Understanding the movement, behaviour and post-capture survival of recreationally caught Swordfish from southeast Australia

– a pilot study

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Executive Summary

While recreational fishers in Australia have targeted Swordfish in the past, both at night-time with shallow set baits and during the day with deep-set baits, success had been limited with only a few Swordfish reported landed. In 2014, adjacent to the coast of Tasmania an individual fisher had repeated success targeting Swordfish on the continental shelf break using the deep-dropping method during the day-time, fishing in depths of approximately 400 – 600 m. The reporting of this success garnered significant interest by the game fishing community in Australia, and the fishery developed further in Tasmania over subsequent years, as well as southeast Victoria. A small amount of targeted effort using the same methods and subsequent catch was also reported in Western Australia, New South Wales and Queensland. The fishery however is still relatively niche. In Tasmania, over the period of 2014 – 2016, approximately 35 boats/skippers reported catching a Swordfish, with six boats accounting for 52% of the landed fish, but the majority reported only catching one or two over this period. The number of Swordfish landed from 2014 – 2016 in Tasmania, including those caught as part of this research study was 89. Of the 74 that were reported caught by the recreational sector 11% were released. The average size of fish caught that were weighed was 177 kg (range: 60 – 354 kg, *n* = 44). Fish were caught from February to July inclusive, with peak catches reported in March and April.

As the fishery developed there was significant debate within both the recreational fishing community and the broader community about responsible fishing for the species. In particular, the discussion centred on whether the fish should be targeted primarily as a catch and release species or whether it was suitable to be retained for food and/or trophy fishing. At the time there was no information on the post-release survival rates of the species from recreational fishing. Hence, the primary objective of this study was to provide an understanding of the post-release fate of Swordfish caught by recreational fishers using the daytime deep-dropping method. Furthermore, there were concerns that the species may be susceptible to localised depletion, as this has occurred in the past in some areas targeted by the commercial fishery in Australia. Therefore, assessing the movement and behaviour of the species in southeast Australia, which had not been assessed previously was a secondary objective of this study to assess the potential for localised depletion to occur.

To assess post-release survival, movement and behaviour of Swordfish, pop-up satellite archival transmitters (PSATs) were used. The tags were attached to the fish after capture and programmed to stay with the fish for a period of time providing an insight into their fate and behaviour. In this study, tags were programmed to stay on the fish for a maximum of 250 days. Physiological assessments of the fish at landing and again prior to release, after a period of resuscitation where the fish was held boat-side as it moved slowly forward to facilitate a flow of water through the fish's gills, were conducted.

A total of 17 fish were caught as part of this research. The physiological assessment at landing and in some cases at the assessment after resuscitation determined that 47% of fish were not in a condition to be released. They were landed in either a moribund state, or their condition deteriorated to a moribund state during the boat-side resuscitation process. The remaining nine fish were released successfully with a satellite tag attached. All tags successfully transmitted data after they detached from the fish. Two of the tagged fish died shortly after release, one immediately and the other on the fourth day after release. The remaining seven fish were deemed to have survived the catch and release event, with the tags reporting normal crepuscular behaviour and migrations away from the locations of capture for the duration that the tags were attached (127 – 250 days). A post-release survival rate of 78% for fish that were identified by physiological assessment as suitable for release was estimated. Considering post-landing mortality combined with post-release mortality an overall survival rate of Swordfish landed was estimated at 41%.

The most common factor leading to the mortality of Swordfish at landing was barotrauma, 63% of fish being assessed as having either mild or severe symptoms of barotrauma. Severe barotrauma was identified as a significant predictor of mortality, in all cases of fish that were unable to descend to re-compress the expanded gases even after extended periods of resuscitation. For fish that presented with mild symptoms of barotrauma and no other signs of physical trauma each fish was able to right itself and descend after a reasonably short resuscitation period (<5 minutes). In two of three cases where this occurred the fish was identified as surviving based on the PSAT data. In the remaining case the fish was identified as dying four days after release. For the six-fish landed that did not present with barotrauma and that were released, the PSAT data indicated that all but one survived. The non-surviving fish was identified as being deep-hooked, however it was released since it showed sufficient eye response, healthy body colour and general activity boat-side. The tag data however, indicated that the fish died within hours of release.

