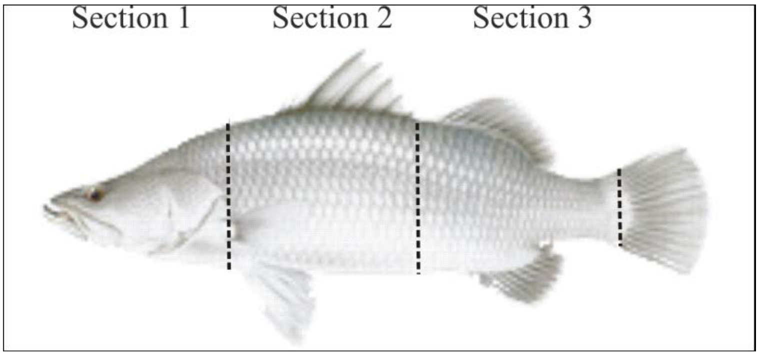

Figure 13. Fish profile and sections used to estimate dermal abrasions.
Drawing by Chris May

8.2.1. Analysis

Continuous variables (i.e. fin damage, fish weight) were analysed for differences between treatment groups using ANOVA. To satisfy the assumptions of ANOVA, the data were tested prior to ANOVA using Levene's test, and all heteroscedastic data were $\log_{10}(x + 1)$ transformed. The differences in categorical data (dermal abrasions) between treatments were analysed by Mann-Whitney U Test. All data is summarised as means ± 1 S.E.

The total scores for each fish, including fish weight and time held in net were root-transformed and a similarity matrix constructed using the Bray-Curtis similarity coefficient. The data set was subjected to the multidimensional scaling (MDS) techniques in the PRIMER package (Clarke and Warwick, 1994), using a cut level of 0.9 and 30 random starts.

8.3. Results

In total, eight barramundi were tested using each of the two landing nets and no mortalities occurred. ANOVA showed that there was no significant difference ($p > 0.05$) between the mean weight of barramundi (2.27 kg ± 0.25 and 2.34 kg ± 0. 29) or the mean time held (64.6 s ± 2.37 and 64 s ± 2.56) in the knotted and knotless landing nets, respectively.

Both types of landing nets were found to cause some damage to the fins. ANOVA demonstrated that fish landed with the knotted net possessed significantly more tears in five of their six fins (i.e. pectoral, rear dorsal, anal ($p < 0.05$), pelvic ($p < 0.01$) and caudal fins ($p < 0.001$) than those landed in the knotless net. There was no significant difference ($p > 0.05$) in the mean tears in the dorsal fin between the treatments with the knotless and knotted mesh recording 1 ± 0.21 and 1.44 ± 0.32 tears, respectively (Figure 14a). The pectoral fin was the only fin that did not receive some injury by both types of mesh, recording a mean tear of 0.31 ± 0.13 for the knotted mesh only.

Each of the three body sections recorded abrasions for the knotted mesh (1.37 ± 0.26, 1.37 ± 0.26, 1.25 ± 0.25 for sections 1, 2 and 3, respectively) while only the first two body sections (1 and 2) recorded abrasions for the knotless mesh (0.37 ± 0.18 for both sections). A Mann-Whitney test showed that there was a significant difference in amount of body abrasions between the two net types ($p < 0.05$ for sections 1 and 2 and $p < 0.001$ for section 3) with the knotted net causing greater abrasions in each case (Figure 14 b).

The amount of fish movement as a proportion of total time held in the nets differed significantly ($p < 0.01$) between the nets, with fish moving an average of 23.13 ± 2.27% and 13.69 ± 1.74% of the total time they were in the knotless and knotted nets, respectively.

