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Capture-induced physiological stress and post-release survival of recreationally caught Southern Bluefin Tuna

FRDC Project No. 2013-25

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Executive Summary

Southern Bluefin Tuna (SBT) are an important component of the recreational game fishery in Australia. Recreational fishers in waters adjacent to South Australia, Victoria, Tasmania and New South Wales catch the species seasonally. Each state manages the recreational fishery adjacent to their waters using individual fisher catch limits, in some states boat limits also apply. Fishers that exceed these limits are required to release the excess catch. A fundamental assumption underpinning the effectiveness of catch limits is that a significant proportion of returned fish survive. This assumption is also key to the practice of catch and release fishing, where anglers target fish for sport or choose to release the fish for other reasons. Recent studies reporting on the catch and effort of the recreational SBT fisheries in Victoria and Tasmania estimate that approximately 25% of SBT are released. A low post-release survival rate could therefore contribute a significant source of unaccounted mortality within the recreational fishery. Prior to this study there was no information to quantify the post release survival rates of SBT.

The primary objective of this study was to assess the post-release survival rate of SBT caught by the recreational fishery in Australia. An analysis was also conducted to determine whether the fate of fish after release could be related to factors occurring during capture. Finally, a Code of Practice (COP) for the recreational SBT fishery was compiled. The COP is based on the results of this study integrated with fact-based information from existing literature relevant to the recreational capture of large pelagic species.

Pop-up archival transmitting (PAT) tags were attached to 59 individual SBT to determine their post-release fate. The tags record the fish's dive behaviour as well as water temperature and light level for a pre-determined period of time. The tags then detached from the fish, floated to the surface and transmitted the archived data. The tags were also programmed to detach if they remained at a constant depth (including floating at the surface) for a period of 2 days or if they sank below 1,600 m depth. These actions were considered indicative of mortality or in some cases premature tag shedding. The suite of data transmitted by the tags was analysed and an assessment made as to whether the fish survived or died after release.

The results showed that recreationally caught SBT have a low incidence of mortality (3%) occurring during the capture event related directly to the hooking and retrieval of the fish. The fate of fish that were landed in a non-responsive state was attributed to deep-hooking damage, with the exception of one large fish that became tail wrapped and was retrieved to the boat backwards, effecting its ability to ram ventilate. An exception to the low pre-landing mortality was attributed to seal predation of SBT caught in Tasmanian waters. Seal predation accounted for mortality of 31% of fish hooked adjacent to Tasmania. This was the greatest source of unintended mortality related to recreational capture assessed in this project. The uniqueness of seal mortality occurring in Tasmanian waters is likely due to the fact that the majority of recreational fishing targeting SBT occurs in close proximity to areas frequented by seals, primarily coastline and islands used by seals as haul outs.

Satellite tagged fish caught on lures configured with J-hooks (*n* = 46) and those caught on circle hooks (*n* = 8) had similar post-release survival (PRS) rates and were combined to increase sample size, revealing a PRS estimate of 83.0% (95% CI: 75.9 – 90.7%, *n* = 54). The PRS estimate of fish caught on lures with treble hooks was much lower, 60% (95% CI: 20 – 100%, *n* = 5). Given the low sample size of fish caught using treble hooks this PRS estimate should be considered indicative, additional samples would improve the statistical robustness of this estimate.

The PRS estimates presented here should be considered conservative; it is possible that the survival rate may be higher as the impacts of taking blood samples and attaching and carrying PAT tags is not well understood, but may have an unquantified detrimental effect. Post-release survival was not significantly related to angling duration, hooking damage, physiological stress, water temperature or time out of water (for processing).

Blood samples, including most PAT tagged individuals, were analysed to provide data on a suite of biochemical indicators related to physiological stress. Fish fork length, lure (hook) type, angling duration, processing time and an observational assessment of the fish's condition were also recorded to test the relationship between these factors and physical damage, physiological stress and ultimately survival.

Angling duration was related to an elevation of several biochemical responses indicative of increased physiological stress, with longer angling durations leading to elevated levels of lactate, cortisol and osmolality in blood plasma. Each of these biological indicators increased at a steady rate as angling duration increased until a point where the responses plateaued. Six large SBT (>70 kg) were caught after protracted angling durations relative to the school size fish. The biochemical indicator values for these fish were particularly high, but again did not prove to be a significant determinant of post-release mortality. It is unknown whether physiological stress contributes to detrimental sub-lethal factors, although 50% of fish that survived post-release retained tags for at least 111 days and 21% of surviving fish retained tags for the full deployment duration (180 days). In each case these fish displayed normal dive and migratory behaviour. Furthermore, one tagged fish was caught by a commercial long-liner within days of release indicating that this fish was feeding normally. The premature tag detachment rates reported here are similar to those presented for other PAT tagging studies on SBT.

Most methods currently used by recreational fishers to capture SBT are effective at minimizing damage to the fish. Ninety-four percent of fish were hooked in the mouth and with the exception of fish caught using lures fitted with treble hooks, only 5% of fish displayed damage beyond a superficial hooking wound. An exception was fish caught using lures configured with two treble hooks, with almost half the fish caught using treble hooks displaying physical damage more severe than a superficial hook wound, and a lower reported PRS rates.

The results suggest that current recreational fishing management strategies utilising catch limits are not compromised by a substantially high post-release mortality rate for SBT. Similarly, voluntary catch and release fishing, given release rates of SBT reported elsewhere, is not expected to greatly increase unintended mortality arising from recreational capture of the species. Predation on hooked SBT by seals whilst fishing adjacent to Tasmania does contribute a substantial degree of unaccounted mortality in the area and further research to investigate measures to reduce interactions are warranted.

The results of this study contribute to furthering knowledge on un-accounted sources of mortality for SBT, and in concert with a robust estimate of recreational fishing harvest, will lead to greater transparency of Australia's recreational fishery for SBT. The results also provide information that can be used by the recreational fishing sector to improve fish capture and handling techniques. Maintaining or improving fish handling practices is fundamental to minimising the unintended impacts of recreational fishing on SBT and improve stewardship of the recreational fishing sector.

The code of practice presented in this report is intended to provide fact based information on strategies to reduce the rate of unintended fish mortality, improve animal welfare, maximize the quality of fish flesh retained for consumption and reduce fish wastage. Each strategy presented in the full version of the COP has a brief explanation of the rationale that underpins it so recreational fishers, whether beginners or experienced, understand the basis for the recommendations. A summary version of the COP was also prepared. The effectiveness of the COP is contingent on broad adoption by key recreational stakeholder groups and the recreational fishing community that target SBT.

Implications

The results indicate that post-release mortality does occur for recreationally caught Southern Bluefin Tuna, but is not significant factor in relation to the total recreational harvest of SBT. Therefore, current management strategies using catch limits, including personal bag or possession limits are reasonably effective. The reported post-release survival rate has been assessed across the size range of fish that is commonly caught by the recreational fishery throughout southeast Australia. These findings will complement future research to investigate the recreational harvest of Southern Bluefin Tuna in Australia (Moore et al. 2015). The combined results of these projects will provide greater transparency around the recreational fishery for Southern Bluefin Tuna, an objective which is an obligation of Australia to the Commission for the Conservation of Southern Bluefin Tuna.

The development of a COP for the recreational capture and handling of Southern Bluefin Tuna based on the results of the study, and others, provides fishers with fact based information to improve fish handling practices, primarily around reducing unintended mortality and reducing impacts on animal welfare. The COP has been endorsed by key recreational fishing representative bodies to champion and assist in dissemination and adoption of the COP document.

Recommendations

This project has captured the attention of the recreational game fishing community. The primary objective of the project was to assess post-release survival and factors that may influence survival of Southern Bluefin Tuna, however the use of PAT tags has provided an additional opportunity to engage recreational fishers through the dissemination of preliminary results on fish movement and behaviour as well as results relating to the primary objectives. The ongoing engagement with recreational fishers throughout the project, primarily through social media, popular recreational fishing magazines, television and information session is likely to have facilitated a better understanding by recreational fishers of the importance and benefits of fisheries science. Perpetuating this engagement with future research projects and continuing education initiatives where possible will foster this relationship and ultimately improve stewardship from the sector by providing fishers with a greater understanding of the role they play in the sustainable use of marine resources.

The code of practice presented here (Appendix 10) collates the recommendations for ‘best practice’ for the catching, handling, release and tagging of SBT. Broad dissemination of the Code of Practice by fisheries management agencies and recreational stakeholder groups is likely to benefit the fishery as a whole. Adoption of practices outlined in the code will improve animal welfare, enhance social license to operate for recreational fishers, possibly improve post-release survival, improve data quality collected from recreational fish tagging programs and reduce fish wastage.

Specific recommendations arising from the research are as follows:

- Additional research is warranted to strengthen the statistical result regarding a lower post-release survival estimate for fish caught using lures configured with treble hooks.
- The inclusion of questions relating to hook type used in future recreational fishing surveys focusing on Southern Bluefin Tuna will provide necessary information if a lower survival rate using treble hooks is proven.
- The promotion of using J-hooks as a replacement to treble hooks is warranted as these hooks were shown to, at least, cause significantly more damage to fish than J-hooks or circle hooks.
- Encouraging lure manufactures to produce hard body lures with J-hooks should be pursued. Noting that some companies have already begun to do this.
- Research into minimising unintentional mortality of SBT arising from interactions between recreational fishers and seals in Tasmania should be considered a priority.

Keywords

Southern Bluefin Tuna, *Thunnus maccoyi,* recreational fishing, physiological stress, post-release survival, responsible fishing, animal welfare, code of practice

1 Introduction

Offshore game fishing in Australia has a long history, particularly along the eastern seaboard where a range of large pelagic species including billfish, tunas and pelagic sharks are targeted (Ward et al. 2012). On the southern and southeast coasts of Australia game fishing is generally limited to tuna and pelagic sharks, as the cooler waters are beyond the thermal niche of most billfish, although some billfish are caught rarely on the east coast of Tasmania (Tracey et al. 2013). The tuna species that dominate the recreational fishery around Tasmania are Skipjack (*Katsuwonus pelamis*), Albacore (*Thunnus alalunga*) and Southern Bluefin Tuna (*Thunnus maccoyii*) (Tracey et al. 2013). Along the south coast of Australia, west of Tasmania, Southern Bluefin Tuna (SBT) are the dominant species with Albacore caught to a lesser extent (Green et al. 2012, Giri and Hall 2015).

Southern Bluefin Tuna are highly prized by recreational fishers in Australia and targeted fisheries can provide significant social and economic benefits to regional communities and trades associated with offshore recreational fishing (Ezzy et al. 2012, Tracey et al. 2013). The species is renowned for high quality flesh for consumption and also the large sizes they grow to, providing fishers the opportunity to capture trophy size fish.

Southern Bluefin Tuna are in high demand for global sashimi markets and attract the attention of commercial fishing activities. The lucrative nature of the Bluefin Tuna sashimi trade has seen significant pressure placed on fish stocks. All three 'true' Bluefin Tuna species found around the world - Atlantic Bluefin Tuna (*Thunnus thynnus*), Pacific Bluefin Tuna (*Thunnus orientalis*) and Southern Bluefin Tuna (*Thunnus maccoyii*) - have been subject to commercial overfishing (Polacheck et al. 2004, Taylor et al. 2011, WCPFC 2013). The Southern Bluefin Tuna spawning biomass is estimated to be at between 8 – 12% of the pre-exploitation levels (CCSBT 2014).

Southern Bluefin Tuna have a highly dispersed distribution throughout the temperate waters of the Pacific, Indian and Atlantic Oceans and are thought to constitute a single stock (Caton 1991). Several countries target SBT throughout this range and as such it is necessary to manage the fishery through a Regional Fisheries Management Organisation. The Commission for the Conservation of Southern Bluefin Tuna (CCSBT) allocates an annual catch to each signatory country as part of a global Total Allowable Catch (TAC). The Australian Fisheries Management Authority (AFMA) is required to set Australia's domestic SBT quota at or below Australia's allocation from the CCSBT. Historically, Australia has used its allocation for the commercial fishing sector. In 2014, the CCSBT agreed to a common definition of attributable catch, which will require all members to account for all sources of mortality, and discussed a timeline for implementation. As part of this, Commission members will begin to consider other sources of SBT mortality, such as discards and recreational catch within their allocation, and in future make efforts to account for it.

The current management arrangement of recreational fishing for SBT in Australia is that each state manages the fishery within their waters. A Memorandum of Understanding between the Commonwealth and state governments was signed in 2004, giving the states management authority for non-commercial fishing of SBT in Commonwealth waters adjacent to their waters. Currently each state restricts catch of SBT using bag and/or possession limits; in some states boat limits also apply. Recent reports indicate that approximately 25% of SBT caught from the epicenters of the recreational fisheries adjacent to Western Victoria and Tasmania are released (Green et al. 2012, Tracey et al. 2013). If regulations become more restrictive or as the SBT population rebuilds further, it could be expected that a greater proportion of the catch will be released.

Recently, a report developing methods for obtaining national estimates of the Australian recreational catch of SBT has been completed (Moore et al. 2015). A post-release survival rate from recreational fishing can be used, in conjunction with a national harvest estimate, to quantify total mortality attributed to the Australian recreational fishery, as well as be used to assess the effectiveness of current state based management of recreational fishing. The broader results on effects of capture, handling and release will provide recreational fishers with fact based information to make educated decisions when interacting with this species, improving stewardship of the fishery, and potentially, survival rates of released fish.

Bag, possession and size limits are traditional tools used globally as a principal means to manage recreational fisheries (Bartholomew and Bohnsack 2005, Tetzlaff et al. 2013). The effectiveness of these regulations is contingent on two major assumptions. The first is that catch and/or effort is monitored to assess the overall harvest from a fishery. While bag limits are effective at reducing the catch of an individual fisher, they do little to address the number of people entering or leaving the fishery, and as such do not effectively control the total harvest (Post et al. 2002, Cox et al. 2003).

Monitoring of catch and effort of the recreational SBT fishery is sparse, with only a few comprehensive targeted state based surveys to estimate the recreational harvest of SBT; onsite creel methods (Forbes et al. 2009, Green et al. 2012, Tracey et al. 2013) and offsite phone-diary methods (Tracey et al. 2013) being completed. While these state based surveys are informative, they do not address the question of the national recreational harvest estimate of SBT. Tuna catch is also reported in statewide recreational fishing surveys but it has been acknowledged that the coarse nature of these surveys is not particularly effective at providing robust estimates for niche fisheries such as the SBT fishery (Henry and Lyle 2003, Moore et al. 2015). Anecdotal reports suggest that participation in the recreational fishery for SBT is increasing in some regions. This heightens the importance of monitoring the recreational fishery, as recreational catch limits may not be effective under increasing recreational fishing effort (Post et al. 2002, Cox et al. 2003).

The second assumption under-pinning the effectiveness of catch limits is that most fish released after the limit is exceeded survive (Cooke and Suski 2005, Arlinghaus et al. 2007, Cooke and Schramm 2007, Tetzlaff et al. 2013) and that fish suffer minimal sub-lethal effects once released (Arlinghaus et al. 2009). Furthermore, many recreational fishers engage in catch and release fishing, where the same assumption on post-release survival exists (Bartholomew and Bohnsack 2005, Arlinghaus et al. 2007). Catch and release fishing is a well-established practice in recreational fishing and is considered a positive action to reduce the impact on a resource by increasing the proportion of fish that can contribute to spawning relative to if the fish were removed from the population (Cooke and Schramm 2007, Stokesbury et al. 2011).

For many species little is known about the fate of fish after release. Over the last two decades, however, there has been a growing body of literature investigating factors that may cause excessive stress or damage to a fish as well as assessing post-release survival rates (Bartholomew and Bohnsack 2005, Cooke and Schramm 2007). Review studies have indicated that post-release survival rates are highly variable between species (Muoneke and Childress 1994, Bartholomew and Bohnsack 2005). This highlights the need to investigate post-release survival on a species-by-species basis.

Assessing post-release survival of highly migratory fish is logistically challenging (Moyes et al. 2006, Donaldson et al. 2008). Conventional tagging studies typically yield low return rates (Kohler et al. 1998). Active tracking of animals for a sufficient period after release using acoustic technology is difficult due to the swimming speed and dispersal range of large pelagic fish (Skomal 2007). While containment experiments are generally not feasible due to the scale of equipment required to hold the fish (Skomal 2007).

The most common approach to assess the fate and behaviour of large pelagic fish after release is the application of pop-up archival transmitter (PAT) tags. This method has been applied to assess survival of large sharks (Skomal and Chase 2002), billfish (Graves et al. 2002, Domeier et al. 2003, Kerstetter et al. 2003, Kerstetter and Graves 2006, Kerstetter and Graves 2008) and tunas (Stokesbury et al. 2011, Marcek and Graves 2014). The data returned from the tags provides a timeline of dive behaviour and temperature experienced after release. From this information, it is possible to determine the fate of the fish.

Previous studies have attached PAT tags to SBT (Patterson et al. 2008, Evans et al. 2012). The primary goal of these tagging studies, however, was to investigate migration and fish behaviour, and therefore appropriately, fish caught by commercial fishers that were in good condition were selected for tagging. This is atypical of a recreational fishing event where fish in sub-optimal condition may also be released (Skomal 2007). Estimating post-release survival rates from previous PAT tagging studies on SBT has the potential to overestimate survival because the animals in the poorest condition are not tagged (Moyes et al. 2006). Additionally, the fish were not caught using recreational fishing methods.

The capture of a fish will always have some impact to its welfare; at the very least the fish is hooked and fought for a period of time, resulting in some physical exertion (Cooke and Suski 2005, Arlinghaus et al. 2007). Factors such as angling duration, water temperature at capture and air exposure have all been shown to induce a physiological stress response (Cooke and Suski 2005). The resulting adaptive physiological responses to stressors that occur during capture can be measured via biochemical responses (Moyes et al. 2006) and reflex impairment indices (Campbell et al. 2009). Furthermore, stressors can be tested against the fate of the fish to assess whether fishers can alter their practices to maximise post-release survival and minimise fish welfare impacts (Moyes et al. 2006). Many of the aspects that affect the physiological responses listed above, including damage associated with choice of tackle, are generally controlled to some degree by the fisher. Often however, a lack of experience or knowledge can lead to differences in capture and handling techniques which may impart undue stress on a fish or ultimately reduce post-release survival rates (Diodati and Richards 1996, Meka 2004, Cooke et al. 2012).

Species-specific information on the effects of capture and handling by recreational fishers can be utilised in the development of scientifically defensible best practices, potentially minimising the impacts of recreational fishing activities on released fish and fish stocks as a whole (Cooke et al. 2012). Importantly, this information enhances the sustainable utilisation of fisheries resources by considering additional sources of mortality in stock assessment and providing results that facilitate informed decision making by fishers, increasing resource stewardship.

In this study we investigate the impact of a range of factors related to recreational catch, handling and release of SBT to physiological stress indicators measured by biochemical variables and ultimately test for the effects of these factors on post-release survival. We conclude by presenting a code of practice for the capture, handling and release of SBT based on the results of this study and consultation with anglers experienced in the capture of SBT and representatives from relevant peak recreational fishing groups.

2 Objectives

1. Quantify post-release survival rates for SBT caught by recreational fishing
2. Determine key factors affecting post-release survival of SBT from recreational fishing
3. Develop a ‘Code of Practice’ identifying strategies that have potential to minimise sub-lethal impacts and increase post-release survival of recreationally caught SBT.

3 Methods

Catching Southern Bluefin Tuna

Southern Bluefin Tuna (SBT) were caught in waters southeast of Tasmania in 2012-14, and in waters adjacent to southwest Victoria and the south coast of NSW (as far North as Sydney) in 2013 and 2014 (Figure 1). These regions are epicenters of recreational fishing activity for SBT in southeast Australia. Fishing occurred between February and July each year, representative of the historical SBT recreational fishing season across the regions. All fish were caught from either charter, recreational, or research (< 7 m in length) fishing vessels. All fish were captured on rod and reel using standard recreational fishing tackle and techniques. Fishing tackle consisted of 15, 24 or 37 kg breaking strength mono-filament line. Six different lure/hook configurations were utilised, there was no specific experimental design relating to lure/hook use as fishing occurred from a range of vessels, with most crews having their own preferences in lure configuration. Lures were categorised as either ‘hard body’ (h) or ‘soft skirted’ (s). Hook configurations were either single 6/0 J-hook (j), two 6/0 J-hooks (jj), two 4/0 treble hooks (tt), or a single 6/0 J-hook with a single 4/0 treble hook (jt). All lure configurations were trolled behind a vessel at 6 – 9 knots. Baited 7/0 circle hooks (c) were used on a few occasions when fishing adjacent to NSW. These were presented to schools of fish while the boat was drifting.

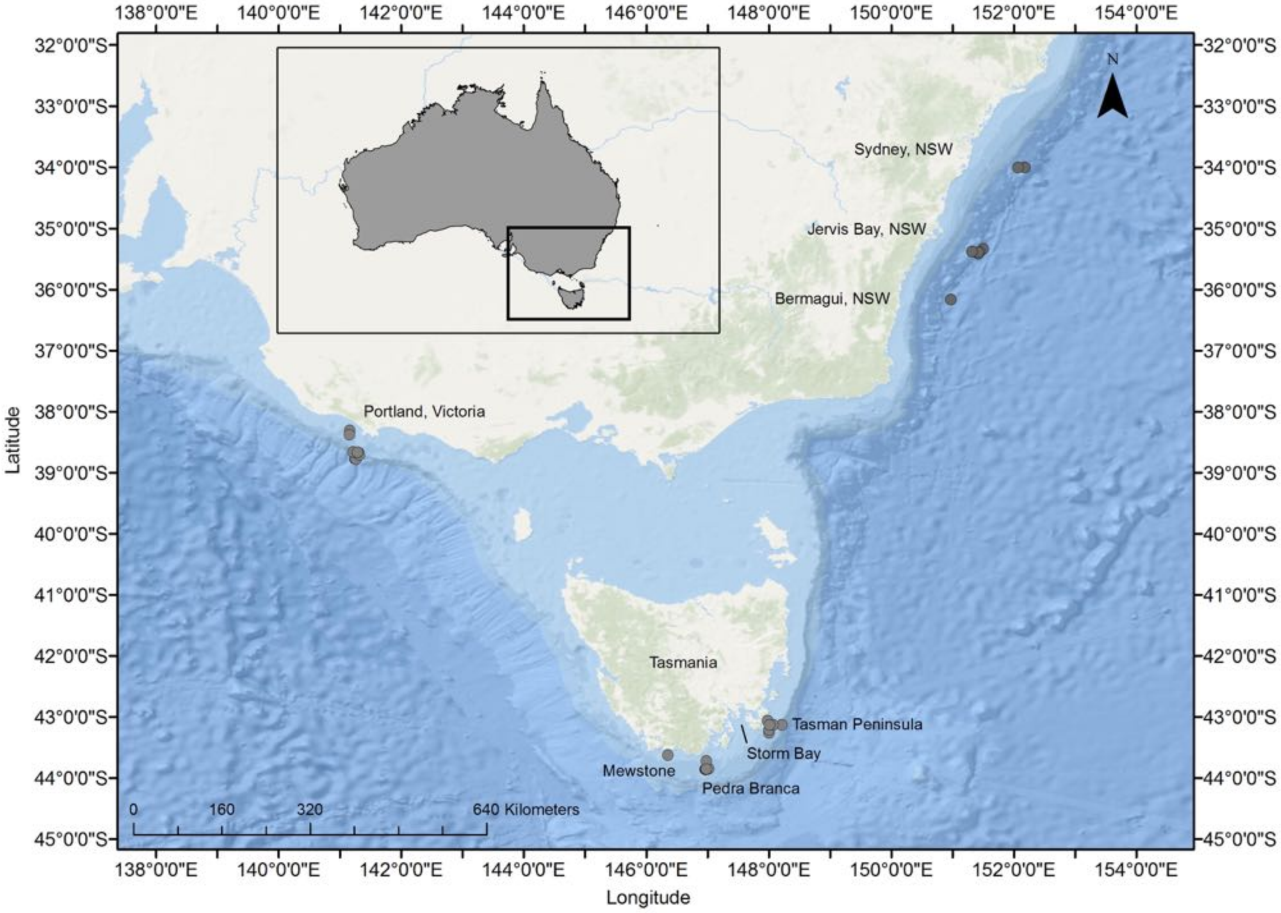

Figure 1. The locations where Southern Bluefin Tuna were caught during this study are indicated by grey circles.