Deep-hooking either in the gill region or deeper was identified as a significant predictor of mortality. The fish described above was the only one identified as suitable for release based on the physiological assessment, one other fish that presented with deep-hooking injuries became moribund boat-side after a short period of resuscitation (2 minutes). One other deep-hooked fish became moribund after 20-minutes of attempted resuscitation, this fish also presented with mild barotrauma.

Angling duration was protracted for most fish landed, ranging from 25-minutes to 8-hours, most commonly between 1 – 3 hours. Angling duration was not a significant predictor of mortality. However, exhaustion related to angling duration may have been a contributing factor in fish that presented with barotrauma not having the energy to descend against the positive buoyancy to a depth where the gases could re-compress. One instance of predation was observed, with a Swordfish being held boat-side immediately after landing being attacked by a Mako shark leading to mortality. No fish were removed from the water until an assessment was made that the fish was moribund. Hook type was not identified as a significant factor in relation to mortality – most probably due to low sample size. Circle hooks, however, were identified as having a much lower probability of deep-hooking than rigs using J-hooks, based on data collected during this study and corroborated by interviews with fishers who landed Swordfish in Tasmania from 2014 – 2016.

Overall, the survival rate of Swordfish caught using recreational deep-dropping methods was relatively low compared to other large pelagic species. In part, this is likely due to the fact that fish are initially hooked at considerable depth, often presenting with barotrauma whereas for most other large pelagic species the fish are caught near the surface and barotrauma is rarely observed. Ultimately, we would suggest that a pragmatic approach to whether a Swordfish should be retained or released is required. We present here an evidence-based assessment of the likelihood of an individual to survive after release. A common-sense approach is required by a fisher as to whether they should release a fish or retain it (if they are within fisheries management regulations). We present several factors that are significant predictors of mortality and these can easily be assessed by fishers. If the fish presents with deep hooking it is highly likely the fish will not survive post-release, and if it presents with barotrauma and cannot descend after approximately 5-minutes it is also unlikely to survive post-release. Therefore, the species is not a good candidate to be promoted as a catch and release only species, and the decision to release should be carefully considered. Fishers targeting Swordfish, even with the intention to release, should give prior consideration to retaining the fish if required and prepare themselves to ensure that if a fish is retained, it is done so to maximise animal welfare and minimise meat wastage. While Swordfish is a highly sought-after fish for consumption and is a good source of protein, it would be advisable for fishers to familiarise themselves with the Food Safety Standards as they relate to the consumption of Swordfish, due to the reported elevated levels of methylmercury.

This is the first study to assess the movement and behaviour of Swordfish caught below 40°S in the Tasman Sea. The opportunity to have a broader understanding of habitat utilisation in this region only came about through the development of the recreational fishery. The findings reported here complement existing PSAT studies on the species that were conducted further north in the Tasman/Coral Sea in conjunction with the commercial fishery that predominately operates in waters adjacent to southeast Queensland and northern New South Wales. In this study, tagged fish undertook in some cases significant migrations which were predominately latitudinal in nature, with fish remaining in the Tasman/Coral Sea basin. This concurs with the findings of previous studies in the region and indicates that the fish caught off southeast Australia are part of the broader population inhabiting this region. There was no evidence of fish migrating further east than 173°E during this study.

Based on PSAT data, tagged Swordfish were predicted to be in latitudes south of 38° from late February until mid-November, with peak cold area-restricted (CAR) behaviour, or resident behaviour, occurring from March to September. It is thought that this behaviour is related to foraging. During this period however, several fish changed their behaviour to directed poleward transient behaviour. All fish that engaged in this behaviour shifted back to an area-restricted behaviour state for a period of one to three months, in waters warmer than 24°C. This behaviour occurred as early as late May but peaked from late July through to December with evidence of persistence into January for the one individual that still retained a tag in that month. It is likely that this behaviour is related to spawning. There was no one area where fish displayed this behaviour, rather these individuals were spread throughout the Coral and northern Tasman Sea, including the Pacific archipelago.

There was evidence of all fish that migrated north initiating a poleward migration after they had spent time in a resident behaviour state in warm water (except one fish that moved East). In most such cases, however, the tag detached before it could be determined how far south the fish was likely to travel. In three of four cases where the return poleward migration was observed, the fish migrated southwest from outside Australia's EEZ back towards the coast of Australia. In one case the fish was observed to return to within 100 km of its release location after a journey of approximately 5,400 km indicating an affinity with a southern home-range for foraging.