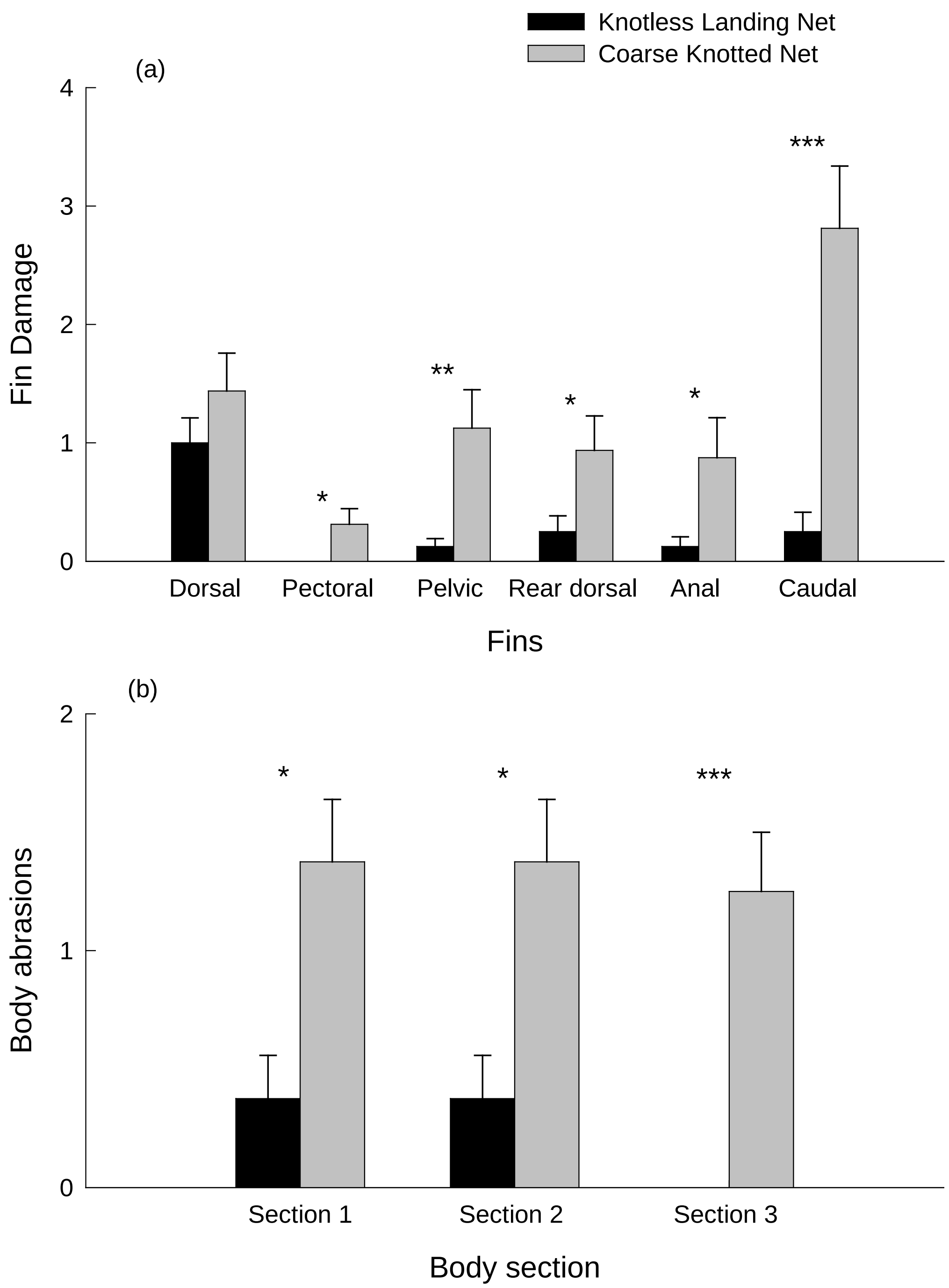

Figure 14. Injury scores associated with the capture and holding of barramundi using the coarse knotted and knotless landing nets. Panel A illustrates fin damage between the two landing nets. Panel B illustrates dermal disturbance for each body section. The level of significance is indicated by * = p<0.05; ** = p<0.01; *** = p<0.001.

When the combined injury data derived from the two nets was subjected to MDS ordination, data from each group clearly clustered together, with the knotless mesh samples clustering towards the right hand side of the plot and the knotted mesh samples towards the left (Figure 15).

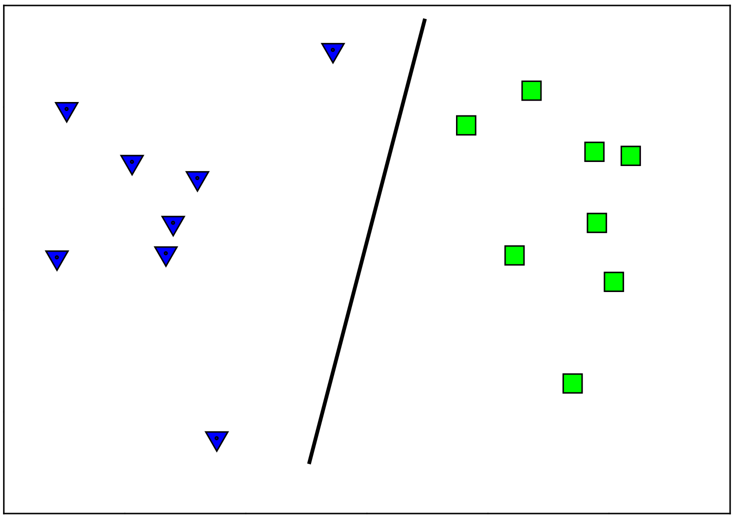

Figure 15. Two-dimensional MDS ordination illustrating the total injury score for each barramundi held in the knotted (solid triangle) and knotless (solid square) mesh landing nets (stress = 0.12)

8.4. Discussion

The results presented in this report demonstrate the level of injury that two different types of landing nets can inflict on barramundi, and that irrespective of the net type, fish will experience some injury. The results also clearly show that the incidence and severity of injury varies significantly between nets. Although all fish experienced some injury during this study due to the net, the act of catching and holding the fish did not cause any mortality during the experiment, or in the 96 hours post-treatment period. These results support those of Barthel et al. (2003) who found that landing nets do cause injuries and that the degree of injury varies with the type of mesh.