Hooked fish were retrieved to the boat by the angler where they were led alongside the vessel, and depending on the size of the fish and the prevailing weather conditions, either lifted into the boat through a sea door using the terminal tackle, a knotless landing net, or a lip gaff (a short gaff carefully inserted into the lower jaw). Once on board the fish was placed on a padded mat and the eyes covered with a wet towel, and the angling duration recorded (time from hook-up until landing).

Processing landed fish

The fork length (FL) of each fish was measured to the nearest cm and the fish was then assessed as to their condition (categorised as vigorous, active, low active or dead), the location of the hook (categorised as mouth, internal, eye orbit, external foul hooked) and severity of bleeding (categorised as nil, minor external, minor internal or major bleeding). The hook was then carefully removed. When conditions allowed, a non-lethal blood sample was taken (0.5 – 3.0 ml) from the lateral artery at the site posterior to the pectoral fin along the lateral line or by cardiac puncture (Ostrander, 2000) using a lithium heparin Vacutainer (Becton-Dickinson) with a 38 mm 21-gauge needle (Figure 2). Blood samples were immediately placed on ice until further processing. In some instances, weather conditions did not allow for a blood sample to be collected, the implication of this are discussed below in relation to statistical methodology.

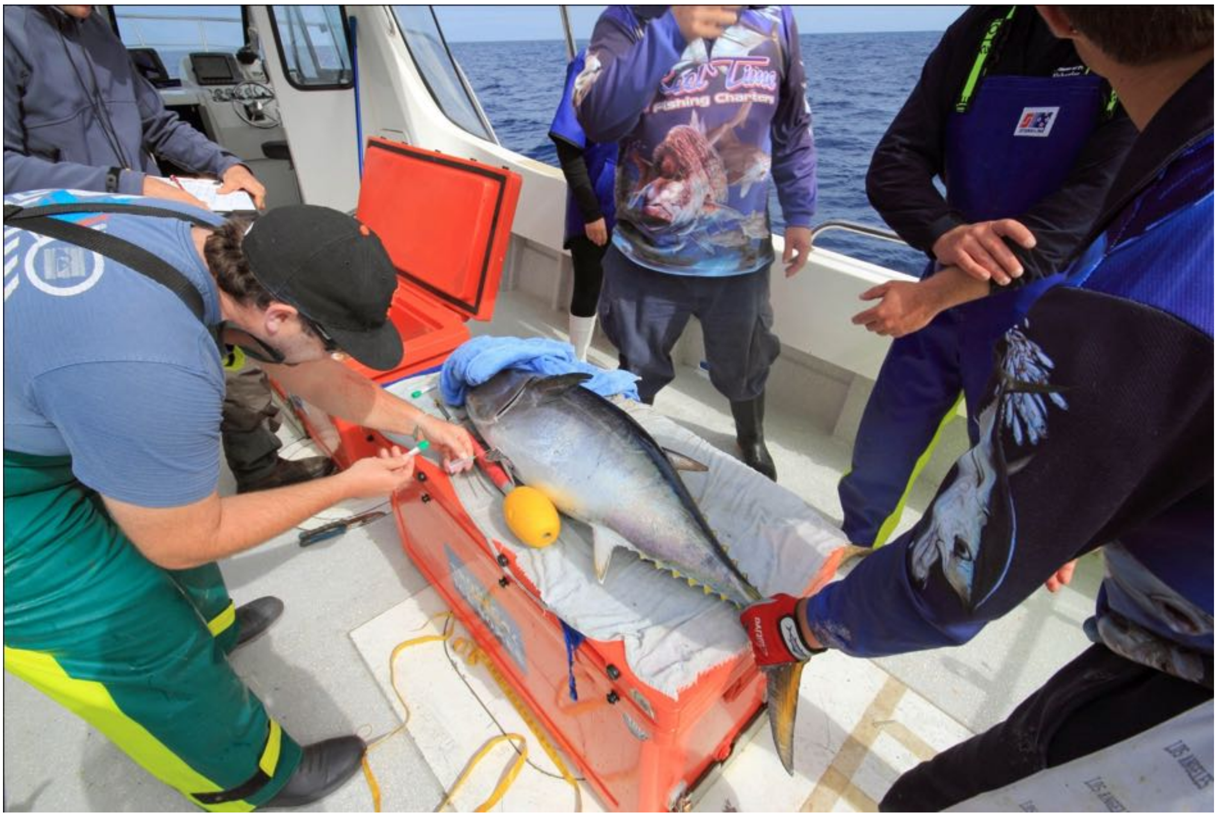

Figure 2. Collecting a blood sample from a Southern Bluefin Tuna. Photo credit: Jarrod Day.

Released fish were held alongside the boat with their head orientated towards the direction of the vessel moving slowly forward to allow water to flow through the gills until the animal freely kicked from the grip of the handler, this time was recorded as 'recovery time'. In some cases, no recovery time was recorded as the fish were 'speared' back into the water. This occurred on vessels with high freeboard or when the prevailing weather was too rough to safely hold the fish in the water. Gear type, release condition (categorised as vigorous, active, low-active, non-active), total processing time (exposure to air), and release location GPS coordinates were also recorded. All qualitative categorical assessments were undertaken by a single researcher to facilitate standardisation.

Satellite tagging

Fifty-nine fish were released with pop-up archival transmitter (PAT) tags (MiniPAT; Wildlife Computers, Redmond, WA, USA) regardless of bleeding or hooking location. To minimise the potential for mortalities related to carrying a satellite tag only fish greater than 90 cm FL were tagged. All 21 fish caught adjacent to NSW were tagged. Only a proportion of fish caught from VIC (*n* = 14) and TAS (*n* = 24) were tagged as a greater number were caught from these locations than tags available, with many fish of a similar size. Fish to be tagged from these locations were selected at random and approximately proportional to the total number of fish caught within 10 cm length (*FL*) bins, spanning the size distribution of all fish caught.

Each PAT was rigged with a Doemeier nylon umbrella dart tag anchor (Domeier et al. 2005). The anchor was connected to the tag via a 200 kg breaking strain stainless steel multi-strand wire tether (covered in plastic heat-shrink) crimped to the corrodible release pin of the PAT tag. An additional single Domeier umbrella anchor crimped to a 24 kg monofilament loop was attached as a secondary anchor approximately 5-10 cm behind the primary tagging location to further secure the PAT tag and to minimise any lateral tag movement. The anchor of each tag was inserted into the musculature at the base of the second dorsal fin using a purpose-made tagging pole, with the aim of inserting the anchor within the pterygiophore complex. For smaller fish the location of the primary anchor was moved anterior to the pterygiophore complex to ensure the tag did not interfere with the tail (swimming ability) of the fish (Figure 3). Fish were not irrigated through the handling process.

PAT tags were deployed in 'standby' mode and programmed to activate when wet and at a depth of greater than 2.5 m. Each tag was programmed to record pressure (depth), temperature, and light in one of three program configurations. The first three tags deployed were programmed to detach from the fish after 40 days and record data every 150 seconds. The next two tags deployed were programmed to detach from the fish after 100 days and record data every 450 seconds. The remaining tags were programmed to detach after 180 days and record data every 450 seconds. One tag that was recovered soon after its initial deployment in 2014 was redeployed with a detachment time of 70 days and recorded data every 150 seconds. Wildlife Computers PAT tags release from the anchored tether at the conclusion of the programmed period via a corrodible release pin. Alternatively, if the tag sank to a depth greater than 1800 m or the depth of the tag did not change by greater than ± 2.5 m over a 2-day period (whether at the surface or at a depth less than 1800 m) the tag was also programmed to detach from the tether, the former controlled by a depth-release device (RD-1800; Wildlife Computers). By examination of data in the hours and days post-release a determination was made as to whether the fish had died or survived. Once the tags detached from the fish they floated to the sea surface where data was transmitted to the Advanced Research and Global Observation Satellite (ARGOS) system. In some cases, the tag washed ashore and were recovered, data from these tags was downloaded directly.

Figure 3. The primary anchor location for a 90 cm fork length Southern Bluefin Tuna. Note the tagging site is anterior to the pterygiophores. The secondary anchor (shown with blue heat shrink cover) is not yet inserted, but its position allows for insertion into the pterygiophore complex of the second dorsal fin. Photo credit: Jarrod Day.

Sea surface temperature

The sea-surface temperature (SST) at the time of capture was identified either by the first temperature recording on a tag at a depth less than ten meters within 24-hours of release. Or for fish that were not satellite tagged, location specific SST at time and location of capture were derived from Advanced Very High Resolution Radiometer (AVHRR) satellite estimates accessed through the Integrated Marine Observing System (IMOS).

Biochemical analysis

Field processing of blood samples

Whole blood glucose and lactate levels were analysed using handheld field meters within 5 hours of capture (and in most cases less than two hours). Lactate was measured using a Lactate Pro LT-1710, Arkray, Kyoto, Japan. Glucose was measured using an Accu-Chek Active, Roche, Mannheim, Germany. The lactate meter was calibrated and standards tested as per the manufacturers guidelines. The remaining blood sample was centrifuged for five minutes at 3300rpm using a portable field centrifuge (LW Scientific Portafuge). The resultant blood plasma was siphoned from the vacutainer using a transfer pipette, dispensed to an aliquot, and frozen in a liquid nitrogen dry shipper (at a minimum of -80°C) until subsequent laboratory analysis.

Cortisol analysis

Quantitative determination of cortisol was conducted using an ENZO Cortisol Enzyme Linked Immunosorbant Assay (ELISA) kit (United Bioresearch Products Pty Ltd, NSW, Australia). Standards and samples diluted 1:5 to 1:100 were prepared and assayed according to manufacturer instructions. Microtitre plates were read at 405nm using a TECAN Genios plate reader (TECAN Australia Pty Ltd). Parallelism of diluted plasma with the standard curve was confirmed according to Plikaytis et al. (1994). Slopes for the reference standards and serially diluted serum were 161.76 and 161.76, respectively. Inter-assay coefficient of variation (CV) using high and low standard reference points was <10%. Intra-assay CV using high, moderate and low plasma samples was similarly <10%. Recovery of cortisol from a spiked plasma sample was 101.2%. Spiked and diluted sample recoveries percentage limits of within 90–110% were considered acceptable.

Lactate, glucose and pH analysis

For samples where there was sufficient blood plasma, glucose and lactate were re-analysed in the laboratory using a GM7 Microstats reader (Analox Instruments, Helena Laboratories, VIC, Australia). Given the laboratory analysis was a more accurate method, the values from field meters were converted to laboratory values based on the parameters of significant linear relationships derived from 139 samples where both field and laboratory values were obtained (Appendix 1). pH was measured using a Minilab Isfet pH meter, Model IQ125 (Hach Pacific, Victoria, Australia).

Potassium

Potassium (K) analyses were measured by the Tasmanian Department of Primary Industries, Parks, Water and Environment (DPIPWE) using a Konelab 20xTi clinical analyser.

Supplementary blood data from fish caught adjacent to Portland, Victoria 2011

Blood samples were collected ancillary to the 2011 on-site survey conducted in Victoria to assess the recreational harvest of SBT (Green et al. 2012). The biochemical data from these blood samples were made available to this project to increase sample size. The fish from which the blood was taken were captured onboard recreational charter vessels using a broad range of gear (3 kg – 24 kg line), blood was drawn via an 18g needle from either the caudal vasculature or the rete mirabile located beneath the pectoral fin. Blood samples were stored on ice for up to 6 hours (although usually considerably less), then centrifuged and plasma stored at -20°C.

Plasma lactate, glucose and potassium constituents were analyzed using a Beckman Synchron CX-5 analyzer (Beckman Coulter, Fullerton, California). Plasma cortisol was measured by radioimmunoassay using cortisol (H-4001, Sigma Chemical Co., St Louis, Mo., USA) as standard. The mean (+/- SEM) recovery of [1,1,6,7-H3]-cortisol Amersham Pharmacia Biotech UK, Little Chalfont, UK) using this extraction procedure is 86%. A comparative analysis of these samples with samples collected during this project was conducted to assess whether the Victorian samples could be included to increase sample size (Appendix 2).

Statistical analysis

Data analysis was conducted in Matlab (R2014b) or R 3.0.3 (R core team 2014). The following libraries were used within R: gdata, ggplot2, MASS, ggbiplot, plyr, nlme, Surv and mgcv.

Testing the influence of capture on physiological stress

The relationships between explanatory factors related to the capture process (blood loss, angling duration, fish length and sea surface temperature at the site of capture) to each of the biochemical responses were investigated using generalised additive models (GAMs) (Hastie and Tibshirani 1990, Zuur et al. 2009). GAMs are semi-parametric models where the dependent variable is linked to explanatory variables through a non-linear link function. The link function consists of a sum of non-parametric smoothed functions of the covariates (Hastie and Tibshirani 1990). The main advantage of GAMs over generalised linear models (GLMs) is that they account for the non-linear relationships between variables that are common in ecological data (Zuur et al. 2009).

Outliers were removed based on visual interpretation of box plots. The error structure of each GAM was determined by the fit to the data with the aim of satisfying the assumption of normality. Correlations between factors were explored and the existence of collinearity between covariates was identified using the variance inflation factor (VIF). The upper threshold value of the VIF was set at ‘3’ which has been identified as a robust approach (Zuur et al. 2010). If collinearity was identified the variables with the highest VIF values were sequentially removed until the VIF value of each factor remaining were less than the threshold (Zuur et al. 2009, Zuur et al. 2010).

The initial, full factorial model was as follows:

$$V_{blood} = a + s_{FL}(FL) + s_{AD}(AD) + s_{SST}(SST) + BL + \epsilon$$

where V_{blood} is the blood plasma variable being assessed, α is the GAM intercept, FL is fork length, AD is angling duration, SST is sea surface temperature, BL is the ordinal blood loss index, ε is an error and s are thin-plate spline smoothers. A thin-plate smoothing spline was applied with the amount of smoothing (k) restricted to avoid over-fitting due to sample size, but adequate to describe the non-linearity between the response and explanatory variable (Zuur et al. 2009).

For each GAM a stepwise backward selection method was applied beginning with all predictor variables. Non-significant variables with the lowest significance levels were excluded at each step and the model run again until only significant predictors remained. The goodness of fit of each reduced model was considered using the unbiased risk estimator (UBRE), where the lowest value is considered as the best model performance indicator, the level of deviance explained, and the lowest Aikake’s Information Criterion (AIC) as per (Zuur et al. 2009). The GAMs were fitted using the mgcv package in R (Woods, 2001). The significance level was set to α = 0.05 for all tests.

Tag retention

A Kaplan-Meier survival analysis was used to investigate tag retention rates for PAT tags that were programmed to detach after 180 days. The analysis was truncated to exclude fish that were identified as succumbing to mortality during the period when the tags were attached.

Post-release survival

Post-release survival was categorised as a binary fate ('survived' or 'died'). A decision rule was implemented to assign a mortality as either related to the capture event or as a natural mortality. Mortality related to the fishing event was considered to have occurred if the tag indicated the fish had died within 10-days post-release. This assumption was based on the behaviour of the fish prior to the mortality event determined from the recorded dive profile, a natural break in the cumulative number of fish identified as dying after this time and existing literature on post-release survival of fish. Mortalities beyond this point were considered to be natural or related to the prolonged effects of carrying the PAT tag. A Kaplan-Meier survival analysis was used to visualise tag retention and mortality events through time. The 95% confidence intervals associated with the catch-induced post release survival estimates were calculated using the release mortality software v. 1.1.0 (Goodyear 2002). Confidence intervals were based on 10,000 simulations. One individual, whose tag prematurely released within the 10-day period, was included in the model as a 'survivor' based on the interpretation of depth data from this tag. Although the fishing and handling techniques replicated 'best practice' recreational fishing methods, the additional processing, including drawing blood samples and application of tags may bias the post-release survival estimate downward.

The effect of capture and physiological stress on post-release survival

Factors related to the capture of the fish, physiological stress imparted during capture and handling duration (time out of water) were modeled against post-release fate using a GAM with a binomial error term. The initial, full factorial model was as follows:

$$Fate = a + s_{FL}(FL) + s_{AD}(AD) + s_{SST}(SST) + BL + s_{Glu}(Glu) + s_{pH}(pH) + s_{Lac}(Lac) + s_{Cor}(Cor) + s_{Osm}(Osm) + s_{HT}(HT) + RL + \in$$

where α is the GAM intercept, FL is fork length, AD is angling duration, SST is sea surface temperature, BL is the ordinal blood loss index, Glu is plasma glucose, pH is plasma pH, Lac is plasma lactate, Cor is plasma cortisol, Osm is plasma osmolarity, HT is handling time, RL is the ordinal release condition index, ε is a binomial error term and s is a thin-plate spline smoother. The same process of identifying collinearity and stepwise backward selection described previously was applied to identify the best candidate model.

Two fish were observed to have been predated on immediately post-release, they were removed from this causative analysis. It was assumed that these fish did not die because of factors tested in this model, rather they were predated on immediately post-release due to the seal engaging with the fish during the capture process. Although, these fish were included as mortalities when calculating post-release survival rates.

In some cases, blood samples could not be taken from PAT tagged fish due to adverse weather conditions and/or the behaviour of the fish (*n*=3), all three of these fish were identified as survivors. In other cases, there was an insufficient amount of blood plasma available to analyse several of the biochemical indicators. Cortisol levels were not obtained for 12 tagged fish. Osmolarity and pH were not obtained for eight of these fish. As the model requires a complete suite of variables for each individual considered, depending on the truncated model (whether the model included these variables) the sample size was reduced. All of the fish that were missing these variables were classified as surviving post-release however, so while the sample size was reduced it did not reduce the number of fish that were determined to have died.

Osmolarity records were not available for three other tagged fish and pH records were not available for two of these fish. Two of these fish were classified as dying post-release. The inclusion of these variables to each model iteration reduced the sample size of fish classified as dying post-release.

4 Results

Catch summary

A total of 280 Southern Bluefin Tuna were hooked between February 2012 and July 2014. Fishing occurred adjacent to western Victoria, southern Tasmania and the New South Wales coast from Sydney to Bermagui (Table 1). These areas are the most frequented by recreational fishers targeting Southern Bluefin Tuna in southeast Australia. During this study, the recreational fishing season ran began in late February – early March and ended in July n Victoria and Tasmania. While in NSW, the season did not start until late June – early July and ended approximately at the end of July, with fish available over a much shorter period than the other two states.

Table 1. The number of Southern Bluefin Tuna hooked in waters adjacent to western Victoria, southern Tasmania and New South Wales (Sydney to Bermagui) from 2012 - 2014. The numbers of fish that were PAT tagged, had blood samples taken and were predated on (resulting in death) during the capture process are shown by capture year and state.

Year	State	Region	Total fish caught (*n*)	PAT tagged (*n*)	Blood sample (*n*)	Predated during capture (*n*)
2012	Tasmania	Mewstone	6	1	3	3
		Pedra Branca	33	0	28	4
		Storm Bay	14	0	11	3
		Tasman Pen.	41	2	27	17
	NSW	Bermagui	3	2	3	0
2013	Tasmania	Pedra Branca	20	11	17	3
		Storm Bay	2	0	2	0
		Tasman Pen.	11	6	10	3
	Victoria	Portland	20	8	20	0
	NSW	Jervis Bay	9	9	8	0
		Sydney	6	6	6	0
2014	Tasmania	Pedra Branca	62	1	43	18
		Tasman Pen.	33	3	21	11
	Victoria	Portland	16	6	15	0
	NSW	Jervis Bay	3	3	1	0
		Sydney	1	1	1	0
TOTAL			**280**	**59**	**216**	**62**

Fate of hooked fish (pre-release)

Seven fish were lost from the line ('dropped') during the capture process. Thirty-six fish were not released and used as samples, either to aid the development of methodologies for this study (*n* = 6), or for a concurrent study on parasitology of SBT (*n* = 30). A further 15 fish were caught by recreational fishers who chose to keep their catch. Where possible, blood samples and capture details were taken from these retained fish (Figure 4).

Seals predating on SBT during the capture process occurred exclusively in Tasmania. Twenty-nine fish were not landed due to being removed from the hook by a seal. It was observed in all cases that these fish did not survive and were consumed by the seals. A further 33 fish were landed but had been damaged by the seals and were either landed dead or in a state where the probability of survival after release was deemed to be negligible. Eight fish were also chased by seals during capture, with only minor superficial grazing occurring. Seal predation on SBT prior to landing accounted for 31% of the fish hooked in Tasmanian waters. The seal predation rate at the Tasman Peninsula (35%) was higher than the South Coast of Tasmania (28%).

A total of six fish were landed either dead or in a non-responsive state. Deep hooking leading to gill damage accounted for five of these cases. The other fish, which was larger than most fish caught during the study at 187 cm FL, became tail wrapped towards the end of an extended retrieval period (2 hours 22 minutes), leading to the fish being led tail-first to the boat. These pre-landing mortalities equated to 3% of the total fish landed (excluding fish that had interacted with seals).