The apparent display of philopatry revealed above suggests that at least some fish may exhibit a degree of homing to cooler habitats found in southeast Australia, and the evidence of seasonal residency in the region for the majority of fish tagged therefore suggests potential for localised depletion. Localised depletion of Swordfish associated with bathymetric features has been reported for the commercial fishery targeting the same population of fish further north. The abundance of fish inhabiting the southeast is unknown however, hence the proportion of fish being extracted by the recreational fishery is uncertain. While the recreational catch is low relative to the commercial fishery, the fishery is occurring on what would be considered the southern range edge of the species for continental Australia, so it is possible that the abundance of fish in the area is significantly less than that occurring further north where the bulk of the population is thought to occur. It is also not known how many 'new residents' may migrate into cooler southern waters, to replenish fish that are removed. There was limited evidence of fish moving below 40°S in the earlier tagging study conducted in the northern Tasman Sea, although only a limited number of fish were tagged.

Given the small number of fish taken in this region by the recreational sector, localised depletion is unlikely to affect the sustainability of the Swordfish population in the region. Rather, if localised depletion of large fish does ensue, it is more likely to affect recreational fishing catch rates, in turn reducing opportunities to target the species in the region. The recreational fishery is limited in its ability to relocate activities further offshore which was the response by the commercial fishery when serial localised depletion occurred in waters adjacent to southeast Queensland.

The vertical behaviour of tagged Swordfish observed in this study was consistent with results of other studies globally. Fish were shown to descend from near the surface at dawn to depths generally between 300 and 700 m and then ascend to near surface waters at dusk. This regular diel pattern was persistent for all tagged fish for the duration the tags were attached. There was evidence that the median depth of fish during the day increased as the fish moved towards the equator. The regular diel dive profile is thought to optimise the fish's opportunity to feed on a range of prey items over a 24-hour period. This concept has been well explored in many other studies of Swordfish behaviour in other regions of the world.

A novel finding of this study was the profiling of the depth and temperature preferences of several fish during the capture event via the use of an accelerometer tag attached to the terminal tackle of the fishing gear. In each case, the fish was observed to ascend from the depth at which it was hooked to the surface or near surface at a reasonably rapid rate and of its own volition. Fish then descended to a depth generally above the thermocline (~50 – 150 m) where the majority of the 'fight' occurred. Based on the theories related to the physiology of Swordfish and their adaptations to tolerate cold, hypoxic water at depth and the requirement for them to spend time near the surface to re-heat and oxygenate muscle tissue (thought to occur during the night or during rare daytime basking events) and to facilitate metabolism, it is likely that the fish ascend to the surface during the 'fight' for a similar reason. An experienced crew could, in theory, exploit this behaviour by applying a similar technique to fishers who target surface swimming marlin, by backing the boat down quickly on the fish to provide an early opportunity to tag or gaff the fish while it is possibly still acclimating and re-oxygenating. It is likely however, that the fish will still be very ‘green’ and care should be taken as large Swordfish are known to be pugnacious and have damaged boats and injured fishers in the past.

The recreational Swordfish fishery that has developed in southeast Australia is likely to further expand as significant interest in the fishery exists although it is possible that the fishery will remain relatively niche compared to other game fish targets in the area, such as tuna. Swordfish have been identified as a relatively poor candidate as a catch and release only species. Some fish are suitable for release; however, fishers should easily be able to identify symptoms that will significantly reduce the probability of post-release survival, including deep-hooking and barotrauma. Fishers should be prepared to dispatch fish humanely and prepare their catch appropriately for consumption to minimise wastage, even if the intention of the fishing trip was to release.

The Swordfish caught off southeast Australia are part of the broader population inhabiting the Tasman/Coral Sea region. The tagged fish spent time foraging in the cooler waters south of 38° during the austral summer, autumn and winter months. Most fish embarked on an equatorward migration, presumably to spawn. Several fish then made return migrations, but it was uncertain if the fish were intending to move back below 38° south as in most cases the tags detached during these southward migrations. In one case however, philopatry was observed with an individual returning to within 100 km of its capture location. The resident behaviour and observed philopatry to cooler waters suggest that Swordfish could be susceptible to localised depletion, but it is unknown whether this phenomenon will have a significant effect on the accessibility of the recreational fishing sector to the resource.