The results also demonstrated a significant difference in the number of fin tears between the two types of landing net, with the knotted meshed landing net causing substantially more tears in all but the anterior dorsal fin. It was observed during the study that fins were generally damaged when the weight or movement of the fish forced the fins through the mesh thus tearing the webbing between the rays. The smaller diameter mesh of the knotless meshed landing net prevented all but the exterior edge of the fins from pushing through the mesh resulting in significantly smaller tears relative to the knotted meshed net. Although the fin injuries observed in this study would not directly cause post-release mortality, the damage sustained to the fins may impede the swimming performance of fish. This may lead to less obvious sublethal effects such as increased susceptibility to predation and starvation (Barthel et al., 2003).

Barramundi caught and held in the knotless net exhibited only small dermal abrasions anterior to the first dorsal fin base and none posterior to the base. This is in contrast to those fish caught and held in the knotted net, which demonstrated relatively significant dermal abrasions to all three assessed areas.

Injuries caused to fish by mesh abrasion have been well described (i.e. Jónsson,1994; Sangster and Lehmann, 1994; Cooke and Hogle, 2000). The dermal mucus covering fish acts as a barrier to colonisation, containing antibacterial and antifungal properties to prevent infections (Alexander and Ingram, 1992; Barthel et al., 2003). The loss of mucus and scales due to contact with abrasive material increases the susceptibility to water born pathogens and may substantially increase the incidence of post-release mortality (Chopin and Arimoto, 1995; Cook and Hogle, 2000; Barthel et al., 2003).

The difference in shape between the two types of net tested may also have contributed to the difference in the incidence of injury. The knotless landing net was more rigid, incorporating a deeper net with a triangular, flat bottom that supported the fish horizontally, spreading the fish weight relatively evenly across the bottom of the net. In contrast, the knotted net held the fish in a more vertical position with the fish weight supported entirely on its head or caudal fin, depending on the orientation of capture (Figure 16). The greater weight and the large mesh size often forced these extremities through the mesh thus tearing or abrading that part. Paradoxically, fish were found to thrash about less in this net compared with the knotless landing net, even though it demonstrated a significantly greater occurrence of injury. The reduced movement was fundamentally due to the way the fish were held. The mesh of the knotted landing net tended to wrap around the extremities of the fish (maxilla, opercle and fins) holding it in one position, whereas fish in the knotless net were relatively unrestricted (Figure 16).

Figure 16. A barramundi held in the knotted net: Note the protrusion of the caudal and anal fins through the mesh

The present study did not record any mortality in the immediate 96 h post-treatment period. This result contradicts that found by Barthel et al. (2003) who recorded mortalities for both knotless (6%) and knotted (10%) meshed landing nets. Disparity between the results may be a function of size or variance in stress tolerance between species, although Barthel et al. (2003) identified fungal lesions (*Saprolegnia* spp.) present on all moribund fish. One difference between the studies was the source of water for the holding tanks. Barthel et al. (2003) frequently flushed the tanks holding the treated fish with lake water whereas the observation aquarium in the present study was continually flushed with bore water. It is possible that the treated bore water would not contain the same array of pathogens normally present in natural conditions, and thus infection rates and subsequent mortality would be significantly lower (Stickney and Kohler, 1990). It is suggested that a further study examining the infection and survival rate of barramundi handled in the two mesh types in a natural environment (i.e. freshwater billabong) or water sourced from the natural environment would be useful.

The results of this study illustrate the injuries caused by landing nets on barramundi. Some authors have suggested that, where possible, fish be released without netting (Malchoff and MacNeill, 1995; Barthel et al., 2003). While this will avoid net related injuries, it may not be wise or practical in situations where large estuarine crocodiles exist. It is strongly recommended, when landing nets are required, that only knotless nets be used. This type of net is standard in the aquaculture industry and is becoming increasing popular amongst conservation minded anglers (Stickney and Kohler, 1990; Barthel et al, 2003).

8.5. Conclusion

Catch-and-release fishing is a growing sport and one that is promoted for most recreational fisheries, including the barramundi fishery in the Northern Territory. One aspect of this is the use of landing nets to hold the hooked fish. This study assessed the effects of the two types of landing nets on barramundi. It was demonstrated that the use of landing nets, regardless of design, does cause dermal abrasions and fin damage to the fish, and that the severity and incidence of damage varies with net type. To increase the chance of post-release survival, it is recommended that barramundi should be caught and released using a knotless flat-bottomed type of landing net, which has been shown to minimise injuries.

9 BENEFITS

The results of this study will greatly benefit the debate about the efficacy of catch and release fishing for barramundi by providing for the first time a real estimate of post-release survival. While extrapolation from a somewhat constrained experimental situation is always risky, this study does indicate that barramundi are a relatively hardy species and that post-release survival is quite high. It has also been clearly demonstrated that new “fish friendly” landing net designs do allow release of fish in much better physical condition than the older knotted types traditionally used. The use of knotless landing nets has been increasing in the past few years and the knowledge gained through this research should speed the uptake of this type of net, especially in relation to barramundi.