The remaining 146 fish were released, 59 of these fish had PAT tags attached to assess post-release survival.

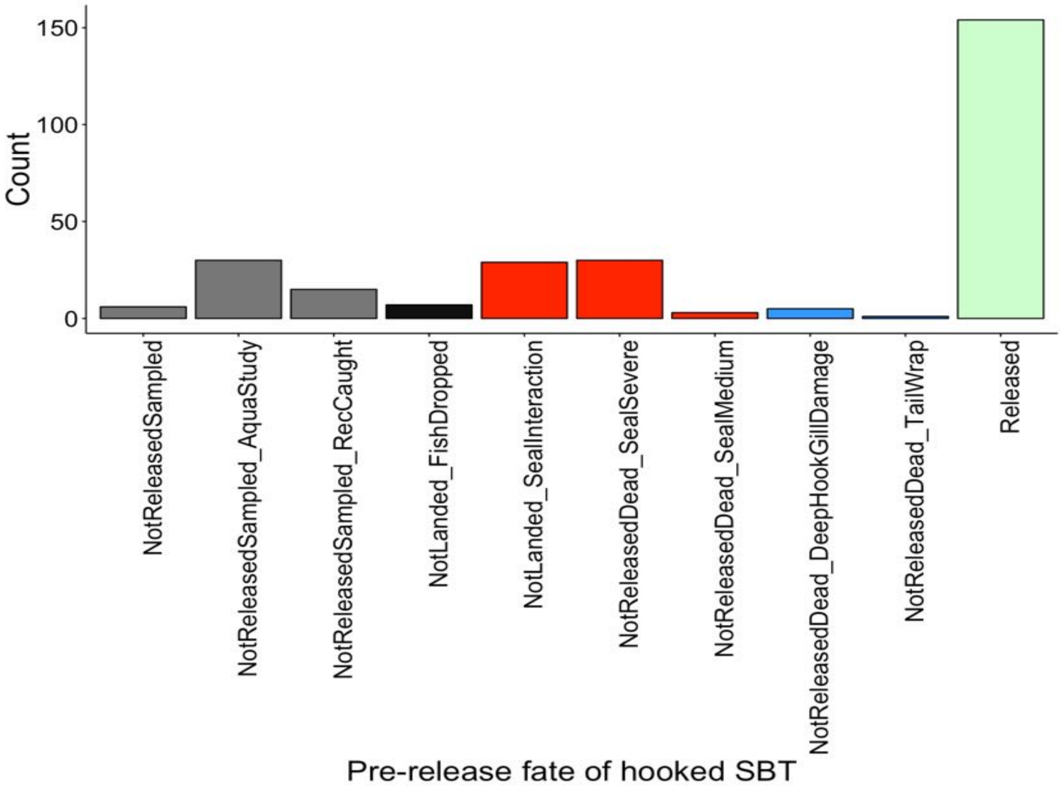

Figure 4. The fate of all hooked Southern Bluefin Tuna (*n* = 280). Grey indicates fish that were dispatched for sampling, black indicates fish that fell off the hook during retrieval, red indicates fish that succumbed to seal predation during capture, blue indicate fish that succumbed to the capture process prior to release, green indicate fish that were released.

Angling duration and the size composition of landed fish

Landed fish ranged in length from 78 – 188 cm FL, with a median size of 98 cm FL (Figure 5). There were significant differences in the size structure of the fish caught adjacent to each state ($F = 37.17_{2,232}$, $P = <0.001$).

The fish commonly caught adjacent to western Victoria were generally smaller than those from the other states, ranging in length from 78 – 110 cm FL, an exception being one large fish (187 cm FL). The median size, excluding this large fish, was 88 cm FL. There were two cohorts of fish that were targeted adjacent to western Victoria. The first were slightly larger fish (~ mean 100 cm FL) caught on or around the continental shelf break, the second were smaller fish (~ mean 85 cm FL) that tended to arrive later in the season and were targeted much closer to shore.

The fish commonly caught around southeast Tasmania ranged in size from 79 – 129 cm FL, four larger fish were also caught (162, 172, 184 and 188 cm FL). The median size of fish commonly caught around Tasmania, excluding the larger fish, was 98 cm FL. There were also within season differences in the size of fish available to the recreational fishery in Tasmania with larger fish (~ mean 115 cm FL) available earlier in the season, particularly from southern sites (Pedra Branca and Mewstone). Later in the season the fish tended to be smaller (~ mean 95 cm FL).

The fish caught adjacent to NSW tended to be larger again than those caught in the other two states, ranging in length from 100 – 155 cm FL. While fish from a range of cohorts were caught the median size was 130 cm FL (Figure 5).

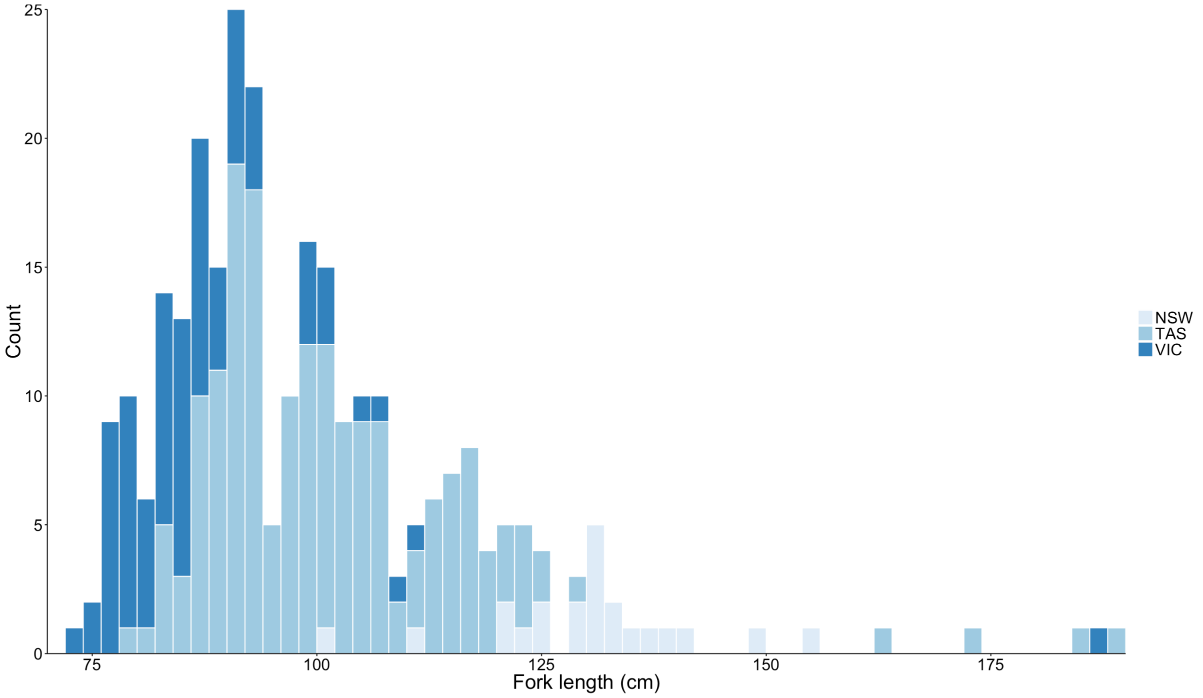

Figure 5. The size frequency composition of landed Southern Bluefin Tuna that were in a condition to measure fork length ($n = 236$). Shading indicates the state of origin as per the figure legend.

A total of 236 Southern Bluefin Tuna, including some fish damaged by seals, were landed where both the angling duration (time from hook up to landing) and fish length were recorded. There was a significant positive relationship between fork length and angling duration ($r^2 = 0.47$, $P < 0.001$), with larger fish having a longer angling duration (Figure 6). Three large fish, with disproportionally long angling durations (> 60 minutes) were removed as outliers. The effect of the breaking strain of the line was not considered, due to the confounding effects of drag settings on the fishing reels as well as angler experience.

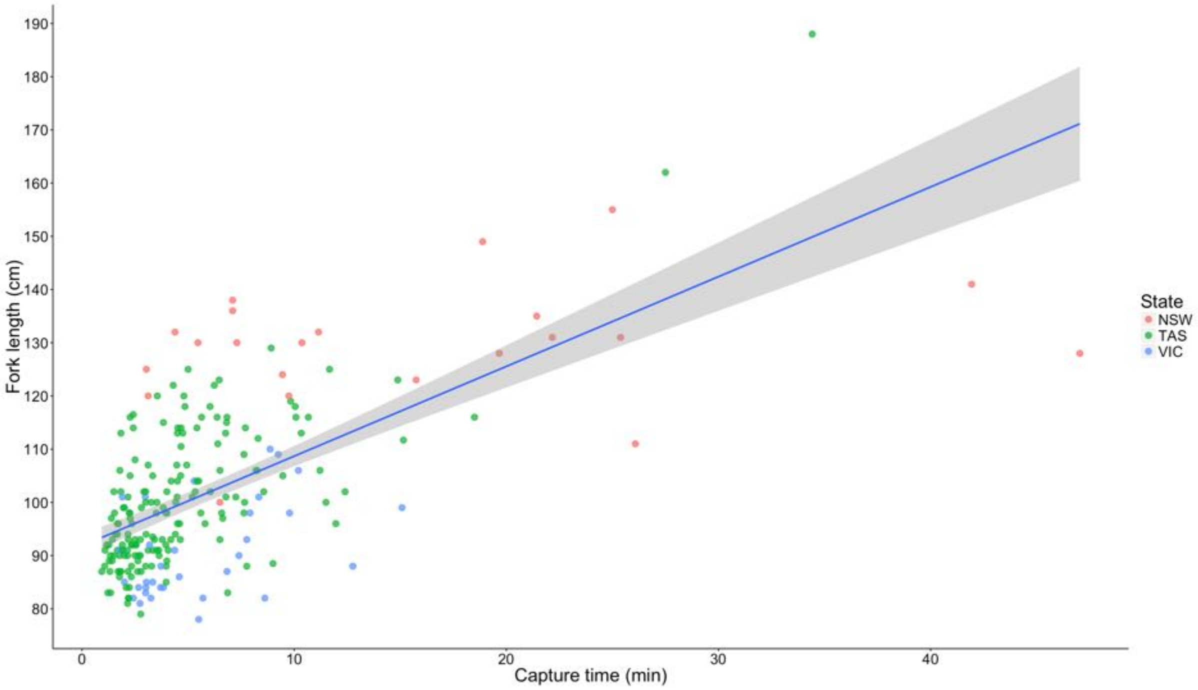

Figure 6. The relationship between angling duration and fork length of Southern Bluefin Tuna caught using recreational fishing methods (excluding three large fish with angling durations greater than 60 minutes). The blue fitted line is a linear regression and the grey shading indicates the 95% confidence intervals of the regression. The colour of the circles indicates the state from which the fish were caught as per the figure legend.

The effect of lure-hook configuration

The majority of fish (95%) were hooked in the corner of the mouth or lower jaw (Figure 7). The percentage of fish that had damage greater than a superficial hooking wound was less than 5% for the ‘sj’, ‘hj’ and ‘hjj’ lure/hook configurations (n = 192). Hard-body lures with two treble hooks (htt) caused hooking damage greater than a superficial wound to 40% of fish caught using this configuration (n = 10) (Table 2).

The use of baited circle hooks (n = 8) also resulted in minimal hooking damage, with all but one fish mouth hooked. This fish was deep hooked in the vicinity of the gills. For this individual the fishing line was cut and the hook left in before being PAT tagged and released. This fish survived with the tag shedding from the fish 123-days post-release.

Table 2. The number of Southern Bluefin Tuna hooked and landed, succumbing to capture induced mortality during retrieval to the boat (or soon after being landed) and the percentage of fish that had damage greater than a superficial hooking wound for each lure/hook configuration used during the study. Capture mortality (pre-release) includes fish listed in the damaged fish column where relevant. Note that there was no experimental design to the usage of particular configurations so the proportion of fish caught by each configuration cannot be interpreted quantitatively.

Lure/hook configuration	Fish hooked (*n*)	Capture mortality (pre-release)	Damaged fish
Soft skirted, single ‘j’ hook (SJ)	128	4%	5%
Hard body, single ‘j’ hook (HJ)	20	0%	0%
Hard body, two ‘j’ hooks (HJJ)	44	2%	2%
Hard body, two ‘treble’ hooks (HTT)	10	0%	40%
Hard body, 'J' hook and ‘treble’ hook (HJT)	1	0%	0%
Circle hook (Circ)	8	0%	0%

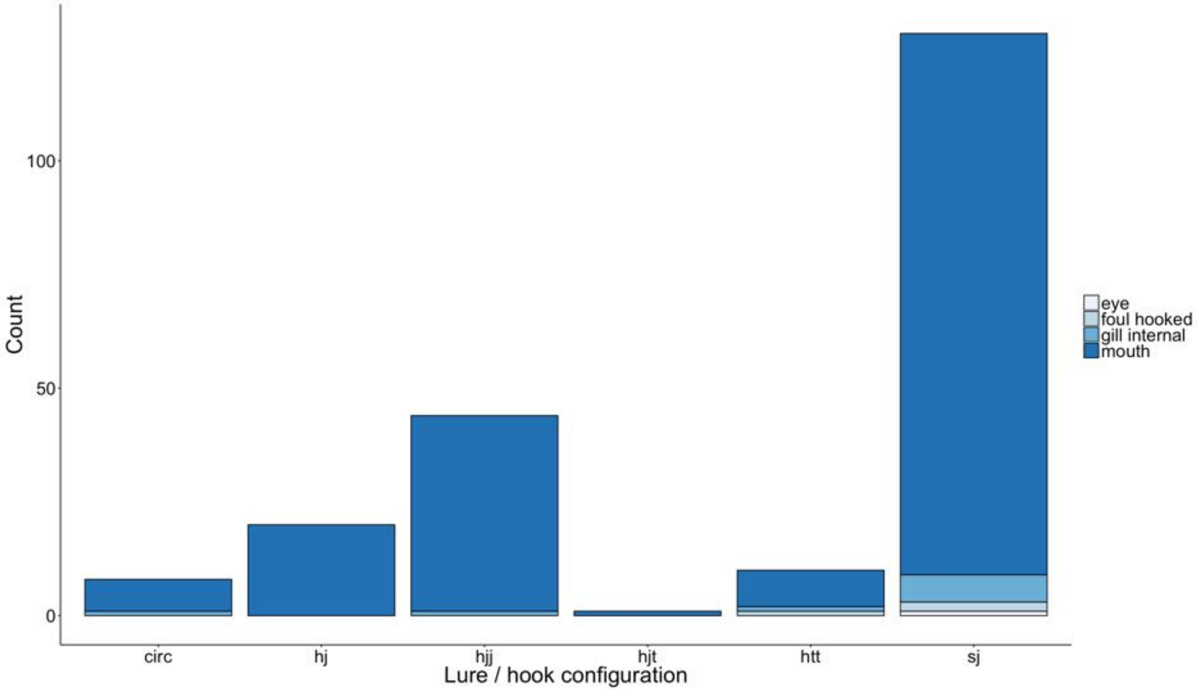

Figure 7. The number of Southern Bluefin Tuna caught using each lure/hook configuration used during the study indicating the hooking location for each fish as per the figure legend. Column labels are as follows: Baited circle hook (circ), hard body lure with a single ‘j’ hook (hj), hard body lure with two ‘j’ hooks (hjj), hard body lure with a single ‘j’ hook and a single treble hook (hjt), hard body lure with two treble hooks and a skirted lure with a single ‘j’ hook (sj).

Handling time

Handling time was defined as the time from the fish being removed from the water until the time it was returned. Handling time varied depending on weather conditions and the vigor of the fish, but in all cases the intention was to minimise the handling time and to return the fish to the water as soon as possible. The handling times of PAT tagged fish ranged from 1:25 to 5 minutes, with an average of 2:32 minutes.

Fish condition

Thirteen percent of fish caught that were not dead or moribund were categorised as 'vigorous', 65% categorised as 'active', 19% as 'low active' and 3% as 'not active'. There was a significant difference between each of the release condition categories when assessed using a proportional odds logistic regression (Table 3). The model was initially run with all blood variables and fish length included as predictor variables. Cortisol (p = 0.43), glucose (p = 0.46) and fish fork length (p = 0.21) were not significant predictors and were removed. Lactate, osmolarity and pH were all identified as contributing to the significant difference between the categories (Table 3).

Table 3. Results of a proportional odds logistic regression testing the suite of biochemical responses and fish length as predictor variable against the categories that defined the condition of Southern Bluefin Tuna as they were released after recreational capture. Bold values indicate significance at the $\alpha = 0.05$ level.

Variable	Estimate + SE	t_{value}	P_{slope}
Plasma pH	-1.134 + 0.456	-2.482	**0.013**
Plasma glucose (mmol/L)	0.233 + 0.314	0.743	0.457
Plasma lactate (mmol/L)	-0.175 + 0.073	-2.400	**0.016**
Plasma cortisol (ng/ml)	0.003 + 0.005	0.782	0.434
Plasma osmolarity (Osml/L)	-0.157 + 0.007	-2.231	**0.026**
Fork length (mm)	0.002 + 0.002	1.247	0.212
Not active | Low active	-18.379 + 0.054	-342.530	**<0.001**
Low active | Active	-16. 255 + 0.816	-19.918	**<0.001**
Active | Vigorous	-11.720 + 1.048	-11.184	**<0.001**

Correlation between factors related to capture

Several factors related to the recreational capture of SBT were identified as significantly correlated to each other (Figure 8). The strongest correlation existed between angling duration and fish fork length (r = 0.56). The analysis also showed a significant positive correlation between SST and fish fork length (r = 0.38) as well as angling duration (r = 0.37). This is not surprising as larger fish were caught in NSW where consistently warmer water temperatures were encountered and as identified earlier, larger fish have longer angling durations. Variance inflation factor values for each of these covariates were below the pre-determined threshold. Thus, indicating that the inclusion of all factors in the subsequent models did not significantly violate the assumption of collinearity.

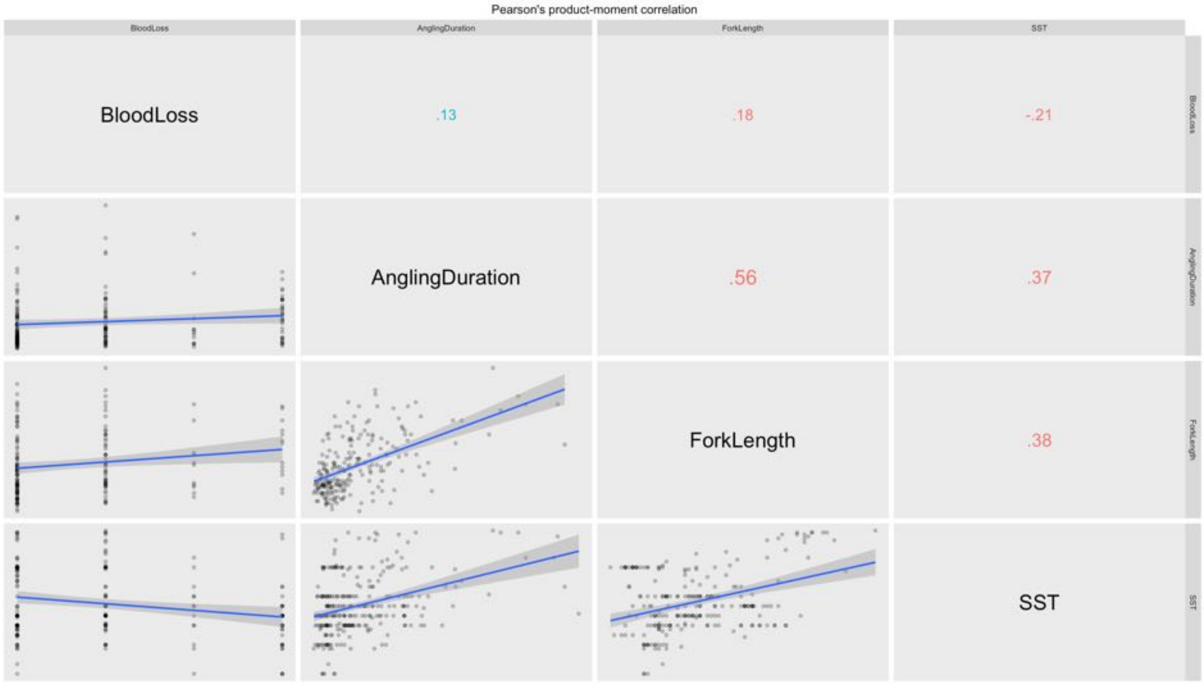

Figure 8. Pairwise plots of explanatory factors and corresponding correlation scores. Red scores indicate statistically significant correlations, while blue scores indicate non-significant correlations.

The effect of capture on physiological stress

Plasma cortisol, lactate, glucose and osmolarity levels were significantly affected by angling duration whereas potassium and pH were not (Table 4). The response of each of the significant relationships increased with angling duration, the rate of increase however reduced for longer durations (Figure 9). In the case of glucose and lactate, the smoothing functions are a poor fit for durations greater than 1500 seconds, this is due to the heavy weighting of samples to shorter durations with the confidence intervals broad at longer duration times due to fewer samples (Figure 9).

Sea surface temperature at the location of capture was significantly related to the response of glucose and lactate in blood plasma and fish size was significantly related to lactate response (Table 4). Blood loss was not identified as significant in the resulting models and was subsequently removed.

Table 4. The results of generalised additive modeling between the suite of biochemical indicators and angling duration, fork length and sea surface temperature. The full initial model was $y \sim s_{angl.\ dur.}(angl.\ dur.)+s_{fork\ length}(fork\ length)+s_{SST}(SST)+blood\ loss$, where angl. dur. is angling duration. Bold values indicate significance at the $\alpha = 0.05$ level. The model was reduced for each response variable using a backwards stepwise process. The significant explanatory variables for each reduced model are shown for each response variable.