Introduction

Swordfish (*Xiphius gladius*) are an epi- and mesopelagic, oceanodromous species distributed throughout all the major ocean basins, as well as the Mediterranean Sea, the Sea of Marmara, the Black Sea, and the Sea of Azov (Nakamura, 1985). They are recognised as a Highly Migratory Species (HMS) in the 1982 United Nations Convention on the Law of the Sea. The species is important commercially and ecologically, with the global catch of Swordfish increasing steadily from approximately 25,000 t in the 1950s to approximately 100,000 t in 1995. The catch has remained relatively constant since this time at around 100,000 – 130,000 t (FAO, 2015).

Within Australia's exclusive economic zone (EEZ), Swordfish are caught commercially along both the east and west coasts. Fish caught in the Indian and Pacific Oceans are considered to be distinct biological stocks and are managed by separate regional fisheries management organisations.

The Indian Ocean population is considered a single biological stock (Muths et al., 2013) and is managed by the Indian Ocean Tuna Commission (IOTC). The commercial catch of Swordfish in the Indian Ocean, at last assessment, was 34,822 t. The IOTC assessed the fishery as not subject to overfishing and has not been overfished (IOTC, 2015). Within the Australian EEZ, Swordfish adjacent to Western Australia are caught commercially under the jurisdiction of the Western Tuna and Billfish Fishery (WTBF) administered by the Australian Fisheries Management Authority (AFMA) and with consideration to Australia's commitments to the IOTC. The fishery is managed by individual transferable quotas (ITQs) for the target species within a total allowable commercial catch (TACC). Swordfish are the main target species in the WTBF, with catches peaking at more than 2000 t in 2001. From 2004, with declining fishing effort, catch of Swordfish dropped dramatically and has remained below 500 t up until the last assessment in 2013 (Patterson and Stephan, 2014). At the 2013 assessment the TACC was set at 3,000 t, but only 204 t were caught (Patterson and Stephan, 2014).

In the Pacific Ocean, the population structure of Swordfish is more complex (discussed below). For management purposes, however, the fish adjacent to the east coast of Australia are considered part of a south-west Pacific stock and managed by the Western and Central Pacific Fisheries Commission (WCPFC).

Within Australia's EEZ the south-west Pacific Ocean management unit is fished by Australian vessels endorsed to fish in the Commonwealth Eastern Tuna and Billfish Fishery (ETBF). This fishery is multi-species and is managed through total allowable catches (TAC) allocated as ITQs set by AFMA. In 2012, the TAC of Swordfish in the ETBF was set at 1,396 t of which 1,157 t were landed (Larcombe and Stephan, 2014). This is a small proportion of the total harvest from the broader WCPFC management area which was 19,457 t in the same year (Davies et al., 2013) although that total may be derived from more than one stock.

Currently there is uncertainty around the status of the Swordfish stock in the Western and Central Pacific Ocean. This uncertainty has arisen due to two different growth and maturity schedules being applied in the latest stock assessment, resulting in different estimates of fishing mortality (Davies et al., 2013, Farley et al., 2016). Both versions of the model indicated that the stock is not recruitment overfished, but the results varied as to whether overfishing is occurring. This uncertainty has led to sustainability status of Swordfish being classified as 'uncertain' in this region (Larcombe and Stephan, 2014). A recent report by Farley et al., (2016), has resolved some of this uncertainty. They concluded that age estimates produced from otoliths are more reliable than ages derived from fin rays, particularly for larger fish. From otoliths, they estimated a slightly lower growth rate and a higher maximum age (21 years) than previously reported (Young et al., 2004, DeMartini et al., 2007). They also refined the length and age at 50% maturity for fish from the southwest Pacific. The length at 50% maturity for female Swordfish was estimated at 161.5 cm orbital-fork length (OFL); 4.42 years of age (Farley et al., 2016). These new life-history parameters differ from those estimated for the Hawaiian region, supporting the hypothesis, and recent molecular studies (Lu et al., 2016), of geographically separate populations. It is likely that these new parameters will improve the stock status assessment of Swordfish in the SW Pacific.