10 FURTHER DEVELOPMENT

The need to identify the effects of angling on the post-release survival of fish is increasingly being recognised by fishery managers. This study has identified the physiological effects and post-release survival of barramundi in a freshwater billabong. However previous studies have illustrated a difference in the magnitude and duration of the physiological response between freshwater and saltwater environments (Muoneke and Childress, 1994; Percival, 1999). It is recommended that the physiological response of saltwater barramundi to angling is experimentally assessed. The determination of this is especially important as there is a growing trend in both the recreational and Fishing Tour Operator fisheries to target the larger and more spectacular trophy fish which typically reside in estuarine or near shore marine areas. Furthermore, these barramundi are often sexually mature females and an understanding of the sublethal effects of angling on the reproductive function of these fish will be important in the overall sustainable management of the barramundi fishery.

Information on the effects of angling on stress physiology of barramundi in salt water and the sublethal effects is an obvious extension of the current study with the results complementing those already obtained.

11 CONCLUSION

Recreational fishing harvest is often perceived to be that portion of the fish caught and kept, and little regard is given to that portion of the recreational catch that was released but died (post-release mortality). Knowledge of post-release mortality is important for the management of any fishery in which catch-and-release fishing is practised or enforced through regulations. The barramundi fishery is a major component of the recreational fishery in the Northern Territory and is one where catch-and-release fishing is promoted though both management regulations and angler practices. Although catch-and-release is used to conserve and protect fish stocks, its success is based ultimately on the survival of the released fish. In a fishery that has a high proportion of released fish, such as the NT barramundi recreational fishery, the effects of angling on the released fish have the potential to detrimentally affect the barramundi resource. Given this, the objectives of the study were to describe the effects of angling on the physiological stress response and post-release survival of barramundi. Furthermore, this study has described the effects of landing nets on barramundi, a facet of catch-and-release fishing that is rarely considered as a contributing factor in post-release mortality.

The study found that the post-release survival rate of barramundi in a freshwater environment was about 90%, with all of the mortalities recorded during the summer period. Furthermore, the action of hooking and landing barramundi elicited a physiological (plasma cortisol) and metabolic (plasma lactate) stress response. This response was still elevated at 24 hours suggesting that the period of recovery from the stress of angling for barramundi is greater than 24 hours. The fish size and the time taken to land a barramundi was not found to influence the magnitude of the physiological response but significantly increased the metabolic (plasma lactate) response, reflecting the duration of anaerobic exercise. The effect of season was significant in this study, with those fish sampled in summer demonstrating significantly elevated physiological and metabolic variables and recording a post-release survival rate of only 80% compared with a 100% survival rate in winter.

Larger species of fish are typically held and removed from the water in landing nets, although the resulting effects have not, until now, been described for barramundi. This study assessed the effects of two types of landing nets on barramundi and found that landing nets, regardless of design, will cause injuries. However, the severity and incidence of damage was found to vary with net type, with the knotless flat-bottomed landing net causing significantly less injury.

The results from this study should encourage the use of catch-and-release as both a management tool and conservation practice. The effect of season on both the stress response and post-release survival of barramundi is significant and should be used as a guide for future management strategies. To increase the chance of survival, it is suggested that only knotless flat-bottomed varieties of landing net should be used when handling the larger fish.

This study describes the short-term effects of angling on barramundi. The elevated stress responses, as shown in this study, have been associated with longer term sublethal effects such as reduced growth and reproductive capacity in other species. The authors suggest that these factors need to be investigated before the effects of recreational angling on barramundi can be clearly understood and that until such time the precautionary principle should be applied to any management changes based on these results.

12 REFERENCES

Alexander, J.B. and Ingram, G.A. (1992). Noncellular nonspecific defence mechanisms of fish. *Annual Review of Fish Diseases*. **2**, 249-279.

Ayvazian, S.G., Wise, B.S. and Young, G.C. (2002). Short-term hooking mortality of tailor (*Pomatomus saltatrix*) in Western Australia and the impact on yield per recruit. *Fisheries Research*. **58**, 241-248.

Barnett, C.W. and Pankhurst, N.W. (1998). The effects of common laboratory and husbandry practices on the stress response of greenback flounder *Rhombosolea tapirina* (Günter, 1862). *Aquaculture*. **162**, 313-329.

Barthel, B.L., Cooke, S.J., Suski, C.D. and Philipp, D.P. (2003). Effects of landing net mesh type on injury and mortality in a freshwater recreational fishery. Short Communication. *Fisheries Research*. **63,** 275-282.

Barton, B.A. and Schreck, C.B. (1987). Influence of acclimation temperature on interrenal and carbohydrate stress responses in juvenile chinook salmon (*Oncorhynchus tshawytscha*). *Aquaculture*. **62**, 299-310.