Response variable (*y*)	Explanatory variables	n	*GCV*	*F*	*P*	R^2 *adj*	*Deviance explained*	*Error family(link)*
Glucose (mmol/L)		262	1.09			0.05	6.5%	Gaussian
	s(Fork length)			4.68	**0.009**			
	s(SST)			2.69	0.048			
Lactate (mmol/L)		262	15.15			0.36	37.4%	Gaussian
	s(Angl. dur.)			42.97	**<0.001**			
	s(Fork length)			7.90	**<0.001**			
	s(SST)			6.11	**0.014**			
Cortisol (ng/ml)		177	2237.7			0.58	58.9%	Gaussian
	s(Angl. dur.)			50.0	**<0.001**			
Osmolarity		180	0.004			0.27	29.9%	Gamma(log)
	s(Angl. dur.)			22.51	**<0.001**			
Potassium		64	0.03			0.17	19.4%	Gamma(log)
	s(Angl. dur.)			6.22	**0.003**			

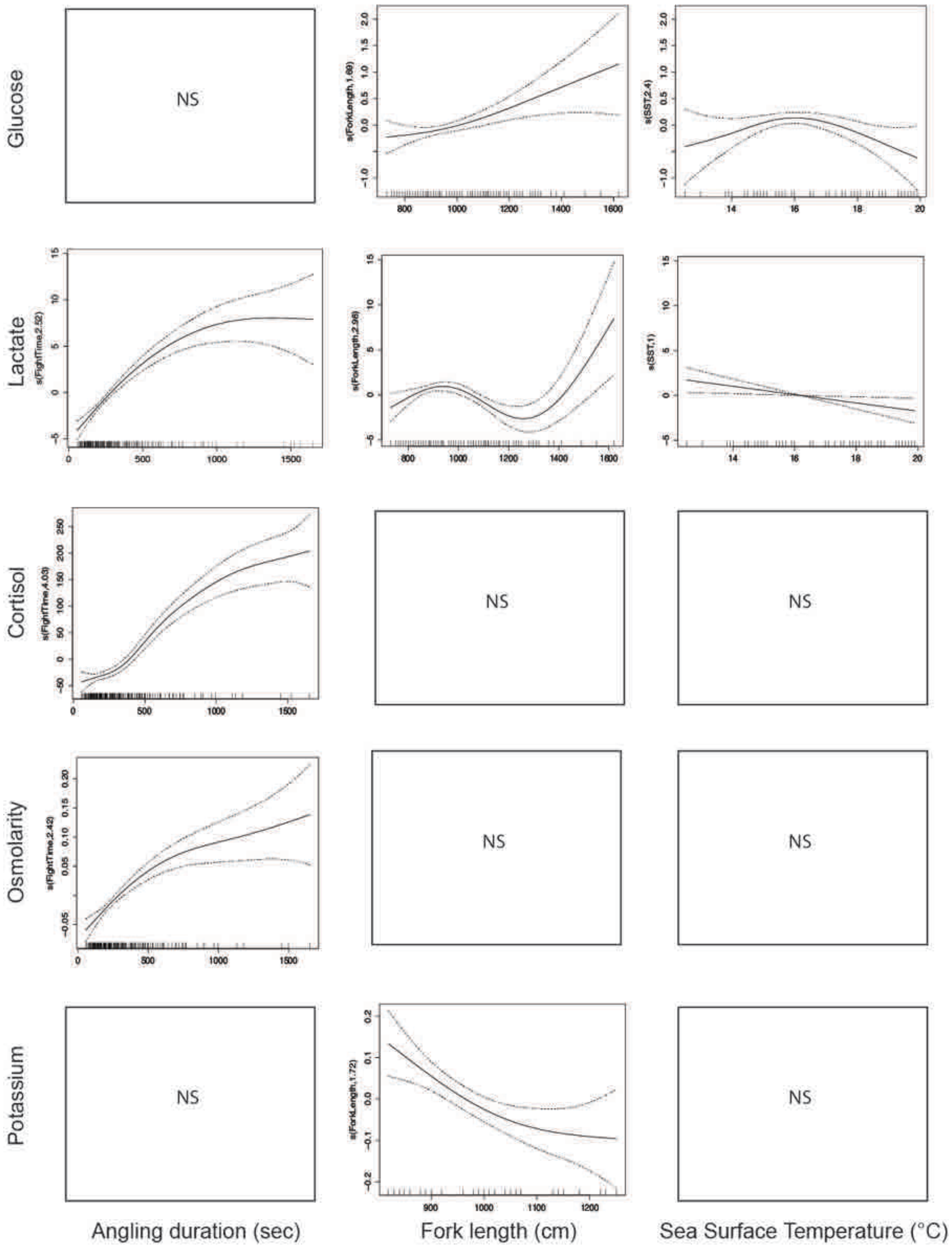

Figure 9. The estimated thin-plate regression spline smoothers calculated for ‘angling duration’, fork length and sea surface temperature in the generalised additive model explaining each of the significant biochemical variables from recreationally captured Southern Bluefin Tuna. The solid lines indicate the best fit and the dashed lines the 95% confidence intervals. Internal dashes on the x-axis indicate the presence of a sample. Data was truncated to angling durations less than 45 minutes to remove outliers.

Correlation between biochemical variables

Several of the blood plasma biochemical variables were identified as significantly correlated to each other (Figure 10). Lactate was significantly correlated with all other biochemical variables with the exception of Potassium and the strongest correlation was identified with cortisol (*r* = 0.49). Cortisol was also significantly correlated with glucose (*r* = 0.43) and osmolarity (*r* = 0.51).

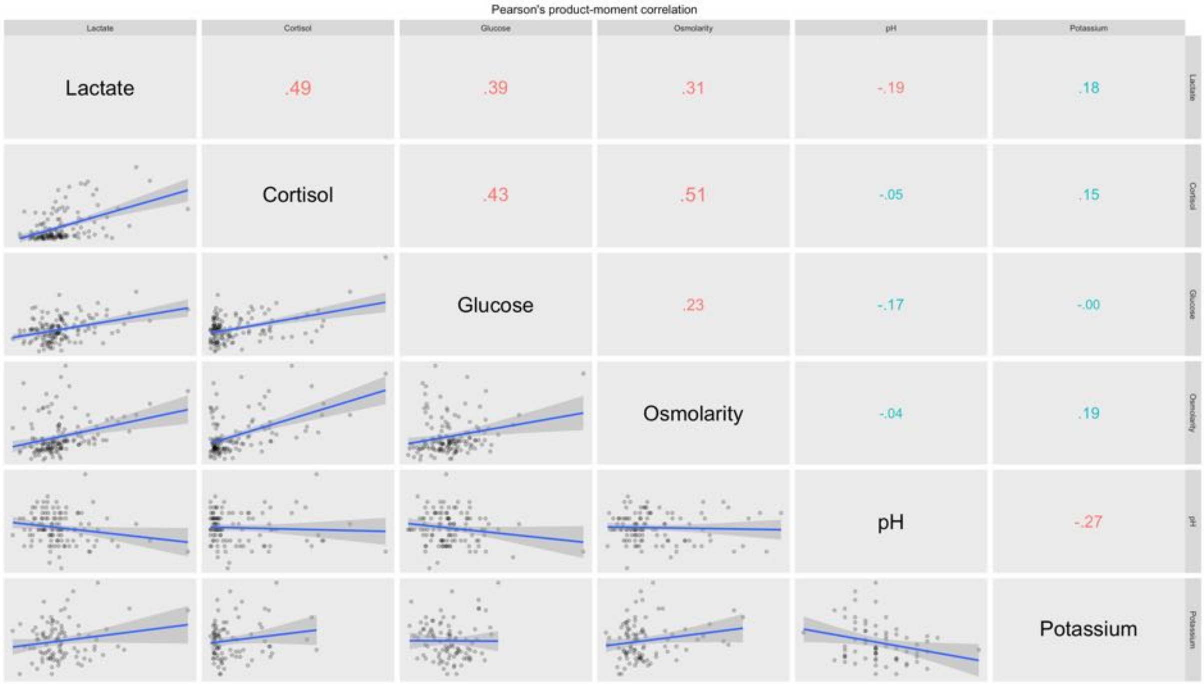

Figure 10. Correlation matrix illustrating pairwise plots of the blood plasma biochemical variables and corresponding correlation scores. Red scores indicate statistically significant correlations, while blue scores indicate non-significant correlations.

Pop-up archival tags

All 59 PAT tags successfully transmitted data (Appendix 3). A total of 12 tags (20%) stayed attached to the fish for the full-program duration. Eight of these were programmed for the maximum duration used in this study – 180 days. Two were programmed to detach after 100 days and the remaining two were programmed to detach after 40 days. The remaining 47 tags detached early, either due to a mortality event or premature tag detachment.

For the 42 PAT tags that were programmed to detach after 180 days, and were attached to fish that did not suffer mortality, the mean attachment duration was 91 ± 8.1 s.e days. A Kaplan-Meier survival model indicated that 50% of the tags were detached after 111 days and that by 180 days 21% of the tags remained attached (Figure 11).

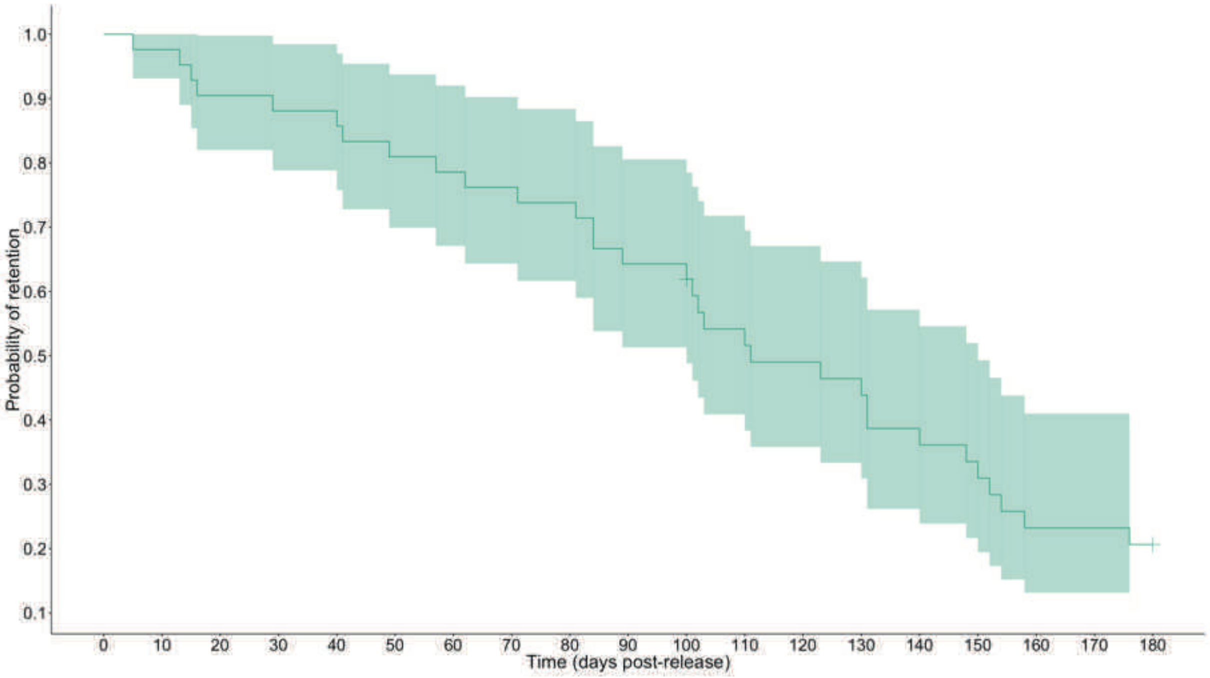

Figure 11. The probability of a PAT tags remaining on a Southern Bluefin Tuna on a given day post-release as estimated using a Kaplan-Meier survival function. The shaded area indicates the 95% confidence intervals. All PAT tags considered in this analysis were programmed to stay attached for 180 days. Individuals that were determined to have succumbed to mortality were excluded from this analysis. The truncated sample size was 42 individuals.

Table 5. Fate of the 59 fish fitted with PAT tags. Mortalities occurring on or within 10-days post-release were attributed to the capture event (PRM_{CI}), with the exception of a recapture. Mortalities occurring after 10-days post-release were considered natural or potentially due to the influence of carrying the PAT tag.

Fate description	No. of fish (≤ 10 days)	No. of fish (> 10 days)
PRM_{CI} - Early onset catch induced	4	-
PRM_{CI} - Delayed onset catch induced	2	-
PRM_{CI} - Catch induced post-release predation	3	-
PRM_{CI} - Observed post-release predation	2	-
PRM_{N} - Natural/tag induced mortality	-	2
PRM_{N} – Natural/tag induced predation	-	2
PRM_{R} – Recapture	1	-
PRS – Premature tag shedding	-	31
PRS – Full term	-	12

Post-release survival rate

Sixteen of the 59 satellite tagged fish were determined to have died during the period they had tags attached, 11 of which died within 10-days after release, and were attributed to the catch and release event (Table 6). Four mortalities were considered natural, occurring greater than 19-days after release (Table 5, Figure 12). The allocation to these categories are explained in Appendix 4. One individual was recaptured less than 24-hrs after release by a commercial long-line vessel. This fish was categorised as not dying due to the recreational catch and release event, as taking a baited long-line hook was evidence of feeding behaviour. It was assumed that this reflects that the fish was not significantly stressed or injured at the time of recapture.

Seven fish (63% of mortalities associated with the recreational fishing event) died within 24 hours of release (Table 6). Four of these fish were classified as direct catch-induced mortalities, one was inferred as a post-release predation based on dive and temperature data recorded by the tag and two were observed post-release predation by seals (Tables 5 & 6).

The post-release survival (PRS) rate of fish caught on lures rigged with J-hooks, excluding the two fish that were observed to be predated upon immediately once they were returned to the water, was 86.6% (95% CI: 77.3 – 95.5%, *n* = 44). For fish caught with circle hooks the PRS rate was 87.4% (95% CI: 70 – 100%, *n* = 8), and for fish caught on lures with treble hooks the PRS rate was 60% (95% CI: 20 – 100%, *n* = 5). As the PRS rates of fish caught with J-hooks and circle hooks were similar, these categories were combined to increase sample size. The resulting PRS rate, with the inclusion of the two fish that were observed to be predated on, was 83.0% (95% CI: 75.9 – 90.7%, *n* = 54). Given the PRS rate of fish caught using lures with treble hooks was much lower, these individuals were not pooled with the other two hook categories. Noting however, that the sample size of treble hooked fish is low and the result is therefore indicative rather than statistically robust.

It is not possible to measure the effect of the tagging process or carrying an external PAT tag on survival so the predictions of post-release survival should be considered conservative, as the estimate may include some degree of 'tag effect'.

Table 6. The number of fish dying each day post release (up to 10-days), as well as the cumulative number of fish to die and the subsequent post-release survival (PRS) rate. Fish caught on J-hooks (J) and circle hooks (C) are combined as the PRS rates were similar. Fish caught on treble hooks (T) are reported separately as the PRS was much lower than for the other two hook categories.

Day of mortality post-release	Moribund		Predation		Total died		Cumulative number died		PRS (%)	
	J & C	T	J & C	T	J & C	T	J & C	T	J & C	T
1	4	0	2	1	6	1	6	1	88.9	80.0
3	0	0	1	0	1	0	7	1	87.0	80.0
5	1	0	0	0	1	0	8	1	85.2	80.0
8	0	1	0	0	0	1	8	2	85.2	60.0
10	0	0	1	0	1	0	9	2	83.3	60.0

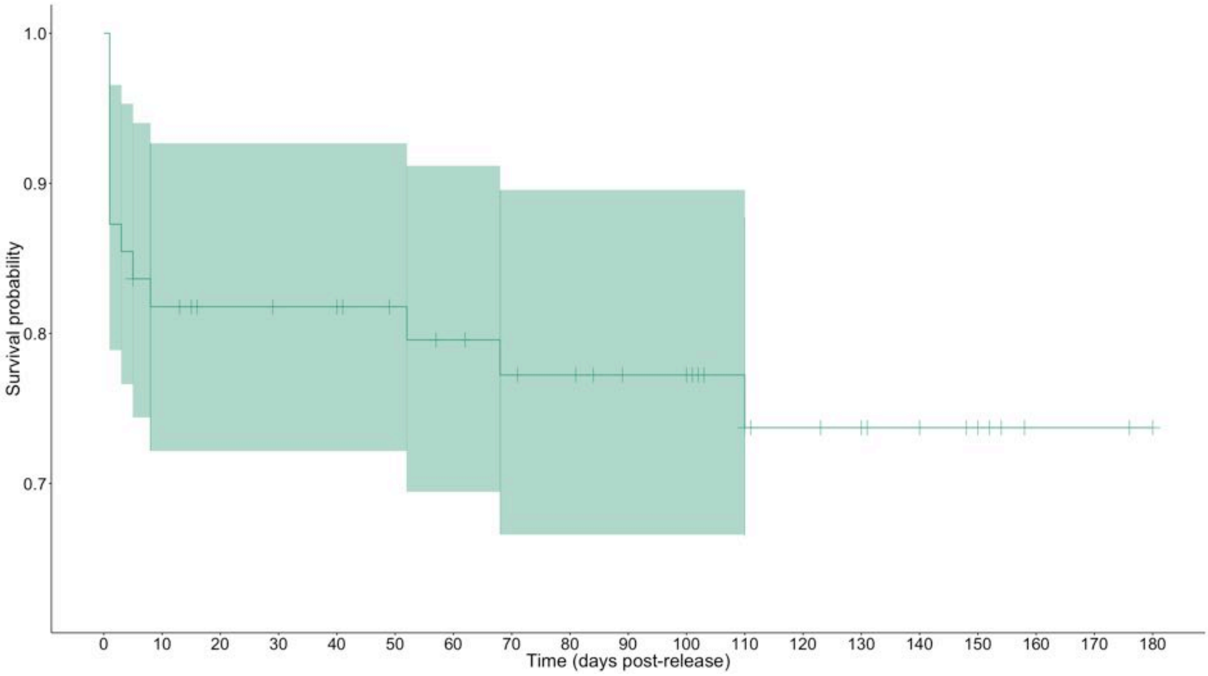

Figure 12. The proportion of Southern Bluefin Tuna surviving on each day post release as estimated using a Kaplan-Meier survival function (*n* = 59). The shaded area indicates the 95% confidence intervals. The small vertical lines on the plot indicate the times a sample was lost from the analysis due to premature tag shedding.

No explanatory variables were identified as significantly related to post-release survival by GAMs. A visual inspection of the relationships between angling duration, fish length, SST and each biochemical variable confirmed no obvious differences between fish that were classified as 'survived' or 'died' (Figure 13).

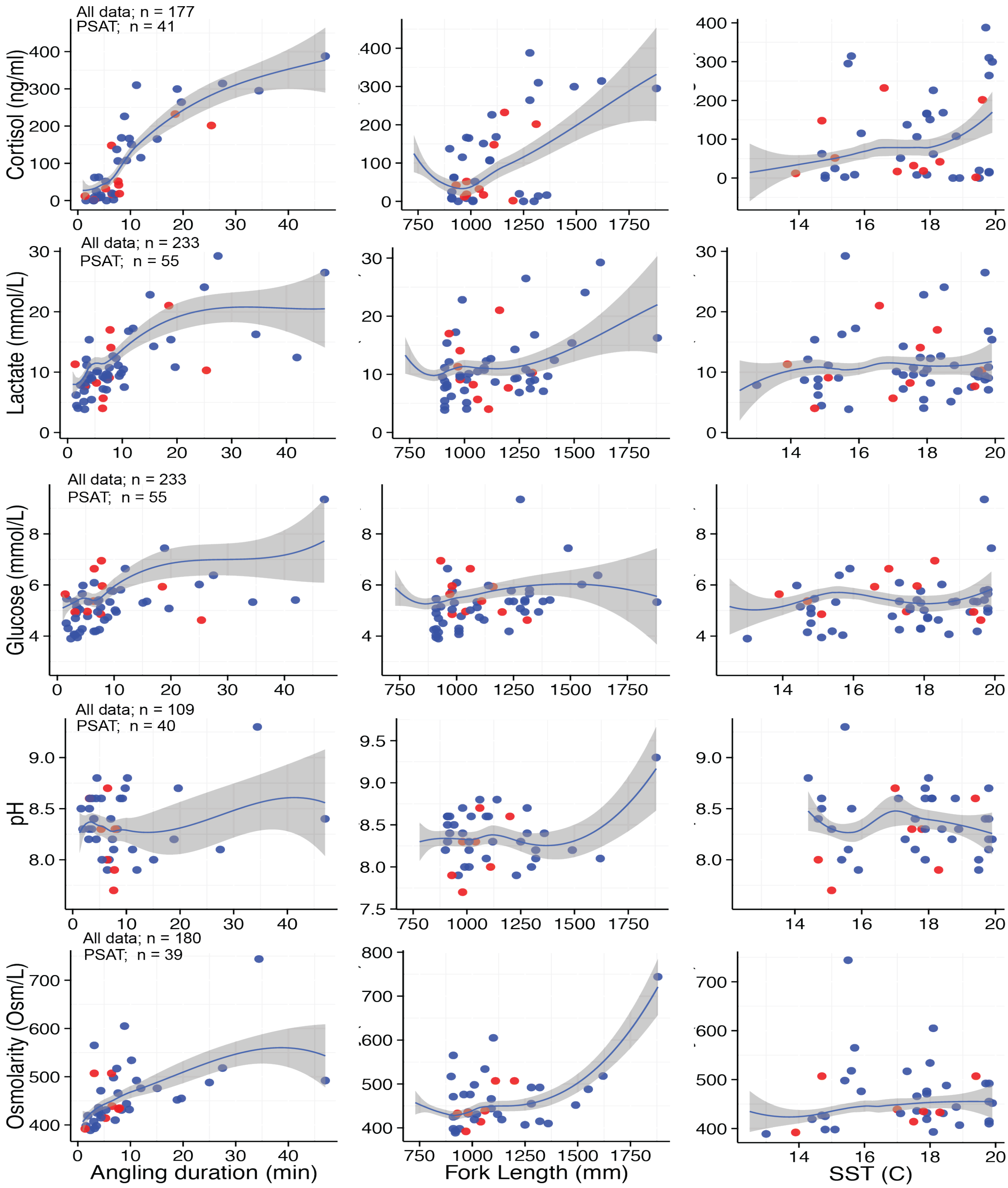

Figure 13. The response of biochemical blood plasma variables to increasing angling duration, fork length and Sea Surface Temperature (SST). The fitted lines are LOESS smoother fitted to all available data and the grey shading illustrates the 95% confidence intervals of the smoother fit. Blue points are Southern Bluefin Tuna (SBT) that were PAT tagged and survived more than 10 days post-release, red points are SBT that were PAT tagged and did not survive beyond 10 days post-release. Data points from SBT that were not tagged have been removed to aid the visualisation of biochemical values of the tagged fish against the expected fits.

A visual inspection of the size frequency composition of PAT tagged fish showed that mortalities were evenly distributed across size classes, supporting the result that the size of the fish was not a determining factor in regard to mortality (Figure 14).