Current working hypotheses of the population structure of Swordfish in the Pacific Ocean, based on genetic and fisheries data include variations of two, three and four stocks (Lu et al., 2016). The most recent molecular study conducted to resolve the population structure of Swordfish in the Pacific utilised high resolution multilocus single nucleotide polymorphism (SNP) data. The study rejected the hypothesis of panmixia in the Pacific, finding samples from temperate regions differed from most tropical samples (Lu et al., 2016). Interestingly, Lu et al., (2016) identified no significant difference between the temperate samples despite large distances separating them. This finding is at odds with tagging studies that, to date, have not recorded trans-Pacific crossings in temperate regions (Abascal et al., 2010, Evans et al., 2014, Takahashi et al., 2003, Dewar et al., 2011, Abecassis et al., 2012). In contrast, tagged fish have largely maintained a regional association to release sites. For instance, in the South Pacific Ocean region, a satellite tagging study identified a lack of connectivity between the southern and northern regions of the western and central Pacific Ocean (WCPO) and the WCPO and the eastern Pacific Ocean (EPO) (Evans et al., 2014). This study also identified limited connectivity between the eastern and western areas of the Tasman and Coral Seas, but a degree of latitudinal connectivity between temperate and tropical waters in this region. This study was conducted with the assistance of the commercial fishing fleet with tag deployments focused in the Australian Fishing Zone (AFZ) between ~24°S and 29°S. Latitudes where the Australian commercial fleet focus much of their effort. The displacement of fish was largely limited to a region bounded by the latitudes ~20°S and ~35°S and the east coast of Australia out to ~165°E (Evans et al., 2014). Exceptions included a small number of individuals that migrated north to ~15°S, and one individual that moved south to ~41°S. These results conformed to the broader area where the commercial fishing fleet were focusing their effort in the region and set the basis of our knowledge for habitat preferences in the Tasman/Coral Seas.

In other regions where electronic tagging studies have been conducted, migration towards temperate or cold water to feed during summer months has been reported (Takahashi et al., 2003). This migration is most common for larger individuals, particularly females, noting that Swordfish are sexually dimorphic with females growing larger than males, which then return to warmer waters to spawn. Evans et. al. (2014) found limited evidence of individuals moving poleward into temperate waters. This may be due, however, to the relatively small size of the fish tagged, where the median estimated weight reported was 100 kg, noting that Swordfish are known to grow up to ~500 kg.

There is also evidence to suggest that the migratory behaviour of Swordfish is also interspersed with periods of site fidelity (Wilcox, 2014) linked to a degree of philopatry to particular areas, presumably focused on geographic features such as anomalies on the continental shelf break and seamounts which makes them vulnerable to localised depletion (Campbell and Hobday, 2003). As the Australian domestic longline fishery rapidly expanded in the late 1990s from the grounds of southeast Queensland, effort increased in both the number of hooks being set as well as the spatial extent of area fished. Initially, catch rates of Swordfish increased but then began to show a steady decline the longer an area had been fished. This led to evidence of serial depletion, with a strong inverse relationship between catch rates, total annual effort in a year and the number of years any area had been fished, with higher catch rates maintained on the periphery of the fishery as it continued to expand further offshore (Campbell and Hobday, 2003). This trend was particularly evident in fishing areas that were associated with seamounts. Campbell and Hobday (2003) indicate that the sequential decline in catch rates is consistent with the fishing down of resident populations around seamounts. Conversely, this trend was not significant for other target species in the fishery, including Striped Marlin (*Kajikia audax*) and Bigeye Tuna (*Thunnus obesus*), and they postulate that the fishery is having a smaller localised impact on these species (compared with Swordfish) as they are highly migratory, and the fishing grounds are being replenished each season from other regions.

Recreational fisheries for Swordfish

It is believed that recreational fishing for Swordfish began in the 1920s on the northeast coast of the United States as an incidental night-time fishery for vessels targeting Yellowfin Tuna (*Thunnus albaceres*) during the day (De Sylva, 1974). By the 1960s, about 50 Swordfish were caught annually with rod-and-reel recreational fishing gear in the United States (Service, 1999), with most fishing around this time conducted during daylight hours, targeting large Swordfish basking at the surface (Levesquee and Kerstetter, 2007). During the 1970s the recreational fishery expanded into the warmer waters of Florida, the Bahamas, and also southern California (De Sylva, 1974). Around 1976, the primary recreational method to target Swordfish changed, with drifted baited lines deployed at night-time gaining favour. This shift in method was concurrent with a significant increase in the number of reported recreationally caught Swordfish across the US

(Beardsley and Conser, 1981). By the early 1980s however, recreational interest in Swordfish declined due to decreasing catch rates and increasing commercial fishing effort. A resurgence in the recreational fishery for Swordfish occurred during the 2000s, mainly still as a night-time fishery. More recently in the US there has been a shift to target Swordfish during the day using deep-set baits on rod-and-reel (Nick Stanczyk *pers.comm.*).