Beggs, G.L., Holeton, G.F. and Crossman, E.J. (1980). Some physiological consequences of angling stress in muskellunge, *Esox masquinongy* Mitchill. *Journal of Fish Biology*. **17**, 649-659.

Bettoli, P.W. and Osborne, R.S. (1998). Hooking mortality and behaviour of striped bass following catch and release angling. *North American Journal of Fisheries Management*. **18**, 609-615.

Box, G.E.P and Cox, D.R. (1964). An analysis of transformations. *Journal of the Royal Statistical Society Series B*. **26**, 211-243.

Caillouett, C (1971). Lactate acidosis as a cause of mortality in captured sharks: An hypothesis. *Transactions of American Fisheries Society* **100 (1)**, 139-140.

Campbell, P.M., Pottinger, T.G. and Sumpter, J.P. (1992). Stress reduces the quality of gametes produced by rainbow trout. *Biology of Reproduction*. **47**, 1140-1150.

Carmichael, G.J., Tomasso, J.R., Simco, B.A. and Davis, K.B. (1994). Confinement and water quality-induced stress in largemouth bass. *Transactions of the American Fisheries Society*. **113**, 767-777.

Carragher , J.F. and Rees, C.M. (1994). Primary and secondary stress responses in golden perch, *Macquaria, ambigua*. *Comparative Biochemical and Physiology*. *Part A.* **107,** 49-56.

Chopin, F.S. and Arimoto, T. (1995). The condition of fish escaping from fishing gears – a review. *Fisheries Research*. **21**, 315-327.

Clarke, K.R. and Warwick, R.M. (1994). *Changes in marine communities: An approach to statistical analysis and interpretation*. Natural Research Council, Bournemouth.

Clapp, D.F. and Clarke, R.D. (1989). Hooking mortality in smallmouth bass caught on live minnows and artificial spinners. *North American Journal of Fisheries Management.* **9**, 81-85.

Clements, S.P., Carragher, J.F., Hicks, B.J. and Dedual, M. (2002). The effect of a trapping procedure on the stress response of wild rainbow trout. *North American Journal of Fisheries Management*. **22** (3), 907-916.

Coleman, A.P.M. (1998). Fishcount: A Survey of Recreational Fishing in the Northern Territory. NT Department of Primary Industry and Fisheries. *Fishery Report* **43**.

Coleman, A.P.M. (2004). The National Recreational Fishing Survey. The Northern Territory. NT Department of Business, Industry and Resource Development. *Fishery Report* No. **72.**

Cooke, S.J. and Hogle, W.J. (2000). Effects of retention gear on the injury and short-term mortality of adult smallmouth bass. *North American Journal of Fisheries Management*. **20**, 1033-1039.

Cupper, J. and Cupper, L. (1981). *Hawks in Focus: A study of Australia's birds of prey*. Jaclin Enterprises, Australia.

Davis, M.W., Olla, B.L. and Schreck, C.B. (2001). Stress induced by hooking, net towing, elevated sea water temperature and air in sablefish: lack of concordance between mortality and physiological measures of stress. *Journal of Fish Biology*. **58**, 1-15.

Diodati, P.J. and Richards, R.A. (1996). Mortality of striped bass hooked and released in salt water. *Transactions of the American Fisheries Society*. **125**, 300-307.

Griffin, R.K. (1987). NT Barramundi Fishery Mary River Monitoring Program 1986-1987. Fisheries Division, NT Department of Business, Industry and Resource and Development. Unpublished Report.

Gustaveson, A.W., Wydoski, R.S. and Wedemeyer, G.A. (1991). Physiological response of Largemouth bass to angling stress. *Transactions of the American Fisheries Society*. **120**, 629-636.

Haddy, J.A. and Pankhurst, N.W. (1999). Stress-induced changes in concentrations of plasma sex steroids in black bream. *Journal of Fish Biology*. **55**, 1304-1316.

Harrell, R.M. (1988). Catch and release mortality of striped bass with artificial lures and baits. *Proceedings of the 41st annual Conference of South-eastern Association of Fish and Wildlife Agencies*. ***41***, 70-75.

Henry, G.W. and Lyle, J.M. (2003). The national recreational and indigenous fishing survey. G.W. Henry and J.M. Lyle (*eds*). *NSW Fisheries Final Report Series **48***.

Insightful Corporation. *S-Plus 6 for Windows* Seattle, WA.

Isely, J.J., Young, S.P., Jones, T.A. and Schaffler, J.J. (2002). Effects of antenna placement and antibiotic treatment on loss of simulated transmitters and mortality in hybrid striped bass. Management Briefs. *North American Journal of Fisheries Management*. **22**, 204-207.

Jepsen, N., Davis, L.E., Schreck, C.B and Siddens, B. (2001). The physiological response of chinook salmon smolts to two methods of radio-tagging. *Transactions of the American Fisheries Society*. **130**, 495-500.

Jónsson, E. (1994). *Scale damage and survival of Haddock escaping through cod-end meshes (tank experiment)*. International council for the Exploration of the Sea. Fish Capture Committee. **C.M 1994/B:16, Ref.G**. Marine Research Institute, Reykjavik.