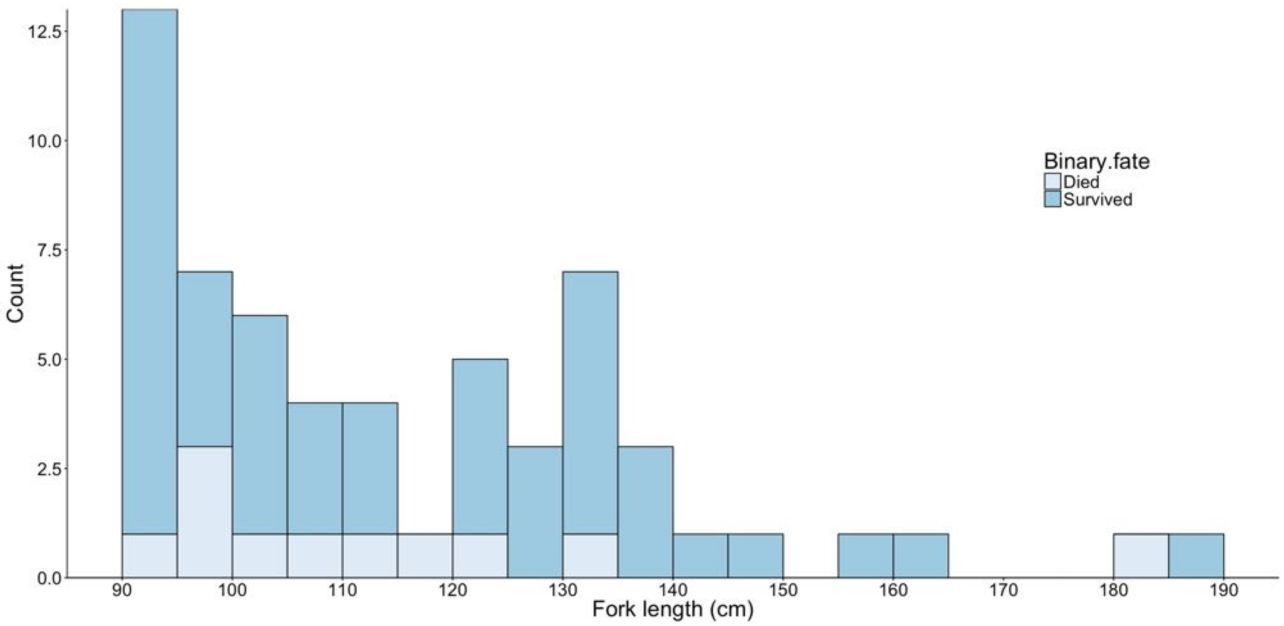

Figure 14. The size composition of Southern Bluefin Tuna that had PAT tags attached. The colour of the columns represent whether the fish died or survived post-release as per the figure legend.

5 Discussion

The recreational fishery for Southern Bluefin Tuna in Australia

Recreational fishing for Southern Bluefin Tuna (SBT) in Australian waters centers around western Victoria, the south and east coasts of Tasmania and the south coast of NSW up to Sydney and South Australia. The size of fish caught in each of these regions varies, but the vast majority, by number, are juveniles, with a small number of larger, mature fish caught (Green et al. 2012, Tracey et al. 2013). In this study, the mean size of fish caught adjacent to Victoria and Tasmania were consistent with previously reported size frequency compositions from the recreational fishery in these states (Green et al. 2012, Tracey et al. 2013). Anecdotally, the size of fish caught adjacent to NSW were also consistent with what is typically caught by the recreational fishery.

The smaller fish caught in western Victoria ranged in length from 78 – 110 cm FL. Based on size, these fish constitute age classes ranging from one to three years in age (Farley et al. 2007). The fish caught adjacent to Tasmania ranged in length from 79 – 129 cm FL, and are estimated to be one – five years of age (Farley et al. 2007). While the fish caught adjacent to NSW ranged in length from 100 – 155 cm FL, estimated to be three to ten years of age (Farley et al. 2007).

The effects of recreational fishing on Southern Bluefin Tuna

Excluding fish retained, the affects of capture on fish can be broken down into several categories. The effect can be either i) instantaneous mortality due to direct capture induced mortality or predation prior to landing or soon after release, or ii) delayed mortality due to physiological stressors imparted on the fish. Sub-lethal effects can also occur, including physical damage, or physiological stress (Arlinghaus et al. 2007). The factors most commonly associated with the capture of fish that can lead to mortality, include exhaustion related to angling duration, water temperature, hooking damage, predation attempts and barotrauma (Muoneke and Childress 1994, Bartholomew and Bohnsack 2005, Arlinghaus et al. 2007). Barotrauma is not likely to be a major determinant for Bluefin tuna that have a physostomous gas bladder and are therefore not significantly affected by decompression.

Mortalities

The percentage of fish that were determined to have died 'on the line' prior to being retrieved to the boat, with the exception of seal predation, was low (3%). In five of the six cases the fish had significant damage due to deep hooking, in the other case the fishing line became tangled around the fish's tail during the capture and was retrieved to the boat backwards. This altered the flow of water across the fish's gills impeding the process of ram ventilation. Stokesbury et al. (2011) also reported a tail wrapping event leading to mortality of a large Atlantic Bluefin Tuna caught using recreational fishing methods.

This is the first study to assess the survival rate of recreationally caught SBT after release. The reported post-release survival estimate should be considered conservative as the effects of processing, in particular drawing blood samples and attaching satellite tags are unknown and may have biased the results towards a higher mortality rate (Cooke and Schramm 2007). With the exception of hook type, no other factors tested were found to significantly influence the post-release survival rate. Therefore, the survival estimate is representative of a broad range of recreational fishing activities which differ by factors such as size distribution of fish caught, angling duration and sea surface temperature at location of capture. Fish caught on lures configured with treble hooks had a lower post-release survival rate than fish caught on either baited circle hooks or lures configured with J-hooks. Given the low sample size of fish caught on treble hooks, however, it was not possible to determine if this result was significant. Different hook types have been shown to significantly influence post-release survival for other species (Skomal et al. 2002, Horodysky and Graves 2005), and as such further research into the effects of treble hooks on the post-release survival of SBT is warranted.

Previous studies on recreationally caught Atlantic Bluefin Tuna, *Thunnus thynnus* (ABT) have reported post-release survival rates of 100% for juveniles (Marcek and Graves 2014) and 94-97% for adults (Stokesbury et al. 2011). While the estimates presented for SBT are lower than the estimates presented for ABT, they are similar to those presented for other large pelagic fishes caught by recreational fishing methods, including White Marlin *Tetrapturus albidus* (82.5%) (Horodysky and Graves 2005), Black Marlin *Istiompax indica* (89%) (Musyl et al. 2015), Sailfish *Istiophorus platypterus* (91.8%) (Musyl et al. 2015), and Striped Marlin *Kajikia audax* (74%) (Domeier et al. 2003).

There have been no comprehensive studies to date on the national recreational harvest, or release rates, of SBT within Australia. However, two studies have been conducted that provide estimates of harvest and release rates from the recreational SBT fishery at a state level. The first was conducted in 2011 in Victoria (Green et al. 2012). Using a comprehensive onsite creel method, the recreational harvest of SBT was estimated at 240 t and the release rate reported as 25%, which equates to approximately 42 t assuming released fish had the same size composition as retained fish. By applying a post-release mortality rate (19%, all hook methods combined in lieu of no information on the proportion of fish caught by each hook type) an estimated 7.8 t were lost as post-release mortality from the Victorian recreational fishery in 2011. The second survey was conducted in 2012 using an offsite longitudinal phone-diary survey in Tasmania (Tracey et al. 2013). A total harvest of 79 t was estimated and a release rate of 24%. Applying the same principals as for the Victorian survey this equates to 14 t of fish released with 2.6 t lost to post-release mortality. These estimates indicate that post-release mortality of SBT adds approximately 3% to the total recreational harvest as unaccounted mortality and that this additional tonnage is insignificant relative to the Australian allocation of the global TAC (5,193 t in 2014).

The majority of SBT that were attributed to have died due to the capture process occurred within 24-hours after release (63%). This is also consistent with other studies on large pelagics showing mortality occurring shortly after release (Domeier et al. 2003, Horodysky and Graves 2005, Kerstetter and Graves 2006, Kerstetter and Graves 2008).

Natural mortality

Four PAT tagged fish were assessed to have died due to natural causes. Natural mortality estimates for SBT are non-linear and age dependent, with higher mortality rates for young fish and lower for older fish, plateauing at age 10 before increasing rapidly at age 25 years (Gunn et al. 2008, CCSBT 2009). The Extended Scientific Committee of the CCSBT use three estimates of annual mortality for one year olds (M_A = 0.26, 0.3, 0.33). Two mortality estimates (using different models) have also been determined from conventional tagging studies for fish 2 – 4 years of age ($M1_A$ = 0.2 – 0.42/year; $M2_A$ = 0.2 – 0.23/year) (Hampton 1991). The proportion of fish that were attributed to have died of natural causes during this study (0.08) is therefore consistent with previous related work. Further noting that the tags were programmed to stay on the fish for only half a year with 79% shedding before this period.

Predation

The ability to avoid and evade predators is based on being able to sense the predator and then respond appropriately. Catching a fish can significantly alter its ability to deal with predatory advances. During the angling period, when the fish is being retrieved to the boat, the fish's ability to evade a predator is limited as the angler is restricting its movements. Predatory interactions may also increase during this period, as predators may be attracted by the noise and irregular movements, or by olfactory or other stimuli related to the fish being stressed or injured (Smith 1992, Schreck et al. 1997, Bleckmann and Hofmann 1999), particularly predators with sensitive chemoreception abilities, such as sharks (Ellis et al. 2005, Danylchuk et al. 2007).

Fishing for SBT adjacent to southeast Tasmania generally occurs in close proximity to the coastline and geographic features frequented by seals - Australian Fur Seals (*Arctocephalus pusillus*) and Long-nosed Fur Seals (*Arctocephalus forsteri*). Anecdotally, the proximity of fishing to these areas has seen an increasing trend in seal interactions with recreationally hooked SBT. In fact, predation by seals prior to landing an SBT was the greatest contributor to mortality assessed in this study, with 31% of fish hooked adjacent to southeast Tasmania succumbing to seal predation (22% of all fish hooked in the study). This predation rate is similar to the estimate (32%) reported from an offsite phone-diary survey of recreational fishers targeting SBT adjacent to Tasmania in 2012 (Tracey et al. 2013).

Predation of fish during the capture event did not occur in waters adjacent to Victoria or NSW. Recreational fishing in these areas generally occurs further from the coast. Seals were the only predators identified as interacting with the fish during the capture process in this study.

There were two occurrences of observed predation by seals on SBT after release. On both occasions the seals interacted with the fish prior to landing (chased the fish – inflicting minor superficial grazing), and even though efforts were made to move on from the area before release, the seals chased the boat and re-engaged with the fish. The PAT tag attached to the smaller of the two fish recorded temperatures of approximately 38°C – the typical body temperature of a seal (Austin et al. 2006) - indicating that the seal had ingested the tag. The elevated temperatures were concurrent with reduced light levels for a period of near 48-hours, further supporting that the tag was in the seal's gut.

The other fish was much larger, estimated at 123 kg, the data on the tag indicated that it may have been removed from the fish, presumably by the seal which was observed predating on the fish, with the tag recording a maximum depth of only 10 meters. These two fish were included as mortalities in the post-release survival estimate for completeness, however these mortalities were not directly related to the factors tested in this study and, as such, were excluded from the predictive analysis. Seal predation however, is an important consideration for the management of the recreational SBT fishery. It is unlikely that seals would be a common predator of an uninjured SBT in a natural situation, and the effect of fish being restricted in their ability to avoid predation while hooked on a recreational fishing line is contributing to this source of mortality. After identification of these mortalities we did not tag and release any fish that had interactions with seals during the capture process.

Direct observation of predation of fish after release has been reported in other studies e.g. Danylchuk et al. (2007), but due to the logistics of observing fish for an extended period post-release, predation events are more commonly identified when PAT tags are utilised. Post-release predations of PAT tagged fish has been reported for Albacore (*Thunnus alalunga*) (Cosgrove et al. 2015), Black Marlin (*Istiompax indica*) (Pepperell and Davis 1999), White Marlin (*Tetrapturus albidus*), Opah (*Lampris guttatus*) (Kerstetter et al. 2004, Polovina et al. 2008), and Atlantic Salmon (Lacroix 2014). The depth, temperature and light level data often reveal clear evidence of a predatory event, and in some cases, the data can provide insight into the predator's taxa or even species (Kerstetter et al. 2004, Beguer-Pon 2012, Marcek and Graves 2014).

Of the nine fish (excluding the two observed seal predations) that died within 10-days after release, three were classified as predation events based on the data retrieved from the PAT tags. A further two fish were predated upon, but well after the release date (19 and 68 days), and as such were considered natural or tag induced predatory events.

The tags from two of the fish that were predated upon within 10-days post-release, and the tags from the two fish that were predated upon later all indicated an increase in temperature up to approximately 26°C, 6 – 8°C above the ambient water temperature recorded prior to the predation event. These increases in temperatures were concurrent with a sustained drop in light level recorded on the tag. The low light levels are indicative of the tag being within the gut of the predator. The temperatures recorded on the tags while ingested by predators are indicative of endothermic animals, and assuming the predator predated on the animal and not just the tag, they must have been of sufficient size to consume an SBT, the smallest of which was approximately 15 kg. We propose that the most likely candidates were Lamnid sharks, and based on species distribution most probably Shortfin Mako (*Isurus oxyrinchus*), which are commonly found in the offshore waters adjacent to NSW and the east coast of Tasmania where these predatory events occurred (http://www.ala.org.au).

Mako Sharks are opportunistic predators, typically feeding on smaller prey items, but have also been identified as predating on large, fast moving pelagic fish such as Swordfish and scombrids (Stillwell and Kohler 1982, Maia et al. 2006, Young et al. 2010). These shark species tend to maintain a body temperature 7–10°C above ambient (Carey and Teal 1969). The recorded depth profiles during the period when the tags were ingested were also consistent with behaviour of Lamnid shark (Sepulveda et al. 2004, Stevens et al. 2010). It is also possible that these predations were by White Sharks (*Carcharodon carcharias*), which are capable of catching and predating large pelagics, including scombrids. White sharks typically maintain internal temperatures between 23°C and 27° C (Goldman 1997).

Physiological stress

Stress in fish is accompanied by a number of physiological and biochemical changes. The primary response involves the rapid release of catecholamines and corticosteroids which are followed by downstream secondary metabolic effects (Mazeaud et al. 1977). Tertiary effects result from the partitioning of energy substrates from vital physiological processes such as growth and reproduction (Iwama 1998).

Despite the large body of knowledge documenting the consequences of stress in a range of fish species, assessment of the stress response can be difficult. Commonly measured secondary metabolic stress responses include plasma glucose and lactate concentrations. Elevations in plasma glucose are associated with the increased energy demand arising from stress and are a result of glycogenolysis and/or gluconeogenesis predominantly in the liver (Iwama 1998). Elevated plasma lactate, a consequence of anaerobic metabolism, is also often associated with strenuous exercise (Wood 1991). Changes in blood pH resulting from the increased production of lactic acid and elevations in CO_2 can also be indicative of acid-base disturbances (Barton and Iwama 1991). A decrease in pH in the muscle, can lead to leaching of protons into plasma, and subsequent disruption of ionic/osmotic balance (Wood 1991).

Cortisol is considered to the best quantitative indicator of physiological stress (Ellis et al. 2007) and responds to a variety of both acute and chronic stressors (Pickering 1992, Barton 2000, Fridell et al. 2007). Under normal conditions cortisol is vital for general body function and can have both beneficial and protective effects (Lane 2006). Chronically elevated levels however are more often associated with adverse consequences such as reduced growth rate (Jentoft et al. 2005) and immune-suppression (Watanuki et al. 2002) as it shifts energy investment from anabolic to catabolic activities, such as energy mobilisation and maintenance of homeostasis (Bonga 1997).

In this study a typical stress response was observed in relation to angling duration. Plasma cortisol concentrations from SBT were elevated and sharply increased in association with angling duration with peak levels observed within 10-30 mins, although cortisol concentrations will likely increase post-release as values do not typically peak until 1-2 hours following exercise (Barton et al. 2002). Plasma glucose and lactate concentrations followed a similar trend and were significantly associated with cortisol and angling duration, concurring with other studies (Gustaveson et al. 1991). These biochemical responses are typical of exercise, akin to burst swimming, with the duration leading the fish towards an exhausted state. Plasma glucose, lactate, cortisol and osmolarity however, all tended to asymptote after a period of angling. This may suggest that the fish reduce their energy expenditure prior to reaching a state of full exhaustion – noting that neither angling duration, nor any biochemical indicators were significantly related to the fate of SBT post-release.

Cortisol concentration in fish captured were similar to those observed for ranched SBT subjected to commercial harvest (Kirchhoff et al. 2011a). Values obtained for glucose and lactate were also within the range observed for fish commercially harvested (Kirchhoff et al. 2011a, Kirchhoff et al. 2011b). The positive correlation between plasma cortisol and osmolarity but not potassium indicates that prolonged angling durations resulted in osmotic but not ionic disturbance. Ionic/osmotic disturbance in relation to stress is associated with the actions of adrenaline on increased diffusional and osmotic permeability of the gill (Pic et al. 1974). Elevated osmolality has been documented in association with both exhaustive exercise and angling stress (Rao 1968, Gustaveson et al. 1991, Wood 1991, Suski et al. 2007).

It was not possible to hold fish in this study to assess how long physiological changes take to return to normal. Nevertheless, other studies on fish have indicated that resting levels are achieved with 2-24 hours, depending on the biochemical variable being assessed, once the application of a stressor is removed from the fish and providing that it is in an oxygenated environment (Suski et al. 2007). An SBT caught and tagged off the NSW coast was caught by a commercial long-liner on a baited hook in the vicinity that the fish was released within 48-hours post release. This indicates that the fish had resumed feeding behaviour supporting that fish recover within, at least, two days post-release.

Hook type and hooking location

Hooking location has been reported as the single most important factor related to a fish's fate as a result of recreational capture (Bartholomew and Bohnsack 2005). When fish are deep hooked they tend to experience increased bleeding and damage to vital organs (Lyle et al. 2007). This often equates to high rates of immediate and short-term mortality (Bartholomew and Bohnsack 2005, Cooke and Suski 2005, Arlinghaus et al. 2007, Lyle et al. 2007). Deep hooking rates vary species to species and often depend on the predatory behaviour of a fish when attacking the bait or lure as well as the method of fishing used. For example, deep hooking rates have been reported as relatively high for marlin (Horodysky and Graves 2005, Graves and Horodysky 2008) where baits are trolled slowly and in some cases the drag on the reel is released to stop the bait moving through the water to mimic an injured prey item. Studies investigating hooking damage and mortality of marlin have shown that the use of circle hooks over traditional 'J' style hooks significantly reduces the risk of deep hooking and subsequent mortality (Domeier et al. 2003, Horodysky and Graves 2005).

In this study, seven of the 59-tagged fish were caught using circle hooks when fishing with baited hooks while drifting over a school of SBT. Six of these fish were hooked in the corner of the mouth and one was deep hooked, in the latter case the fishing line was cut and the hook left in the fish. This practice has been shown to reduce mortality rates relative to removing the hook, with the fish often shedding the hook over time (Jordan and Woodward 1994, Schill 1996, Tsuboi et al. 2006, Lyle et al. 2007). Of the fish caught on baited circle hooks, the five mouth hooked fish and the deep hooked fish were all identified as surviving, while one mouth hooked fish died as a result of predation three days after release.

The remaining 52 PAT tagged fish were caught by trolling lures with a range of hook configurations, including J-hooks and treble hooks. When high speed trolling, which is typical when targeting tuna, fish often approach the bait or lure more aggressively and do not have an opportunity to swallow the bait before the hook engages (Graves et al. 2002). A high rate of mouth hooked fish were reported here equating to 94% of all fish that were caught whilst trolling, and 96% of troll caught fish that were PAT tagged, supporting findings that fast trolled baits or lures increases the likelihood of the hook lodging in or around the mouth (Graves et al. 2002, Horodysky and Graves 2005, Marcek and Graves 2014). The type of hook used however had a significant effect on the amount of damage inflicted on a fish, and potentially the survival rate.

The percentage of fish with damage greater than superficial hooking damage was low (6%) for fish caught on lures configured with J-hooks, including skirted lures with a single 'J' hook and hard body lures with either a single or two J-hooks. For hard body lures with two treble hooks however, the percentage of fish with damage greater than superficial hook damage was much higher (40%). In most cases, when a hard body lure with two treble hooks was used the fish would be mouth hooked on one of the treble hooks. The second treble hook would then damage the fish around the head, operculum or gill region as the fish was retrieved to the boat. The post-release survival rate of fish caught on lures configured with treble hooks was lower than for the other two hook types. The sample size of fish caught using treble hooks was low however, reducing the statistical confidence of this finding.

Of the five fish that were identified as succumbing to the effects of deep-hooking prior to landing, four were caught with trolled skirted lures with a single J- hooks and one was caught using a hard body lure with two J-hooks. These hook induced pre-landing mortalities only accounted for 3% of SBT caught.

The results indicate that bait fishing using circle hooks and fast trolling (7 – 9 knots) with lures using J-hooks are effective methods to minimise damage to SBT and increase the probability of survival after release. The use of treble hooks however, should be avoided, particularly if the fish is to be released as the potential for damaging the fish is high, and the fish will have a lower chance of survival.

Bleeding

The amount of bleeding from a fish after capture is strongly dependent on the degree to which specific tissue is damaged and whether the injury results in damage to the cardiovascular system, such as the gills, heart, or vasculature.

In this study, 59% of the SBT that had PAT tags attached were identified as having no or very little bleeding, 32% had minor bleeding associated with the hooking location in the mouth, 5% had minor internal bleeding within the mouth (in some cases observed from the operculum) and 2% had major bleeding, one around the mouth and the other due to major external damage ventral to the operculum from a treble hook. Both the major bleeds were pulsating, indicative of significant vascular damage with a direct pressure connection to the cardiovascular system.

Blood loss due to hooking damage was not significantly related to the fate of the fish post-release. One fish that died within 10-days post-release however, had minor internal bleeding from the gill region inflicted by a treble hook. An underwater photo taken during the angling event revealed that this hook was observed to cause damage to the gills. Once landed though this damage was not evident as the operculum was closed and only minor bleeding was evident. This injury was not realised until the photos were assessed days later. This fish was predated upon within hours' after release.

Of the remaining 10 fish that died within 10-days after release, five had no or very minor bleeding, while the other five had minor bleeding from the hooking location in the jaw. The two fish that had major bleeding both survived, one full-term (180 days) and the other prematurely shed its tag after 152 days.