As of 2007, the United States was one of only three (including Venezuela and New Zealand) nations to have a well-established recreational Swordfish fishery (Levesque and Kerstetter 2007), although other locations including the Azores and the Cayman Islands and more recently, Australia, have developing fisheries.

Development of the recreational Swordfish fishery in Australia

The Game Fishing Association of Australia (GFAA) was formed in 1936 and has maintained lists of record-sized fish caught by members of affiliated game fishing clubs since then. However, the first 'line-class' record for Swordfish was not recorded by the Association until 17 June 1989 when a 50 kg fish was caught off Tathra, New South Wales (Game Fishing Association of New South Wales Yearbook, 1990). Under GFAA rules, to qualify as a line-class or all-tackle record, the weight of a fish must be greater than the breaking strain of the line used for the capture. Prior to 1989, some small to very small Swordfish (<10 kg) were occasionally caught by anglers off eastern Australia, but none had qualified as a line-class record.

The 1989 capture of a line-class Swordfish was particularly significant since it was achieved while actively targeting the species. The presence of Swordfish off the southeastern Australian coast had been known for some time since Japanese longline catches had been recorded at such locations from the 1970s. Further evidence came in the early 1980s when domestic commercial drop liners occasionally caught relatively large Swordfish tangled in their lines as a bycatch while fishing over undersea canyons off southern New South Wales (Julian Pepperell, unpublished data). As a result, some pioneering anglers set out to catch line-class Swordfish in the 1980s by night-time drift fishing over these canyons using squid baits illuminated by cyalume light-sticks set at relatively shallow depths. Some of these expeditions were successful in hooking Swordfish but lost them when near the boat. The 1989 capture, achieved via the night-time method, naturally created considerable interest, and larger line-class records were progressively set over the next several years by anglers using the same method. Specifically, the subsequent all-tackle record sequence for Swordfish was as follows: 98.5 kg, Merimbula NSW, April 1990; 105.8 kg, Eden NSW, May 1991; 175 kg, Merimbula NSW, June 1996 (data supplied by GFAA). Interest in this style of fishing which involved all night expeditions in cold, rough weather, often with no result, then waned, resulting in a 19-year hiatus until the breaking of this record by a 263.5 kg Swordfish captured off Coles Bay Tasmania in March 2015 using the new method of daytime deep-dropping as described in this report. The current GFAA all-tackle record now stands at 276 kg for a Swordfish caught off Lakes Entrance, Victoria in May 2017, although as also noted later in this report, considerably larger Swordfish have been captured in the new fishery by non-club affiliated anglers, most notably, a 354 kg gutted fish caught off St Helens, Tasmania in 2016 and a 347 kg fish caught off Mallacoota Victoria in June 2017.

Evidence of other historic catches of Swordfish by Australian recreational anglers is contained in the records of the Gamefish Tagging Program operated by NSW Department of Primary Industries (NSW DPI) which has operated continuously since late 1973. Conventional plastic 'spaghetti' tags are supplied to recreational anglers free-of-charge, and data from tagged fish are recorded by anglers on pre-paid mail cards and subsequently entered on a database at NSW DPI. As at July 2017, the database held records of 446,345 tagged fish, 162 of which were Swordfish. Of those, 99 were tagged by recreational anglers, five off Western Australia and 94 off the east coast. The remaining 63 fish were tagged from Australian commercial longline vessels off the east coast (information supplied by NSW DPI).

These records indicate that first Swordfish tagged by a recreational angler in Australian waters was tagged off Bermagui, NSW in April 1986 with an estimated weight of just 3 kg. In fact, the majority of Swordfish tagged by recreational anglers up to 2016 have been small, with 74% estimated at 10 kg or less and just 3% estimated at greater than 100 kg. It is important to note that the great majority of these fish were caught opportunistically, with no targeting. Subsequently, tagging of Swordfish has accelerated due to the targeted daytime deep drop fishery off Tasmania and Victoria. In fact, of the 105 recreationally tagged Swordfish since 1986, 15 were tagged between January and June 2016. These ranged in estimated sizes from 18 to 200 kg with a mean of 106.8 kg.