Kieffer, J.D., Currie, S. and Tufts, B. (1994). Effects of environmental temperature on the metabolic and acid-base responses of rainbow trout to exhaustive exercise. *Journal of Experimental Biology*. **194**, 299-317.

Lewis , A.E. and Muntz, W.R.A. (1984). The effects of external ultrasonic tagging on the swimming performance of rainbow trout, *Salmo gairdneri* Richardson*. Journal of Fish Biology*. **25**, 577-585.

Lyman, J. (2002). Cultural values and change: Catch and release in Alaska's Sport Fisheries. *In* Catch and Release in Marine Recreational Fisheries. J.A Lucy and A. L. Studholme. (*eds*.). *American Fisheries Society Symposium* **30**. American Fisheries Society. Bethesda, Maryland

Malchoff, M.H. and MacNeill, D.B. (1995). Guidelines to increase survival of released sport fish. *Fact Sheet*. Cornell Cooperative Extension, Cornell University, New York.

Mazeaud, M.M., Mazeaud, F. and Donaldson, E.M. (1977). Primary and secondary effects of stress in fish: some new data with a general review. *Transactions of the American Fisheries Society*. **106**, 201-212.

Mommsen, T.P., Vijayan, M.M. and Moon, T.W. (1999). Cortisol in teleosts: dynamics, mechanisms of action, and metabolic regulation. *Reviews in Fish Biology and Fisheries*. **9** (3), 211-268.

Muoneke, M.I. and Childress, W.M. (1994). Hooking Mortality: A Review for recreational fisheries. *Reviews in Fisheries Science*. **2**(2). 123-156.

Nelson, R.S. (2002). Catch and Release: A Management Toll for Florida. *In*. Catch and release in marine recreational fisheries. J.A. Lucy and A.L. Studholme (*eds*). *American Fisheries Society Symposium* **30**. 11-14.

Neter, J., Kutner, M.H., Nachtsheim, C.J. and Wasserman, W. (1995). *Applied Linear Statistical Models*. Fourth Edition, Irwin, Chicago.

Osborne, R. and Bettoli, P.W. (1995). A reusable ultrasonic tag and float assembly for use with large pelagic fish. *North American Journal of Fisheries Management*. **15**, 512-514.

Pankhurst, N.W. and Dedual, M. (1994). Effects of capture and recovery on plasma levels of cortisol, lactate and gonadal steroids in a natural population of rainbow trout. *Journal of Fish Biology*. **45**, 1013-1025.

Percival, P.A. (1999). Physiological stress response of barramundi (*Lates calcarifer*). PhD Thesis. James Cook University, Queensland.

Pickering, A.D. and Pottinger, T.G. (1985). Cortisol can increase the susceptibility of brown trout, *Salmo trutta* L., to disease without reducing the white blood cell count. *Journal of Fish Biology*. **27**, 611-619.

Pickering, A.D., Pottinger, T.G., Carragher, J. and Sumpter, J.P. (1987). The effects of acute and chronic stress on the levels of reproductive hormones in the plasma of mature male brown trout, *Salmo trutta*. *General and Comparative Endocrinology*. **68**, 249-259.

Pottinger, T.G. (1998). Changes in blood cortisol, glucose and lactate in carp retained in anglers' keepnets. *Journal of Fish Biology*. **53** 728-742.

Radonski, G.C. (2002). History and application of catch-and-release fishing. The good, the bad and the ugly. *In* Catch and Release in Marine Recreational Fisheries. J.A Lucy and A. L. Studholme. (*eds*.). *American Fisheries Society Symposium* **30**. American Fisheries Society. Bethesda, Maryland.

Reubush, K.J. and Heath, A.G. (1997). Secondery stress responses to acute handling in striped bass (*Morone saxatilis*) and hybrid striped bass (*Morone chrysops* x *Morone saxatilis*). *American Journal of Veterinary Research*. **58** (12), 1451-1456.

Siewert, H.F. and Cave, J.B. (1990). Survival of the released bluegill, *Lepomis macrochirus*, caught on artificial fly, worms and spinner lures*. Journal of Freshwater Ecology*. **5**, 407-411.

Sokal, R.R. and Rohlf, F.J. (1996). *Biometry*. Third Edition. Freeman, New York.

Steeger, T.M., Grizzle, J.M., Weathers, K. and Newman, M. (1994). Bacterial diseases and mortality of angler-caught largemouth bass released after tournaments on Walter F. George Reservoir, Alabama-Georgia. *North American Journal of Fisheries Management*. **14**, 435-441.

Stickney, R.R. and Kohler, C.C. (1990). Maintaining fishes for research and teaching. pp 633-663. *In* C.B. Schrech, and P.B. Moyle. (*eds*.), *Methods for Fish Biology*. American Fisheries Society, Bethesda, MD.

Taylor, R.G., Whittington, J.A. and Haymans, D.E. (2001). Catch-and-release mortality rates of common snook in Florida. *North American Journal of Fisheries Management*. **21** 70-75.