There are many instances where injuries include minor or moderate bleeding that is unlikely to result in mortality (Arlinghaus et al. 2007). Unless there is a major wound and significant blood loss, the bleeding will usually stop quickly, the wound will heal, and the fish will survive (Arlinghaus et al. 2007). Evidence of blood clotting was observed for many of the SBT; including the two fish that had PAT tags attached that had major bleeding.

These results support the case that treble hooks are more likely to increase the risk of physical damage and that damage to the gills can lead to mortality.

Angling duration

Longer angling time has been shown in many studies to increase physiological disturbance and the time required for recovery (Cooke and Suski 2005, Cooke et al. 2008). Few studies however have found a relationship between angling time and post-release mortality, including studies on Striped Bass (Diodati and Richards 1996), Rainbow Trout (Schisler and Bergersen 1996) and Striped Marlin (Domeier et al.

2003). Our results were consistent with this, longer angling durations did not relate to the fate of the SBT post-release.

We did not investigate the specific relationship between angling duration as a function of line class × fish size as angling experience and the drag settings on the reel were un-tested in many cases. Nevertheless, there was a positive linear relationship between angling duration and fish size, which was expected and consistent with other studies (Thorstad et al. 2003). While the results do not indicate that angling duration affects survival of Southern Bluefin Tuna, extended durations do increase the physiological effects on the fish (discussed above) and therefore consideration should be given to using appropriate tackle relative to the size of the fish to minimise the angling duration, subsequently improving the welfare of the animal (Cooke and Suski 2005, Iwama 2007).

Water temperature

Water temperature at the location of capture was not related to the fate of SBT post-release. This is not surprising given the broad thermal niche of the species. Satellite tags indicated that the fish spent time in water ranging from 8 - 22°C normally distributed around a mean of 16°C. The ability of Bluefin tuna to tolerate such a wide range of temperatures is due to their endothermic physiology, whereby they can retain metabolic heat. The vast majority of literature on the effects of fish caught across a range of temperatures relates to ectothermic fish (Cooke and Suski 2005), where extreme water temperature, particularly at the warmer end of the continuum, correlated with increased physiological disturbance and probability of mortality (Cooke and Suski 2005).

Handling time

All SBT that were caught and subsequently had PAT tags attached were removed from the water for processing. The fish were handled carefully and time out of water was minimised to the extent allowed by the time taken to process the animal. In many cases recreational fishers will remove a fish from the water to take a photo. While handling time was not significantly related to the fate of the fish post-release, handling fish out of water can cause scale/slime removal, air exposure, tissue damage, hypoxia/temperature and confinement (Arlinghaus et al. 2007), and has been shown to effect equilibrium state in Bonefish (Danylchuk et al. 2007). Cooke et al. (2001) found that for rock bass (*Ambloplites rupestris*) exposed to air, heart function took significantly longer to return to normal levels compared with fish not exposed to air.

6 Conclusion

The fishing methods used in this study were based on common practice within the recreational fishery for SBT. Experienced recreational fishers were consulted, providing advice on fishing methods and in some instances engaged in sampling. The areas fished were also confirmed, by fishers, as the key target areas of recreational fishers focusing on SBT in the states where sampling occurred. As such, the sampling design is considered representative of the recreational fishery for SBT.

Southern Bluefin Tuna have a low incidence of mortality occurring during the capture event related directly to the hooking and retrieval of the fish, with only 3% of fish landed either dead or moribund. The fate of fish that were landed in a non-responsive state was attributed to deep-hooking damage, with the exception of one large fish that became tail wrapped and was retrieved to the boat backwards, effecting its ability to ram ventilate. An exception to the low pre-landing mortality was attributed to seal predation of hooked SBT adjacent to Tasmania. Seal predation was identified as the greatest source of unintended mortality of SBT. The methods used by recreational fishers to capture SBT, for the most part, are effective at minimising damage, with a high proportion of fish mouth hooked (94%) and with the exception of fish caught using lures with treble hooks, a low proportion displayed hook damage beyond a superficial hooking wound (5%). In contrast, almost half of the fish caught on lures configured with two treble hooks had damage beyond superficial hooking damage, leading to a lower chance of survival after release. Treble hooks should be removed from lures and replaced with J-hooks where possible, particularly if the fish caught are intended for release.

Seal predation accounts for the greatest source of unintended mortality of SBT related to recreational capture (31% of fish caught adjacent to Tasmania), but was isolated to Tasmania where the majority of fishing targeting SBT occurs in close proximity to areas frequented by seals, primarily coastline and islands used by seals as haul outs. Anecdotal methods to reduce interactions with seals have been suggested but remain unproven, these include retrieving fish to the boat as quickly as possible, free-spooling the reel if a fish is being chased to allow the fish to avoid the predator unhindered, not drawing the attention of seals while fishing by turning off drag ratchets and avoiding making loud noises, not encouraging interactions by throwing fish frames or offal in the water in the vicinity of seals and moving away from an areas if seal interactions occur. Currently the most effective method is to avoid areas where seals are found in high abundance, however given the nature of the fishery in Tasmania this is likely to significantly limit fishing opportunity for SBT. Further work is warranted to investigate methods to reduce interaction between seals and recreational fishers.

Post-release survival of fish caught using baited circle hooks and lures configured with J-hooks was relatively high. This estimate should be considered conservative, as the impact of attaching and carrying PAT tags on SBT is not well understood, but may have a detrimental effect. Post release survival was not found to be significantly related to any measured factors that occurred during the fishing event, namely biochemical indicators of stress, angling duration, fish size, SST and the time taken to process the fish.

While angling duration was not significantly related to post-release mortality, longer durations did increase physiological stress as indicated by significant relationships with elevated levels of lactate, cortisol and osmolarity in blood plasma. Minimising angling duration may decrease the time it takes for the fish to recover post-release, improving the ability to avoid predation and increasing the capacity of the fish to re-engage with a school and return to normal feeding behaviour.

The results here indicate that current recreational fishing management strategies utilising catch limits (which may result in the release of fish) are not substantially compromised by a high post-release mortality rate. The potential for unintended mortality should be considered in relation to the total number of fish released from the recreational fishery as well as the post-release survival rate. Similarly, voluntary catch and release fishing, given release rates reported elsewhere, is not expected to greatly increase unintended mortality arising from recreational capture of SBT.

Maintaining or improving fish handling practices is fundamental to minimising the unintended impacts of recreational fishing on SBT and improve stewardship by the recreational fishing sector. Based on the results of this study and findings in existing literature we have developed a Code of Practice outlining ‘best practice’ (Appendix 10). The intention of the Code of Practice is to provide concise information to reduce the rate of unintended fish mortality, improve animal welfare, maximise the quality of the flesh from fish retained for consumption and reduce fish wastage. The effectiveness of the Code of Practice is contingent on broad adoption by key recreational stakeholder groups and the recreational fishing community that target SBT. To this end the Code of Practice was developed with broad consultation and will be disseminated using a range of communication mediums to maximise exposure.

7 Implications

The results indicate that post-release mortality does occur for recreationally caught Southern Bluefin Tuna, but is not significant factor in relation to the total recreational harvest of SBT. Therefore, current management strategies using catch limits, including personal bag or possession limits are reasonably effective. The reported post-release survival rate has been assessed across the size range of fish that is commonly caught by the recreational fishery throughout southeast Australia. These findings will complement future research to investigate the recreational harvest of Southern Bluefin Tuna in Australia (Moore et al. 2015). The combined results of these projects will provide greater transparency around the recreational fishery for Southern Bluefin Tuna, an objective which is an obligation of Australia to the Commission for the Conservation of Southern Bluefin Tuna.

The development of a Code of Practice for the recreational capture and handling of Southern Bluefin Tuna based on the results of the study, and others, provides fishers with fact based information to improve fish handling practices, primarily around reducing unintended mortality and reducing impacts on animal welfare. The intention is to seek endorsement from key recreational fishing representative bodies and high-profile individuals from the recreational fishing sector to champion and assist in dissemination and adoption of the COP document.

8 Recommendations

This project has captured the attention of the recreational game fishing community. The primary objective of the project was to assess post-release survival and factors that may influence survival of Southern Bluefin Tuna, however the use of PAT tags has provided an additional opportunity to engage recreational fishers through the dissemination of preliminary results on fish movement and behaviour as well as results relating to the primary objectives. The ongoing engagement with recreational fishers throughout the project, primarily through social media, popular recreational fishing magazines, television and information session is likely to have facilitated a better understanding by recreational fishers of the importance and benefits of fisheries science. Perpetuating this engagement with future research projects and continuing education initiatives where possible will foster this relationship and ultimately improve stewardship from the sector by providing fishers with a greater understanding of the role they play in the sustainable use of marine resources.

The code of practice presented here (Appendix 10) collates the recommendations for ‘best practice’ for the catching, handling, release and tagging of SBT. Broad dissemination of the Code of Practice by fisheries management agencies and recreational stakeholder groups is likely to benefit the fishery as a whole. Adoption of practices outlined in the code will improve animal welfare, enhance social license to operate for recreational fishers, possibly improve post-release survival, improve data quality collected from recreational fish tagging programs and reduce fish wastage.

Specific recommendations arising from the research are as follows:

- Additional research is warranted to strengthen the statistical result regarding a lower post-release survival estimate for fish caught using lures configured with treble hooks.
- The inclusion of questions relating to hook type used in future recreational fishing surveys focusing on Southern Bluefin Tuna will provide necessary information if a lower survival rate using treble hooks is proven.
- The promotion of using J-hooks as a replacement to treble hooks is warranted as these hooks were shown to, at least, cause significantly more damage to fish than J-hooks or circle hooks.
- Encouraging lure manufactures to produce hard body lures with J-hooks should be pursued. Noting that some companies have already begun to do this.
- Research into minimising unintentional mortality of SBT arising from interactions between recreational fishers and seals in Tasmania should be considered a priority.

Appendix 1: Relationships between field and laboratory analysis of blood glucose and lactate measurements

In 2012, blood samples were processed in the field using hand-held meters to measure glucose and lactate levels. In 2013 and 2014, the blood plasma collected at the time of sampling was processed in a laboratory in addition to glucose and lactate being recorded using hand-held meters in the field. We compared the field readings to the laboratory readings for both glucose and lactate using linear regression analysis.

A total of 139 samples from individual fish were available to test the relationship between lactate readings from the LactatePro field meter and the Analox laboratory instrument. A significant linear relationship was identified ($r^2 = 0.78$, $P < 0.001$), with the intercept not significantly different to zero at the 0.05 level (Table 7; Figure 15). One sample from a particularly large fish with a long angling duration was identified as a significant outlier and was removed to improve the fit of the linear model. The Analox meter reading for this fish was 61.65 mmol/L.

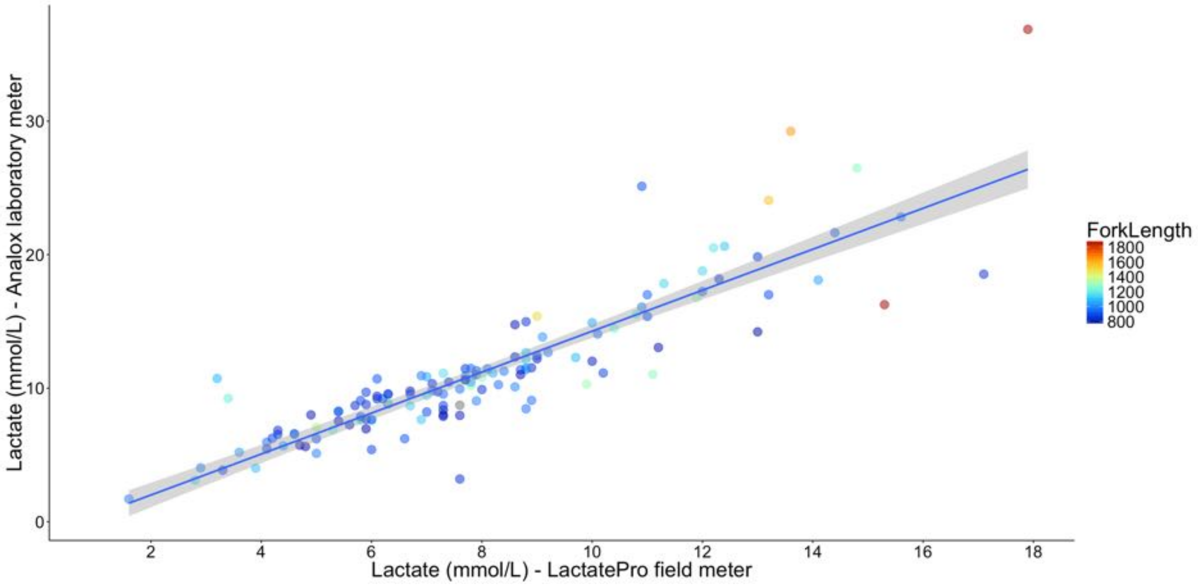

Figure 15. The relationship between lactate readings taken from Southern Bluefin Tuna post-capture using a laboratory based Analox instrument and a field based LactatePro hand-held meter. Field assessments were analysed using whole blood, while laboratory analysis was conducted on blood plasma. The blue fitted line is a linear regression and the grey shading is the 95% confidence intervals of the regression. The colour of the circles indicates the size of the fish (fork length mm) as per the figure legend.

A total of 133 samples from individual fish were available to test the relationship between glucose readings from the AccuCheck field meter and the Analox laboratory instrument. A significant positive relationship was identified, although the coefficient of determination was lower than the fit identified between the lactate measurements ($r^2 = 0.47$, $P < 0.001$), and the intercept was significantly different to zero (Table 7; Figure 16). The removal of the outlier identified in the lactate analysis did not improve the model fit (Table 7; Figure 16).

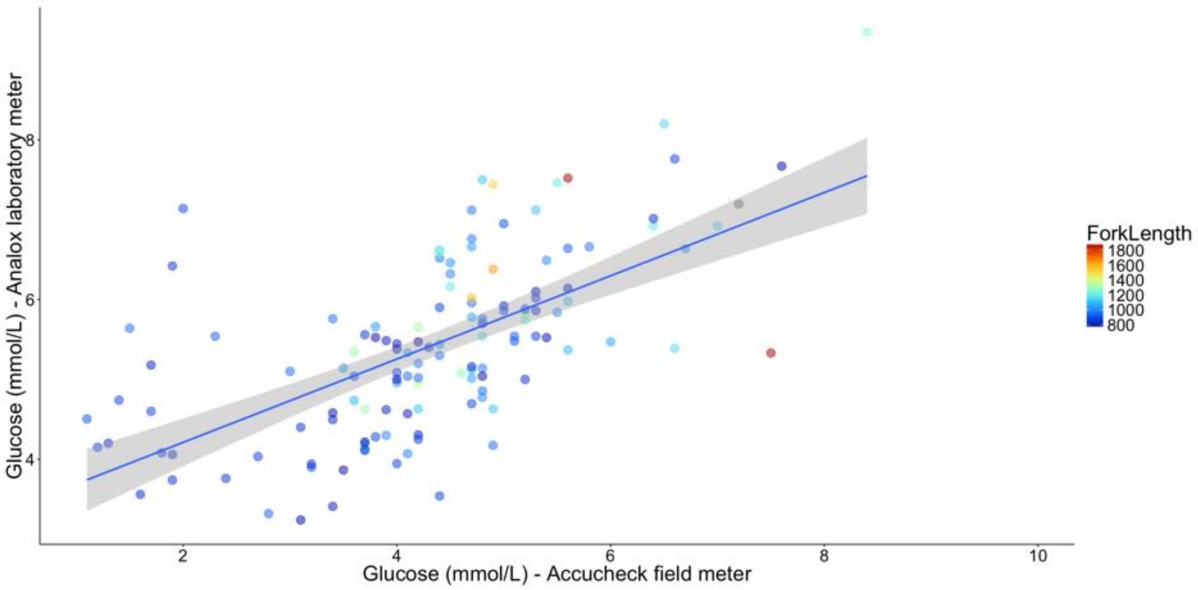

Figure 16. The relationship between glucose readings taken from Southern Bluefin Tuna post-capture using a laboratory based Analox instrument and a field based AccuCheck hand-held meter. Field assessments were analysed using whole blood, while laboratory analysis was conducted on blood plasma. The blue fitted line is a linear regression and the grey shading is the 95% confidence intervals of the regression. The colour of the circles indicates the size of the fish (fork length mm) as per the figure legend.

Table 7. Statistical output of linear regression analysis of biochemical variables measured by field meters and laboratory based equipment.

Variable	*n*	r^2	Intercept (SE)	$P_{intercept}$	Slope (SE)	P_{slope}
Lactate (mmol/L) - all data	139	0.63	-2.49 + 0.97	0.012	1.74 + 0.11	<0.001
Lactate (mmol/L) - outlier rem.	138	0.78	-1.06 + 0.60	0.08	1.53 + 0.07	<0.001
Glucose (mmol/L) - all data	133	0.47	2.80 + 0.26	<0.001	0.61 + 0.06	<0.001
Glucose (mmol/L) - outlier	132	0.40	3.17 + 0.25	<0.001	0.52 + 0.06	<0.001

The regression parameters for both the glucose and lactate regressions were applied to estimate laboratory measurements from the hand-held meters where the former was unavailable.

Appendix 2: Relationship between blood analysis values collected during this study and a previous study conducted in Victoria

A linear regression model (ANOVA) was applied to compare the relationship between the biochemical indicators in relation to angling duration from this study with those provided by the Victorian recreational harvest of Southern Bluefin Tuna project (unpublished data). The data was truncated to a maximum of 30 minutes angling duration to ensure the data was comparable. There was no significant difference between the relationships for lactate, glucose, osmolarity or cortisol values between the laboratory processed blood plasma samples from the two studies (Table 8). There was however, a significant difference in the Potassium values. Given this result the blood sample data from the Victorian project, with the exception of Potassium, can be incorporated to increase the sample size to assess the effect of angling duration on stress as indicated by these biochemical indicators.

Table 8. The results of ANOVA assessing the relationship between laboratory based values of biochemical variables processed from the blood plasma of Southern Bluefin Tuna in relation to angling duration. The comparison is between blood samples collected during this study and blood samples collected during the project 'Assessing the recreational harvest of Southern Bluefin Tuna' which was conducted in Victoria.

Variable	*F*	*df*	*P*
Lactate (mmol/L)	0.558	1, 268	0.456
Osmolarity (osml/L)	0.462	1, 182	0.498
Glucose (mmol/L)	0.768	1, 268	0.382
Cortisol (ng/ml)	0.034	1, 179	0.853
Potassium	75.626	1, 139	<0.000

Appendix 3: Details of PAT tagged Southern Bluefin Tuna.

Releases							Pop-up transmission			
Tag	Location	Date	Latitude	Longitude	Fork length (cm)	Programmed duration (d)	Date	Latitude	Longitude	Actual duration (d)
2012										
115746	TAS	16/05/2012	-43.22	148.01	91	40	3/06/2012	-44.38	149.27	18
115748	TAS	16/05/2012	-43.22	148.01	91	40	26/06/2012	-37.60	139.20	40
115743	TAS	11/06/2012	-43.63	146.36	93	40	23/07/2012	-38.43	139.62	40
115749	NSW	23/06/2012	-36.17	150.97	123	100	3/10/2012	-36.18	158.75	100
115750	NSW	23/06/2012	-36.17	150.97	100	100	2/10/2012	-41.81	149.10	100
2013										
121772	TAS	4/03/2013	-43.85	147.00	109	180	31/08/2013	-43.86	150.77	180
121774	TAS	4/03/2013	-43.86	147.01	106	180	8/04/2013	-44.44	148.91	35
121776	TAS	4/03/2013	-43.86	146.97	116	180	9/03/2013	-43.84	146.91	5
121777	TAS	4/03/2013	-43.85	147.01	123	180	31/08/2013	-36.07	151.96	180
121780	TAS	4/03/2013	-43.85	147.00	112	180	27/08/2013	-39.17	152.72	176
115742	VIC	10/04/2013	-38.78	141.25	109	180	9/05/2013	-39.27	142.42	29
115745	VIC	10/04/2013	-38.78	141.25	101	180	7/10/2013	-38.77	135.60	180
115751	VIC	10/04/2013	-38.78	141.25	110	180	16/09/2013	-41.49	149.45	159
121778	VIC	10/04/2013	-38.78	141.26	106	180	9/10/2013	-35.78	122.66	180
128677	VIC	11/04/2013	-38.66	141.22	91	180	4/07/2013	-39.85	143.10	84
121775	TAS	1/05/2013	-43.13	148.05	188	180	27/06/2013	-39.04	149.17	57
128666	TAS	1/05/2013	-43.13	148.05	102	180	29/10/2013	-42.43	150.47	180
121842	VIC	10/05/2013	-38.31	141.16	90	180	5/10/2013	-36.06	137.64	148
128691	VIC	10/05/2013	-38.42	141.31	93	180	15/05/2013	-38.68	142.96	5
128697	VIC	10/05/2013	-38.38	141.15	92	180	19/06/2013	-38.11	140.77	40
128689	TAS	18/05/2013	-43.12	148.07	184	180	21/05/2013	-43.19	148.11	3
128694	TAS	18/05/2013	-43.13	148.07	162	180	5/10/2013	-39.13	152.19	140
121779	TAS	19/05/2013	-43.26	148.01	111	180	1/06/2013	-43.87	148.04	13
115744	TAS	28/05/2013	-43.86	146.96	101	180	18/08/2013	-37.15	153.21	82
121773	TAS	28/05/2013	-43.86	146.98	98	180	6/06/2013	-40.52	150.76	9
121781	TAS	29/05/2013	-43.13	148.22	91	180	26/10/2013	-38.20	151.31	150
115747	TAS	20/06/2013	-43.83	147.01	91	180	15/08/2013	-31.23	154.76	56
128671	TAS	20/06/2013	-43.73	146.98	92	180	1/11/2013	-40.67	144.53	134
128674	TAS	20/06/2013	-43.86	146.98	94	180	21/08/2013	-41.15	150.41	62
128665	TAS	21/06/2013	-43.85	147.02	91	180	6/07/2013	-43.14	145.69	15
128664	NSW	28/06/2013	-35.34	151.50	149	180	24/10/2013	-38.23	154.23	118
128670	NSW	28/06/2013	-35.38	151.45	135	180	4/10/2013	-41.92	151.10	98
128667	NSW	29/06/2013	-35.39	151.42	131	180	29/07/2013	-35.02	151.13	30
128679	NSW	29/06/2013	-35.39	151.42	130	180	4/12/2013	-41.65	156.70	158
128680	NSW	29/06/2013	-35.39	151.42	136	180	20/10/2013	-43.78	153.52	113
128682	NSW	29/06/2013	-35.41	151.42	132	180	4/07/2013	-32.17	152.50	5
128692	NSW	29/06/2013	-35.39	151.42	128	180	13/11/2013	-43.01	149.10	137
128695	NSW	29/06/2013	-35.41	151.42	132	180	23/10/2013	-38.86	160.32	116
128698	NSW	29/06/2013	-35.39	151.42	128	180	17/10/2013	-43.99	145.84	110

128672	NSW	12/07/2013	-34.01	152.18	138	180	21/12/2013	-44.15	146.71	162
128675	NSW	12/07/2013	-34.01	152.18	130	180	9/12/2013	-46.66	166.64	150
128678	NSW	12/07/2013	-34.01	152.18	130	180	1/10/2013	-35.79	166.46	81
128681	NSW	12/07/2013	-34.01	152.18	124	180	13/11/2013	-42.10	148.34	124
128688	NSW	12/07/2013	-34.01	152.18	120	180	23/07/2013	-34.94	151.09	11
128699	NSW	12/07/2013	-34.01	152.18	125	180	8/11/2013	-39.37	166.63	119
2014										
128669	VIC	2/04/2014	-38.68	141.31	104	180	4/04/2014	-38.67	141.32	2
128676	VIC	2/04/2014	-38.68	141.31	98	180	14/05/2014	-40.05	143.32	42
128685	VIC	2/04/2014	-38.67	141.28	99	180	10/05/2014	-38.64	140.55	38
128686	VIC	2/04/2014	-38.67	141.28	98	180	4/04/2014	-38.62	141.48	2
128696	VIC	2/04/2014	-38.67	141.28	101	180	10/06/2014	-38.37	140.82	69
128684	VIC	3/04/2014	-38.72	141.32	98	180	30/09/2014	-36.98	124.13	180
128683	TAS	27/04/2014	-43.07	147.98	96	180	10/05/2014	-43.0	147.4	13
128668	TAS	8/05/2014	-43.86	146.97	114	180	12/08/2014	-39.4	143.2	96
12868301	TAS	24/06/2014	-43.13	148.01	97	70	4/07/2014	-40.3	150.0	10
128690	TAS	14/07/2014	-43.22	148.01	92	180	11/01/2015	-43.22	148.01	180
133520	NSW	23/07/2014	-34.00	152.07	155	180	27/11/2015	-42.80	152.16	130
128693	NSW	25/07/2014	-35.38	151.32	141	180	12/09/2015	-35.64	160.67	49
133519	NSW	25/07/2014	-35.38	151.32	120	180	05/11/2105	-42.99	154.46	103
133521	NSW	25/07/2014	-35.38	151.32	131	180	19/01/2015	-41.51	168.90	180

Appendix 4: Post-release fate classification

Survived full term

Forty-six fish were classified as ‘survived post-release’. There were however several sub-categories identified within this group, ‘survived full term’, ‘survived premature tag-shedding’, ‘survived natural/tag-induced mortality’ and ‘survived natural/tag induced predation’.