While several anglers have put in significant effort to target Swordfish in Australia, the recently rapid development of the recreational Swordfish fishery in Australia can be traced to the success of one recreational angler. During 2014, adjacent to the coast of Tasmania, that angler began putting in significant effort to target the species. He focused on a method that had been proven to work overseas – the day-time deep dropping method in depths of around 400 – 600 m on the edge of the continental shelf which is approximately 12 nm from landfall on the southeast coast of Tasmania. After several failed attempts and refinement of techniques based on discussions with successful fishers in the United States and New Zealand, on the 21st April he landed the first recreationally targeted Swordfish in the region. This was followed by several more successful trips. Based on his success other recreational fishers in Tasmania began to focus on targeting Swordfish, with several other successful trips reported, both in the southeast and northeast of the state. The last fish in 2014 was caught in late June, with several unsuccessful trips occurring after this time, suggesting that the catchability of the fish was seasonal. The novelty of the fishery and subsequent social media exposure piqued the interest of game fishers all around Australia.

In 2015, the recreational effort targeting Swordfish increased, with several fishers from mainland Australia traveling to Tasmania in an attempt to capture a Swordfish, with fish consistently being caught between March and June. The catch in Tasmania was characterised by a large average size of fish landed. In the same year, there were a few reports of recreational fishers targeting and catching Swordfish using the same methods off the northwest coast of Western Australia, and one or two reports of Swordfish caught off NSW, although these fish were much smaller. In 2016, the fishing effort adjacent to Tasmania increased further, with both local and interstate fishers participating. In April 2016, several recreational fishers in Victoria successfully targeted Swordfish off Mallacoota and Lakes Entrance. This success saw several other Victorian crews travel to the area and land Swordfish. The fish caught in these areas were also relatively large (up to 347 kg as noted above). Around the same time there were reports of a small number of Swordfish landed by recreational fishers south of Albany in Western Australia.

At the end of the 2016 season, recreational Swordfish fishing in Australia had gained national and international attention. Many popular recreational fishing magazines were printing multiple articles per issue on Swordfish and both national and international social media pages were constantly reporting on the catches that were occurring. In particular, these focused on the larger fish that were being caught in the cool temperate waters adjacent to Tasmania and Victoria.

Need for research

It was realised with the rapid development of this new, niche recreational fishery that research was required to understand several key factors relating to the fish that were being caught and the fishing practices that were being employed. Principally, in regard to the suitability of Swordfish as a catch and release species, for those that chose to release their catch following capture by the daytime deep dropping method. More generally, research was needed to determine whether fishing methods could be improved to minimise animal welfare impacts and enhance responsible fishing practices regardless of whether the fish was to be released or dispatched and retained for food.

The development of a new recreational fishery was also seen as a rare event, and the opportunity to investigate new, and perhaps novel methods of managing recreational fisheries that were targeting HMS that are traditionally a component of Commonwealth commercial fisheries, but managed by state fisheries management agencies (complex management – assessment relationship) due to the recreational classification of the fisheries was raised as a research question that may lead to a precedent for other large pelagic gamefish species.

There was also significant interest in whether the fish that are being caught off Tasmania are resident or migratory, primarily to determine the likelihood of localised depletion. The development of the fishery off southeast Australia has also provided a unique opportunity to further understand the migration and behavioural traits of Swordfish in the region, complementing existing satellite tagging studies conducted further north, primarily off central eastern Australia (Evans et al., 2014).

While any possible impacts of the recreational fishery on Swordfish populations are expected to be relatively low, due to the niche nature of the fishery, understanding the seasonal migratory behaviour and potential for localised depletion will provide important information to the sustainable management of this developing fishery in a region where little work has been conducted on the species previously. Furthermore, the results on post-release survival will provide evidence-based findings to assist recreational fishers make informed choices when catching, handling and releasing (if they choose to do so) Swordfish.

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 satellite archival transmitters (PSATs). This method has been applied to assess survival of large sharks (Skomal and Chase, 2002), billfish (Graves et al., 2002, Kerstetter and Graves, 2008, Kerstetter and Graves, 2006, Kerstetter et al., 2003, Domeier et al., 2003), including juvenile Swordfish (Kerstetter and Fenton, 2012) and tunas (Stokesbury et al., 2011, Marcek and Graves, 2014, Tracey et al., 2016). The data returned from the tags provides a timeline of dive and ascent behaviour and temperature experienced after release. From this information, it is possible to estimate the fate of the fish.