Thorstad, E.B., Okland, F. and Finstad, B. (2000). Effects of telemetry transmitters on swimming performance of adult Atlantic salmon. *Journal of Fish Biology*. **57**, 531-535.

Tomasso, A.O., Isely, J.J. and Tomasso Jr, J.R. (1996). Physiological responses and mortality of striped bass angled in freshwater. *Transactions of the American Fisheries Society*. **125**, 321-325.

Tomasso, J.R., Davis, K.B. and Parker, N.C. (1981). Plasma corticosteroid dynamics in channel catfish (*Ictalurus punctatus*) during and following oxygen depletion. *Journal of Fish Biology*. **18**, 519-526.

Turner, J.D., Wood, C.M. and Clarke, D. (1983). Lactate and proton dynamics in the rainbow trout (*Salmo gairdneri*). *Journal of Experimental Biology*. **104,** 247-268.

Wedemeyer, G.A., Barton, B.A. and McLeay, D.J. (1990). Stress and acclimation. pp. 451-489. *In* Methods for Fish Biology. C.B. Schreck and P.B. Moyle, (*eds*). *American Fisheries Society*. Bethesda, Maryland, USA.

Wood, C.M., Turner, J.D. and Graham, M.S. (1983). Why do fish die after severe exercise. *Journal of Fish Biology*. **22**, 189-201.

13 APPENDICES

Appendix 1. Intellectual property

No issues of intellectual property have arisen from this project.

Appendix 2. Staff

The following staff were engaged in this project.

Principal Investigator:	Roland Griffin
Co-Investigator:	Paul de Lestang
Technical Officers:	Quentin Allsop and Graham White

DBIRD Staff:

Richard Sellers, Bill Flaherty, Chris Errity, Poncie Kurnoth, Mark Hearnden, Nathan Crofts, Steve Sly, Annette O'Grady, Murray Barton, Damon Gore, David McKey, Andria Marshall and Stephanie Boubaris.

Appendix 3. Raw Data: Blood chemistry results for barramundi caught at various landing times and sampled at various recovery times

Season	Tag #	Length (cm)	Landing Time (s)	Recovery Time (hours)	Lactate (mmoles/L)	Cortisol (nmoles/L)
Summer	2371	40	30	0	0.5	18
Summer	2142	40	41	0	1.9	18
Summer	2384	50	53	0	1.6	18
Summer	2106	46	54	0	1.8	18
Summer	2135	51	82	0	2.2	27.93
Summer	2147	60	100	0	3.4	18
Summer	2370	41	180	0	5.8	18
Summer	2363	55	180	0	4.7	18
Summer	2140	49	180	0	5.2	18
Summer	2110	50	180	0	4.5	18
Summer	2105	48	190	0	4.4	18
Summer	2367	53	197	0	4.7	18
Summer	2381	49	200	0	4.5	25.04
Summer	2369	58	300	0	8.1	18
Summer	2394	51	300	0	5.1	17.91
Summer	2136	54	308	0	7.9	18
Summer	2383	43	310	0	5.9	51.58
Summer	2111	44	320	0	6.4	18
Summer	2393	46	42	1	4.8	109.08
Summer	2108	59	56	1	9.8	216.14
Summer	2143	52	70	1	4.7	37.94
Summer	2368	44	80	1	4.4	150.21
Summer	2382	38	180	1	8	35.51
Summer	2138	53	190	1	3.7	84.75
Summer	2141	51	195	1	11.5	91.5
Summer	2378	52	197	1	7.3	100.16
Summer	2366	57	206	1	9.9	144.4
Summer	2104	66	300	1	13.3	156.58
Summer	2359	49	302	1	11	208.81
Summer	2380	50	303	1	9.3	123.21
Summer	2392	50	304	1	8.9	243.2
Summer	2365	48	317	1	8.9	41.44
Summer	2361	48	345	1	8.9	223.06
Summer	2362	49	350	1	9.8	216.28
Summer	2358	50	5	4	9.9	93.13
Summer	2356	42	5.83	4	5.8	88.11
Summer	2375	41	53	4	6.1	78.19
Summer	2139	55	61	4	7.1	102.27
Summer	2115	49	75	4	4.1	67.96
Summer	2376	41	144	4	12.6	64.34
Summer	2360	55	180	4	5.1	45.34
Summer	2134	50	190	4	4.7	18
Summer	2118	59	200	4	3.5	29.94
Summer	2113	51	300	4	7.2	80.12
Summer	2377	54	362	4	8.2	112.69
Summer	2391	43	390	4	7	98.48
Summer	2385	45	53	24	0.5	18
Summer	2386	42	55	24	0.5	27.81
Summer	2390	42	80	24	0.9	56.84
Summer	2389	52	104	24	0.5	69.36
Summer	2112	47	180	24	0.5	45.89
Summer	2387	49	180	24	0.6	21.23
Summer	2117	49	180	24	5	18
Summer	2109	47	187	24	0.8	67.56
Summer	2372	50	201	24	0.6	71.27
Summer	2388	66	300	24	0.5	58.15
Summer	2379	45	300	24	0.5	28.64
Summer	2364	54	318	24	0.6	76.35
Summer	2116	48	358	24	0.5	18