If a tag stayed on a fish for the programmed duration it was classified as survived full term. A total of 12 fish were classified to this category. Two tags were programmed to stay on for 40 days, 2 were programmed to stay on for 100 days and the remaining eight were programmed to stay on for 180 days. An example of a typical depth/temperature time series profile recorded for 180-days is shown in Figure 17.

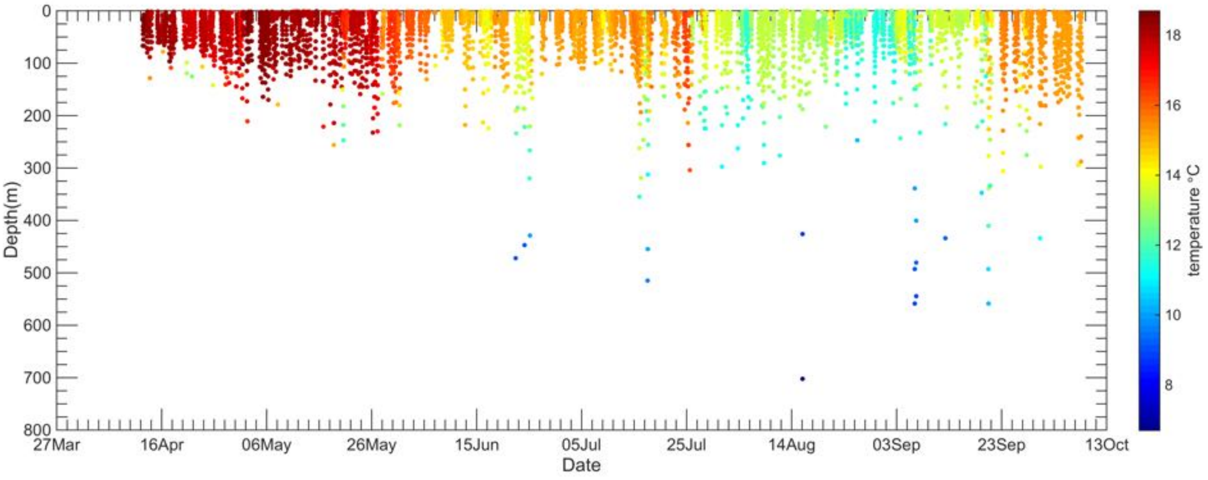

Figure 17. The depth/temperature time series of tag 115745 that was deployed for the maximum 180-day program period used in this study. The tag was attached to a 101 cm FL Southern Bluefin Tuna caught adjacent to Portland, Victoria. The colour of the points indicate the temperature reported by the tag as per the figure legend.

Survived premature tag-shedding

A total of 30 tags were classified as ‘survived premature tag-shedding’. All of these tags were programmed to detach after 180 days, the maximum tag retention duration used during the study. The number of days retained ranged from 15 - 176, with a mean of 94 ± 9 s.e days.

Survived natural/tag induced mortality

Two fish were classified as 'survived natural/tag induced mortality'. This classification was applied when the fish had survived greater than 10 days but were identified as dying prior to tag detachment according to the depth/temperature time series. It was not possible to determine whether the PAT tag being attached was a factor in the mortality. The fish were 91 cm and 149 cm FL, the days to mortality were 54 and 112 respectively. In the case of the smaller fish, the tag (presumably with the fish) sank to below 1500 m (Figure 18). The larger fish also sank, but in this case the pressure release activated at 1688 m.

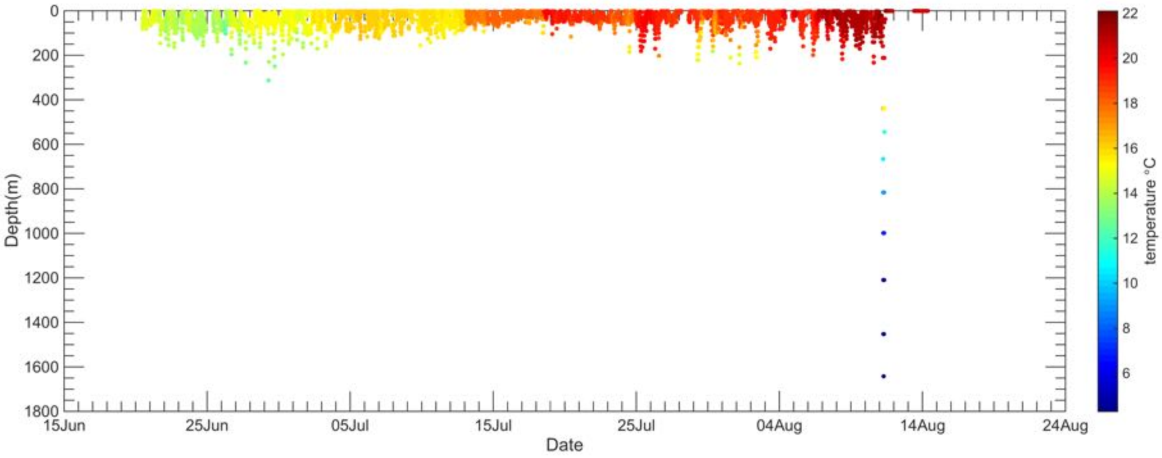

Figure 18. The depth/temperature time series for tag 115747 illustrating the behaviour of a fish that was classified as a 'natural/tag induced mortality'. The tag was attached to a 91 cm FL Southern Bluefin Tuna tagged at Pedra Branca, Tasmania. The colour of the points indicate the temperature reported by the tag as per the figure legend.

Survived natural/tag induced predation

Two fish were classified as 'survived natural/tag induced predation'. The depth, temperature and light data time series from the PAT tags were used to determine this classification, with the difference being that the predation events occurred beyond 10-days post-release. Both fish were the same size (91 cm FL) and tagged adjacent to the Tasman Peninsula.

Tag 115746 indicated that the predation event occurred 19-days post-release, characterised by an abrupt 8 °C increase in temperature and a significant reduction in light level that persisted for six days prior to the tag being ejected by the predator and sinking to 1200 m where the tag anchor shed. It is assumed that the tag was attached to remnants of the fish causing the tag to become negatively buoyant (Figure 19).

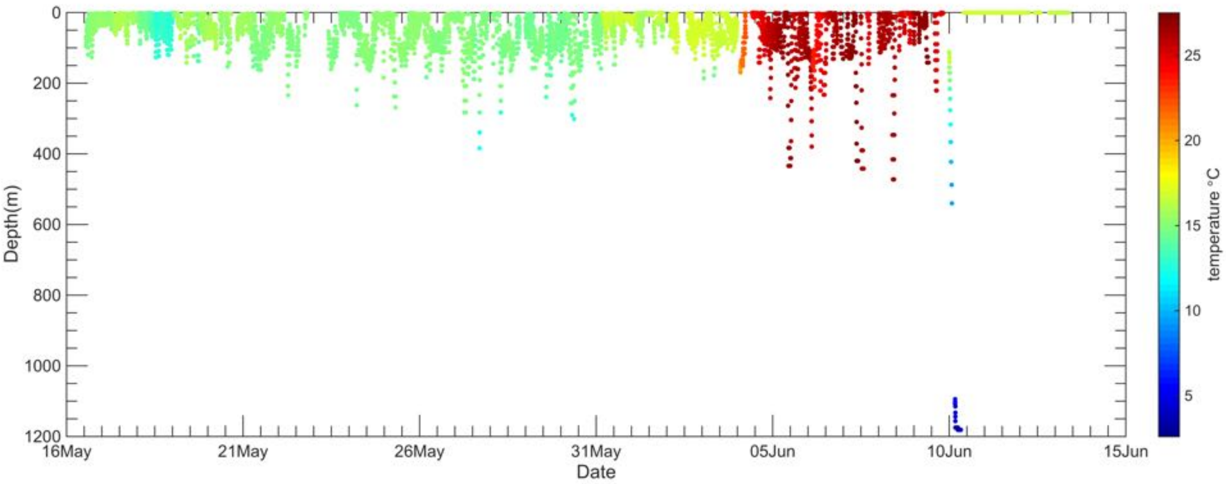

Figure 19. A depth/temperature time series illustrating the indicators of a predation event 19-days post-release. The tag was attached to a 91 cm FL Southern Bluefin Tuna tagged at the Tasman Peninsula, Tasmania. The colour of the points indicate the temperature reported by the tag as per the figure legend.

Tag 121781 indicated that the predation event occurred 68-days post release. Again the predation was identified by a significant, abrupt increase in temperature (6 °C) and a reduction in light level that persisted for three days. Interestingly the tag continued to display a vertical dive profile for approximately 80 days at ambient temperatures and normal light level readings after the predation event, although the dive profile was dramatically different to the pre-predation behaviour. This could be due to the tag becoming stuck to the predator or another animal. Whatever the case the tag became negatively buoyant sinking to 1500 m prior to surfacing and transmitting data (Figure 20). The tag metadata indicated that the pressure release was not activated, so it is assumed that the tag anchor shed from the source of the negative buoyancy.

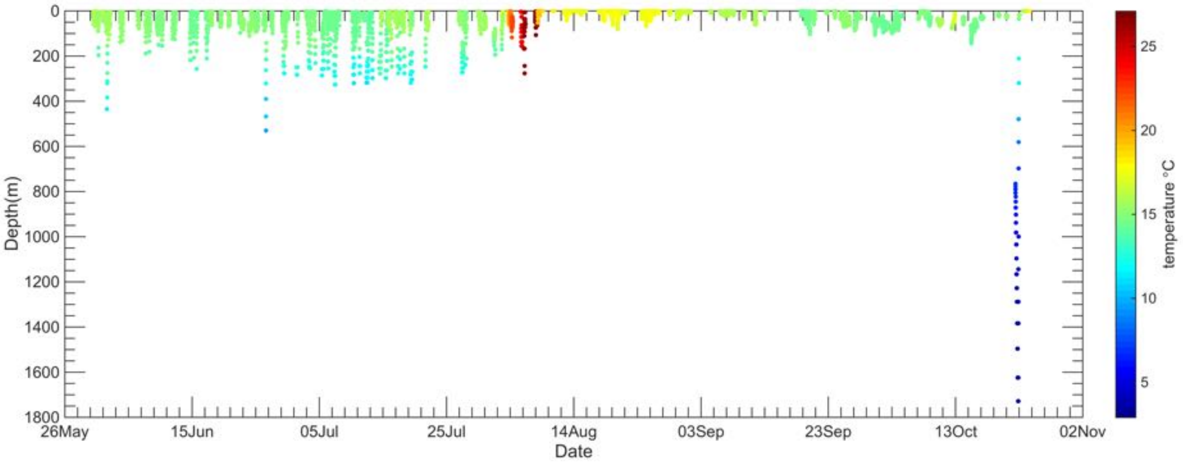

Figure 20. A depth/temperature time series illustrating the indicators of a predation event 68-days post-release (red points). The source of the vertical migration and subsequent negative buoyancy event are unknown. The tag was attached to a 91 cm FL Southern Bluefin Tuna tagged at the Tasman Peninsula, Tasmania. The colour of the points indicate the temperature reported by the tag as per the figure legend.

Survived - commercial recapture

One fish was caught by a commercial long-liner four days after release. Although this occurred within the 10-day catch induced mortality window the fact that it was actively feeding and consumed a baited hook the fish was determined to have survived the recreational catch process.

Early onset catch induced post-release mortality

Early onset catch induced post-release mortality was defined when tag data indicated the fish had died within 24-hours after release.

Tag 128669 was deployed on a fish adjacent to Portland, Victoria on the 2nd of April 2014. The fish (with tag - noting the tag by itself is positively buoyant) sunk directly to the seafloor, approximately 300 m depth. The fish stayed at this depth for approximately four hours then ascended to the surface before again descending to the seafloor where it remained for two days. The tag detached, as programmed, on the 4th of April (Figure 21).

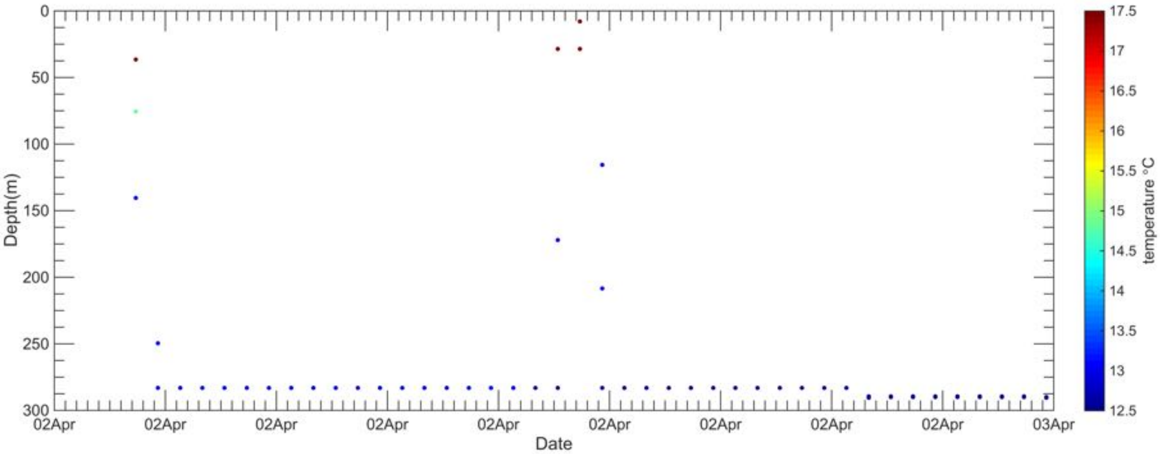

Figure 21. A truncated time-series of the depth/temperature profile of tag 128669 illustrating an immediate post-release mortality. The colour of the points indicates the water temperature as per the figure legend.

Tag 128686 was attached to a fish also caught on the 2nd of April 2014 adjacent to Portland, Victoria. Again the fish sank directly to the seafloor, this time however the tag detached after approximately two hours. It is assumed that the moribund fish was predated on and the anchor was shed from the fish in the process (Figure 22).

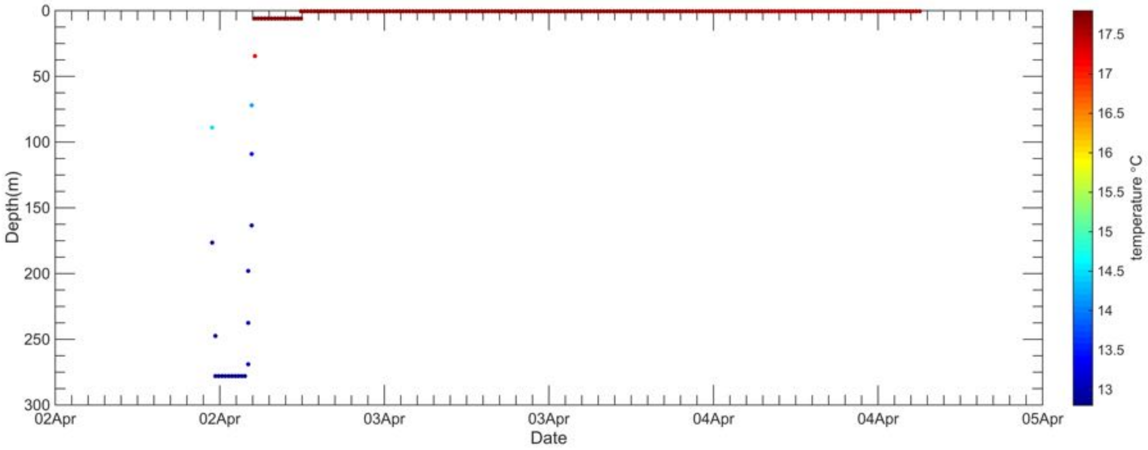

Figure 22. A truncated time-series of the depth/temperature profile reported from tag 128686 illustrating an immediate post-release mortality. The colour of the points indicates the water temperature as per the figure legend.

Tag 128667 was deployed on a fish caught adjacent to NSW, but well over the continental shelf break, on the 29th of June 2013. The tag (presumably attached to the fish) sunk to approximately 1500 m where the tag anchor was shed from the fish (Figure 23). This led to the conclusion that the fish died approximately 10 hours after release. The tag metadata indicated that the pressure release was not initiated. It is possible however, that the pressure at 1500 m caused damage to the fish allowing the tag anchor to shed from the body or that the fish was predated on and the tag shed from the body during this process. As the tag was surfacing it appear to have been eaten by another animal. This was confirmed by very low light levels for the 30 day period until the tag surfaced and also the regular vertical dive patterns reported by the tag (Figure 24).

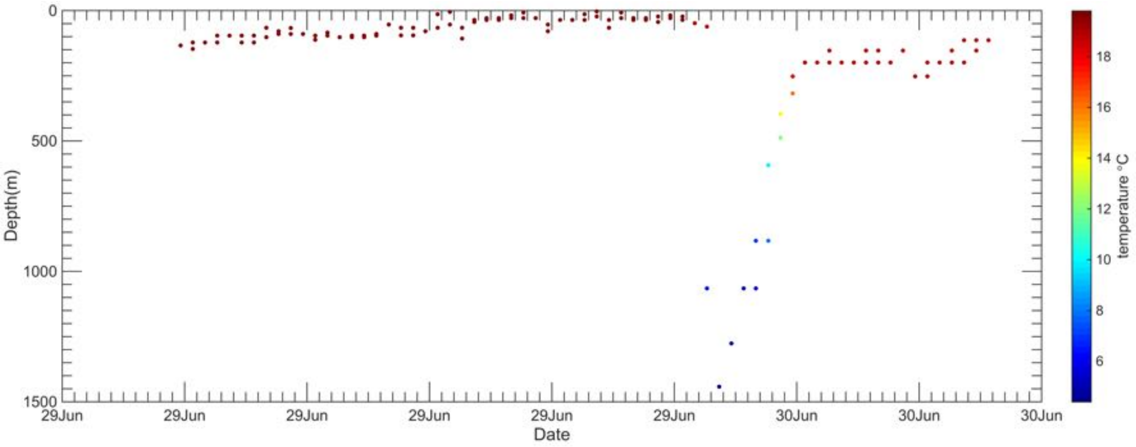

Figure 23. A truncated time series showing the depth/temperature profile of tag 128667 showing the period where mortality occurs. The colour of the points indicates the water temperature as per the figure legend.

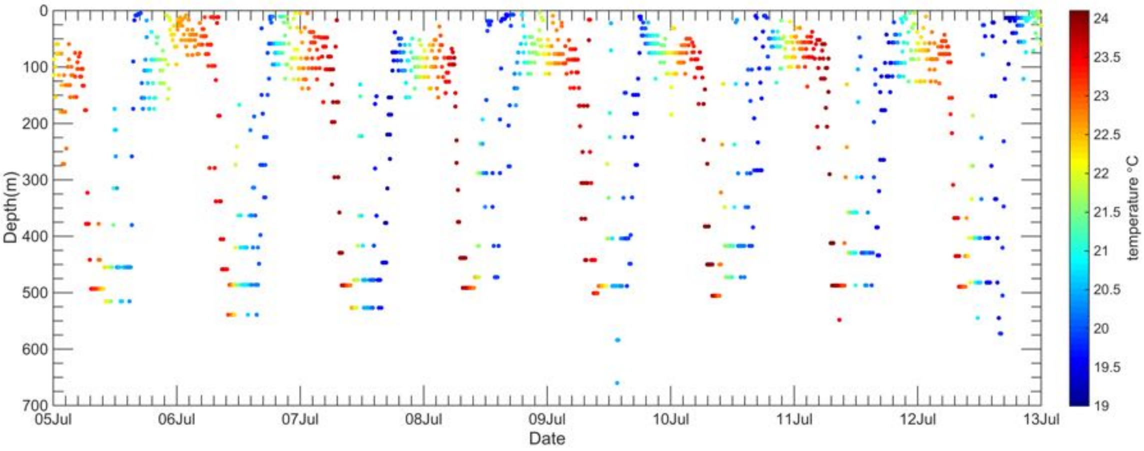

Figure 24. Example of the vertical migration and temperature profile reported for tag 128667 over an eight-day period while in the stomach of an animal that consumed the tag after the tag shed from the moribund SBT at depth. The colour of the points indicates the water temperature as per the figure legend.

Tag 128691 was attached to a fish adjacent to Portland, Victoria on the 10th of May 2013. The tag data indicated that this fish sank to the seafloor approximately one hour after release (Figure 25). It remained on the seafloor for approximately two hours before the tag detached and surfaced. The tag metadata stated that the release pin was still attached. Therefore, it was assumed that this fish had also been predated on whilst moribund on the seafloor and that the anchor shed from the fish during this time.

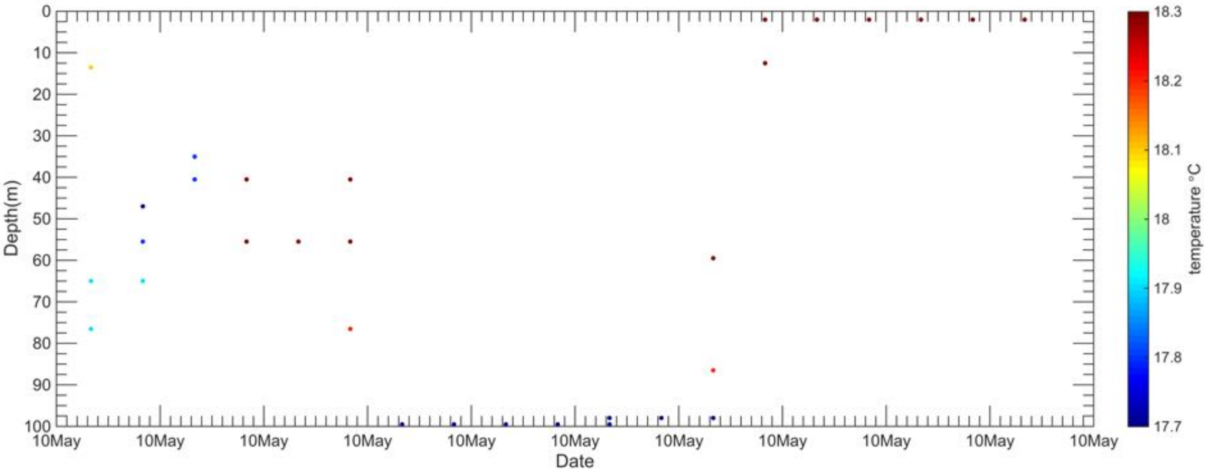

Figure 25. A truncated time-series of the depth/temperature profile reported from tag 128691 illustrating the period the fish is presumed to have died. The colour of the points indicates the water temperature as per the figure legend.

Delayed onset catch induced post-release mortality

Delayed onset catch induced post-release mortality was defined by the fish dying between days two and ten post-release, with no indication of direct predation. Tag 121773 was deployed on a fish adjacent to southern Tasmania (Pedra Branca) on the 28th of May 2013. The fish displayed relatively normal dive behaviour for the first five days post-release (Figure 26). In addition, the tag detached adjacent to St. Helens on the east coast of Tasmania, some 260 nm away from the capture location, indicating that the fish swam a reasonable distance.

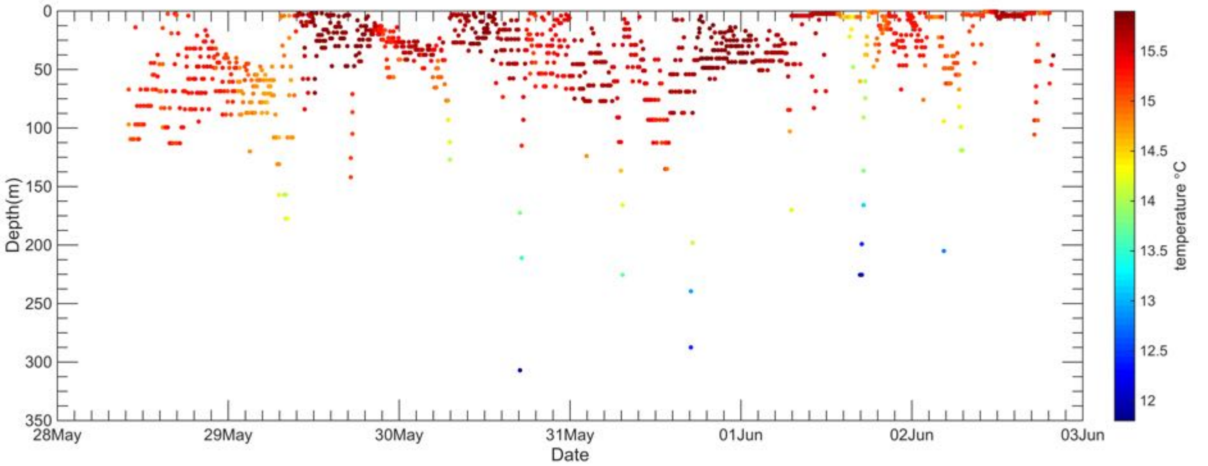

Figure 26. The depth/temperature profile of tag 121773 for the first five-days after release. The colour of the points indicates the water temperature as per the figure legend.

On the 3rd of June however, the tag sunk (presumably with fish attached) to 1600 m (Figure 27). Again the pressure release was not activated so it is assumed that the fish suffered damage at depth or it was predated on which allowed the tag anchor to shed from the fish.

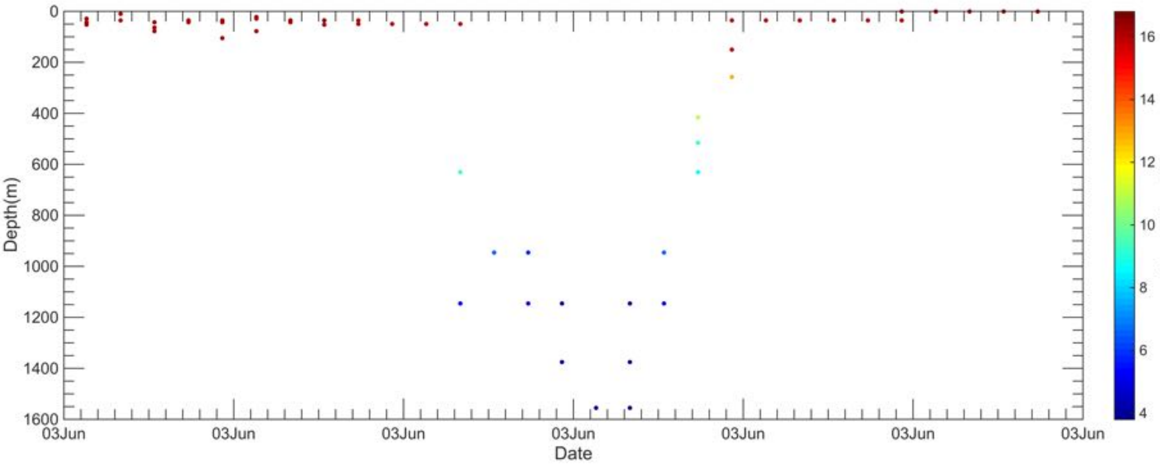

Figure 27. The period of the depth/temperature profile of tag 121773 where mortality occurred. The x-axis shows the date and hour on the day the mortality occurred. The colour of the points indicates the water temperature as per the figure legend.

Tag 121779 was deployed on a fish caught adjacent to the Tasman Peninsula, Tasmania on the 19th of May 2013. The fish displayed atypical behaviour for approximately eight days post-release staying at depths greater than 100 m and not displaying the diurnal vertical migrations typical of other tagged Southern Bluefin Tuna (Figure 28). The tag detached from the fish on day nine post-release. It was assumed from the behaviour that the fish was floundering near the seafloor on the continental shelf prior to being predated upon and the tag anchor being shed and the tag floating to the surface. Alternatively, the tag may have prematurely detached without interaction with a predator. While not definitive, the irregular behaviour and premature release led to this fish being allocated as a post-release mortality.

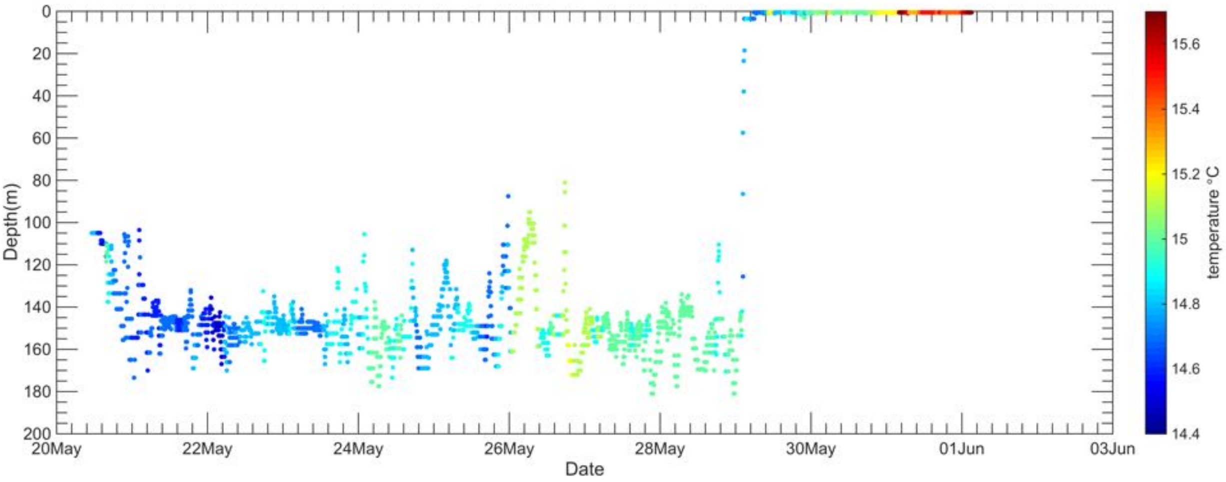

Figure 28. The depth/temperature profile of tag 121779. Based on the irregular behaviour and early tag detachment this fish was identified as a post-release mortality.

Capture induced post-release predation

Tag 128688 was deployed on a fish adjacent to the coast of NSW on the 12th of July 2013. The tag data indicated that the fish was predated on three-days post-release (Figure 29). The fish displayed typical vertical dive behaviour and normal ambient water temperature records for the area it was tagged (~18°C) until mid-afternoon on the 15th of July. An abrupt increase in temperature to approximately ~20°C then occurred, peaking at close to 25°C a day later on the 16th of July.

An indication that this was a predation event and not simply the fish swimming into a warmer body of water is that some of the dives to depth post the predation event are well below the depth of the thermocline where a rapid drop in temperature would be expected - as seen when the tag is finally passed by the predator and sinks to the depth where the pressure release is triggered. At depths of approximately 500 m the temperature on this descent drops to around 12 - 15°C. This is not the case however. For seven days, up until the tag begins to sink, dives to 500 m maintain a recorded temperature of over 20°C, this lack of change further suggests the tag is in the gut of an animal and the temperature is being held relatively constant. The light data also supports this theory, with the recorded light levels remaining below 100 lumens for the period from predation to the tag sinking. Typical light levels recorded by the tags rise to at least 150 lumens and in many cases as high as 250 lumens.

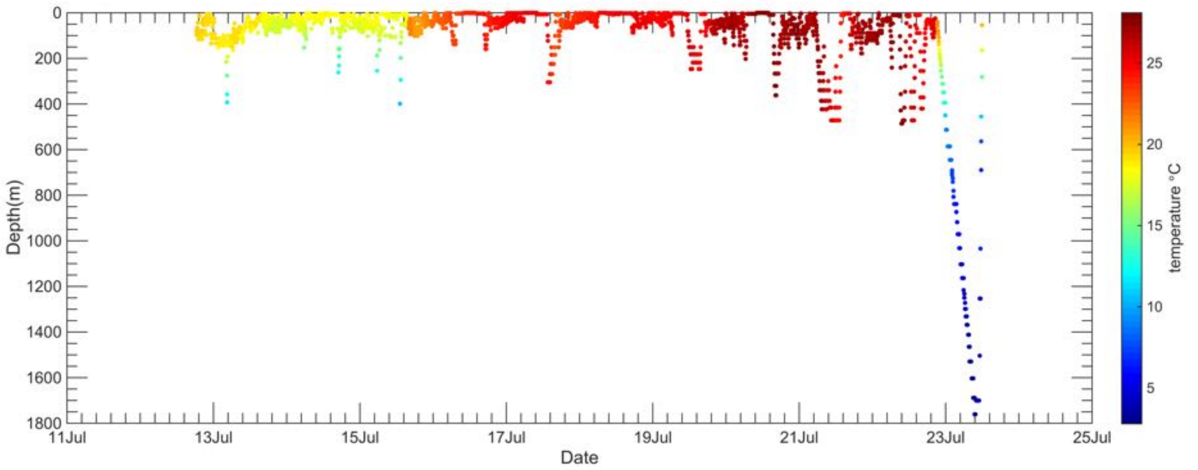

Figure 29. The depth/temperature time series of tag 128688 illustrating a natural/tag induced mortality event. The colour of the points indicate the temperature reported by the tag as per the figure legend.

Tag 12868301 was deployed on a fish caught adjacent to the Tasman Peninsula, Tasmania on the 24th of June 2014. It displayed typical diurnal vertical behaviour for approximately 10 days after release (Figure 30). On the 4th of July the tag abruptly descended to almost 800 m before abruptly returning to a depth of approximately 200 m. The rate of this dive sequence was not unusual, the depth of the dive was, however, anomalous to the behaviour that was displayed by the fish prior to this event. It was assumed that this was a sign that the fish was weakened or distressed. Almost as soon as the fish returned to 200 m it was predated on. This was identified by the tag reporting a rapid increase in temperature of 8°C and a significant reduction in light level, indicating the tag was in the gut of a predator. This warmer temperature and low light level state persisted for six days prior to the tag showing a typical ambient temperature for the region and normal light level readings. The tag immediately floated to the surface indicating there was nothing attached to cause negative buoyancy.

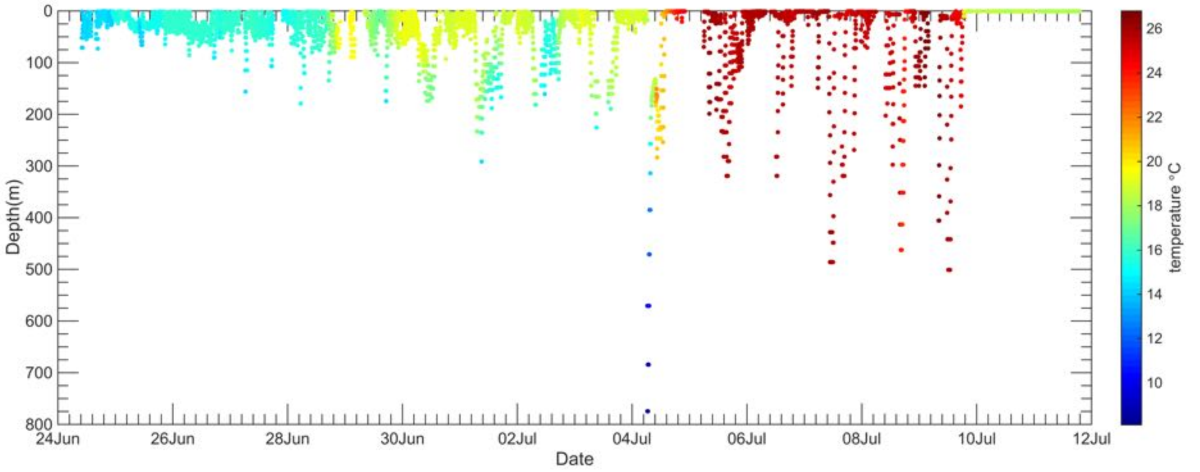

Figure 30. The depth/temperature time series of tag 12868301showing evidence of a predation event 10-days post release. The colour of the points indicate the temperature reported by the tag as per the figure legend.

Tag 121774 was deployed on a fish caught at Pedra Branca, Tasmania on the 4th of March 2013. The tag data suggest that the fish was predated on almost immediately post-release (Figure 31). The light level was at very low levels from the first data point, which was recorded within 24-hours of release, the low light level persisted for a period of eight days. The dive profile was erratic, and the temperature also varied erratically between 12 and 17 °C, but with a poor temperature/depth relationship. This would indicate that the tag was not exposed to light, but if it was in the gut of the predator, the internal temperature increase was not as high as for other predation events (generally around 22 - 25 °C). It is assumed here that the predator was a teleost that was feeding regularly, hence the rapid fluctuations in temperature recorded by the tag due to regular influx of colder water into the stomach while feeding. On the 12th of March the behaviour of the tag changes dramatically. Light level records return to normal, the temperature profile becomes less erratic, but a vertical dive profile continues for 27 days.

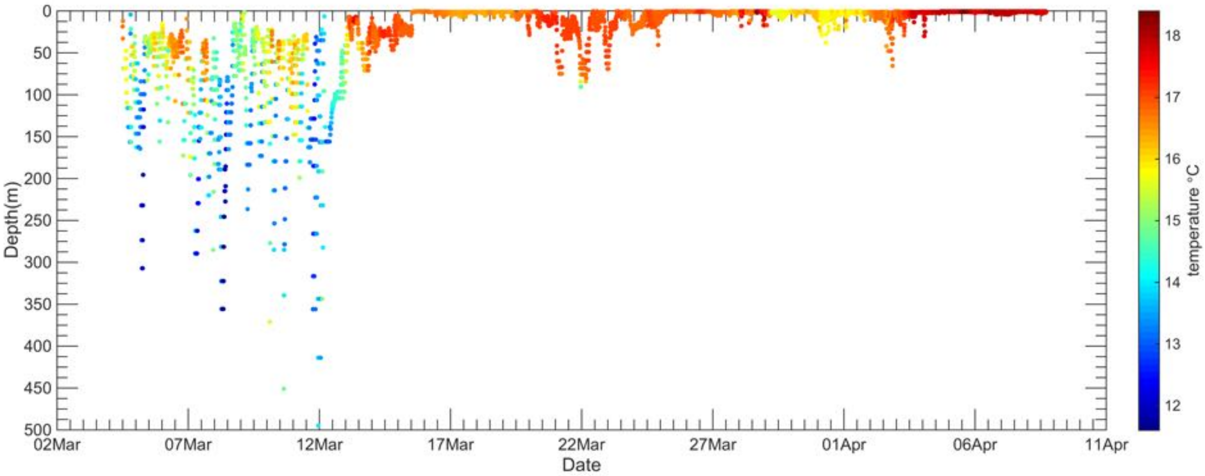

Figure 31. The depth/temperature time series of tag 121774 showing evidence of a predation event immediately post release. The colour of the points indicate the temperature reported by the tag as per the figure legend.

Observed post-release predation by seals

Two satellite tagged fish were observed to be predated on by seals immediately after release. Both these fish were caught adjacent to Tasmania, the first was caught at Pedra Branca early in the project and was 116 cm FL. The fish was chased by a seal for the last 2 minutes and 30 seconds of the retrieval process. The seal caused minor damage near the tail of the fish. Given that the damage was superficial the decision was made to attach a PAT tag and release the fish. While the fish was being processed the boat was driven away from where the fish was hooked to move away from the predatory seal. The seal however chased the boat and even though the fish began to actively swim after release the seal was able to catch and consume the fish.

The second fish was caught at the Tasman Peninsula and was a large individual at 184 cm FL. A seal again chased the fish, in this case for the last 30 seconds of the retrieval process nearing almost two hours. The seal caused superficial damage, failing to puncture the skin. Again the decision was made to attach a PAT tag as the wound was considered minor. While the fish was being processed the boat was again driven away from the seal. Again however, the seal chased the boat and after the fish was released the seal interacted with the fish. Although the consumption of the fish was not observed, the depth data from the tag indicated that the fish was killed soon after release. At this time the decision was made not to attach PAT tags to fish that had interactions with seals during the capture process. It appeared that the seals, once they had interacted with the fish, were likened to a ‘dog with a bone’ they would chase the boat at speed. In other cases, where seals interacted with, and severely damaged fish, they would remain in the vicinity of the boat while the fish was being processed/dispatched, at times trying to observe the fish in the boat through the dive door.

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Appendix 6: Project staff

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Appendix 7: Intellectual Property

The research relating to this project is for the public domain and the report and any resulting publications are intended for broad dissemination and promotion. Data arising from this project is stored at the Institute for Marine and Antarctic Studies. Collaborative use of data will be considered by IMAS and FRDC upon request.

Appendix 8: Extension and Adoption

The project has been communicated to end users, including managers, researchers, recreational fishing key stakeholder groups and the recreational fishing community through a range of mediums including workshops, conference presentations, information sessions, social media and popular recreational fishing media including magazines and television.

Print media

Mounster, B. (2012). Science hooked on finding trauma answers. In The Mercury. Hobart, Tasmania: Davies Brothers Pty Ltd.

Pepperell, J. G. (2012). Southern bluefin mortality study shows early successes. In Bluewater Boats and Sportsfishing: Bluewater Publishing.

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McGlashan, A. (2014). One Perfect Day. In Modern Fishing, pp. 42-50: Express Media Group.

Abela, R. (2014). Jumbo southern bluefin first to wear a satellite tag. In Bluewater Boats and Sportsfishing, p. 34: Bluewater Publishing.

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Presentations

May – 14: Tracey, S., Hartmann, K. and Leef, M. Capture stress and post-release survival of Southern Bluefin Tuna from recreational fishing. 65th International Tuna Conference, California, USA.

Aug – 14: Presentation of preliminary results at the Tasmanian Anglers Broadbill Initiative information evening. Hobart, Tasmania.

Dec – 14: Presentation of preliminary results at the Tasmanian Anglers Broadbill Initiative information evening. Devonport, Tasmania

Television

Big Fish, Small Boats aired on One HD (S1, Ep5)

Big Fish, Small Boats aired on One HD (S2, Ep1)

Big Fish, Small Boats aired on One HD (S2, Ep2)

Big Fish, Small Boats aired on One HD (S3, Ep5)

Big Fish, Small Boats aired on One HD (S3, Ep9)

The Institute for Marine and Antarctic Studies (IMAS) is an internationally recognised centre of excellence at the University of Tasmania. Strategically located at the gateway to the Southern Ocean and Antarctica, our research spans these key themes: fisheries and aquaculture; ecology and biodiversity; and oceans and cryosphere.

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