Appendix 3. Continued

Season	Tag #	Length (cm)	Landing Time (s)	Recovery Time (hours)	Lactate (mmoles/L)	Cortisol (nmoles/L)
Winter	22141	48	16	0	0.92	18
Winter	22137	47	18	0	0.5	18
Winter	22198	50	22	0	2.09	18.29
Winter	22152	47	27	0	0.5	18
Winter	22140	50	27	0	1.28	18
Winter	22170	46	40	0	0.54	18
Winter	22166	50	176	0	3.27	18
Winter	22178	50	178	0	5.17	18
Winter	22167	46	179	0	2.79	18
Winter	22163	52	180	0	3.14	18
Winter	22196	55	288	0	5	18
Winter	22177	55	300	0	4.85	18
Winter	22197	45	300	0	3.46	18
Winter	22145	53	10	1	4.98	87.03
Winter	22138	57	30	1	4.74	128.07
Winter	22142	50	50	1	3.48	44.31
Winter	22146	50	50	1	4.58	49.9
Winter	22154	55	172	1	6.11	21.87
Winter	22155	57	173	1	9.37	67.05
Winter	22158	53	180	1	6.34	55.24
Winter	22199	52	180	1	5.74	32.07
Winter	22200	56	180	1	6.7	38.74
Winter	22169	57	290	1	4.8	88.95
Winter	22172	53	290	1	9.03	68.55
Winter	22173	53	290	1	5.47	68.75
Winter	22159	56	300	1	9.65	43.36
Winter	22174	55	300	1	6.03	99.87
Winter	22184	51	300	1	7.9	58.13
Winter	22168	50	310	1	12.58	29.99
Winter	22134	38	9	4	2.02	34.53
Winter	22135	46	20	4	4.53	20.5
Winter	22147	60	40	4	3.67	28.77
Winter	22148	57	50	4	5.62	30.32
Winter	22149	50	175	4	5.6	95.91
Winter	22179	52	181	4	6.02	43.26
Winter	22150	41	184	4	4.07	65.31
Winter	22151	55	190	4	8.21	58.69
Winter	22143	54	285	4	9.16	18
Winter	22182	57	300	4	11.5	37.44
Winter	22180	55	301	4	7.05	55.66
Winter	22175	51	35	24	0.5	64.14
Winter	22189	53	40	24	0.5	18
Winter	22191	55	52	24	0.5	18
Winter	22193	52	52	24	0.5	47.2
Winter	22192	54	59	24	0.5	18
Winter	22157	53	168	24	0.5	26.71
Winter	22176	56	176	24	0.5	44.14
Winter	22183	46	177	24	1.39	61.99
Winter	22165	55	181	24	0.5	39.23
Winter	22185	49	285	24	0.5	54.02
Winter	22188	50	288	24	0.5	84.3
Winter	22161	48	289	24	5.1	18
Winter	22187	50	294	24	0.5	30
Winter	22171	44	300	24	0.5	45.91
Winter	22160	84	310	24	0.5	18
Winter	22186	53	344	24	0.5	18

Appendix 4. Raw Data: Injury scores of barramundi held in the knotless and knotted landing nets

Mesh Type	No Flips (% Time)	Holding time (s)	Weight (kgs)	Body Section B1	B2	B3	Fin Score Dorsal	Pectoral	Pelvic	Rear dorsal	Anal	Caudal
Knotless	32.77	56	1.9	0	0	0	1	0	0.25	0	0	0
Knotless	28.7	69	1.9	0	1	0	0.5	0	0.25	0	0	0
Knotless	21.29	61	3.5	1	0	0	0	0	0	1	0	0
Knotless	24.13	73	3.1	0	0	0	1.5	0	0.5	0.5	0	0
Knotless	14.25	69	3	0	0	0	1	0	0	0	0.5	1
Knotless	21.3	56	2	1	1	0	2	0	0	0	0	0
Knotless	15.3	71	1	1	0	0	1	0	0	0	0.5	0
Knotless	27.32	57	2.3	0	1	0	1	0	0	0.5	0	1
Knotted	8.45	68	2	2	2	2	0	0	2.25	0	0	0.5
Knotted	22.83	76	3	1	0	1	1	1	1.75	2	3	2
Knotted	12.96	67	3	1	1	1	1.5	0	2	1	1	2
Knotted	11.78	63	2.5	1	2	2	2	0	0.75	1.5	0.5	4
Knotted	16	57	1.8	2	2	2	3	0.5	0	2	1	5.5
Knotted	17.85	61	1.8	2	1	0	2	0.5	1.75	0.5	1	3
Knotted	8.9	56	1.1	0	1	1	1	0	0	0	0.5	2.5
Knotted	10.78	69	3	2	2	1	1	0.5	0.5	0.5	0	3