In addition to being a useful tool to assess post-release survival, the primary application of satellite tags is to determine migration, vertical behaviour and habitat utilisation patterns. The technology has been employed to assess many HMS species, including Swordfish (Abascal et al., 2010, Evans et al., 2014, Holdsworth et al., 2010, Kerstetter and Fenton, 2012, Lerner et al., 2013, Sepulveda et al., 2010, Takahashi et al., 2003, Abecassis et al., 2012, Dewar et al., 2011). There is however a trade-off when using satellite tags for the combined objectives of assessing post-release mortality and migratory behaviour. Most post-release mortality studies propose deploying the tags for a short duration ranging from 10-30 days, suggesting that deployments longer than this can confound results with mortalities occurring after longer duration difficult to differentiate cause due to the capture event or a natural mortality event, and also the likelihood of increases in un-defined tag shedding events. Additionally, the resolution of behavioural data that is reported on a longer deployment needs to be courser due to a trade-off between data transmission and tag battery life. A longer deployment duration however, has the advantage of providing a longer temporal record of a fish's movement and behaviour, if it survives. Given the high cost of the satellite tags, studies investigating the multi-objectives of post-release mortality, habitat utilisation and migration need to consider this trade-off. Here we chose to deploy the satellite tags for a long duration with the intention of recording whether the fish survived or died in a pre-defined period after release, with less focus on the behaviour immediately after release, but a long time-series to be used to assess habitat utililisation and migratory behaviour to align with the objectives of the study. This is similar to the methods employed by Tracey et. al., (2016) to assess the post-release survival rates and migration of recreationally caught southern bluefin tuna.

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, leading in turn to increasing resource stewardship.

In this study, we investigate the post-capture survival rate of Swordfish tagged adjacent to southeast Australia as well as assess their habitat utilisation and migratory behaviour.

Objectives

1. Preliminary quantification of post-capture survival rates for Swordfish caught by recreational fishers in Tasmania
2. Determine habitat preferences and migratory behaviour of Swordfish caught off the east coast of Tasmania based on data from satellite tags
3. Collect biological samples for use in future molecular stock structure and heavy metal accumulation analyses

Method

Recreational catch data

The recreational catch of Swordfish caught in Tasmania was monitored from 2014-16. The monitoring process relied on social media posts, word of mouth and strong networking with the recreational game fishing community in Tasmania, leading to informal discussions with many of the fishers who had caught Swordfish. Given the niche nature of the fishery, the application of a structured survey design leading to quantifiable catch estimates was not within the scope of this project, especially given the expansion of the fishery into Victorian waters and further afield. The capture or targeting of Swordfish would be too rare an event using existing sample frames to have reasonable confidence in the results. Conversely, the fact that the fishery is relatively new, the novelty of the catch tends towards a large degree of conversation and exposure of the catches through the recreational game fishing community and social media. Once a capture had been identified, the fisher or skipper of the vessel were contacted via social media (or by phone if the fisher was known to the research team or had previously been interviewed for other catches) and asked whether they were willing to discuss their catch.

If the fisher responded in the affirmative a standard set of questions were asked followed by an open-ended discussion regarding the capture, so that the fisher had an opportunity to describe the capture and any points of interest. The standard questions included the following information: Name of fisher, date of capture, capture location, time of hooking, fight time, whether the fish was retained or released, approximate resuscitation time if released, whether the fish was landed dead or alive, line breaking strain and type, hook type and rigging configuration, hooking location on the fish, hooking damage, evidence of bleeding, fish length if measured, fish weight if weighed and estimated weight if not weighed.

Several common terms are used by recreational anglers to define an interaction with a fish during a fishing event. A fish is defined as “hooked” if it is on the line for any amount of time. A “dropped” fish is defined as “hooked” but escaped the hook prior to being “landed”. A “landed” fish is defined as being caught and brought alongside the vessel close enough for the angler to touch the leader. At this point the presumption is that the fish is then “captured” and could be “retained” or “released”. A “retained” fish is one that has been killed and retained, while a “released” fish is one that has been let go after being “landed”, with or without a conventional tag. These terms will be used throughout this report.

Sampling of Swordfish for satellite tagging

Sampling of Swordfish for satellite tagging occurred on the continental shelf break adjacent to the east coast of Tasmania between March and July 2016 and between April and May 2017, one fish was also satellite tagged in June 2014. Fishing was focused on areas frequented by recreational fishers targeting Swordfish, specifically east of Eaglehawk Neck, east of Bicheno and east of St. Helens (Figure 1). Noting however, that other areas along the east coast have successfully been fished when targeting Swordfish, but the sample regions tend to be more popular due to proximity to major populous areas and quality boat launching facilities. Fish were caught from either a 7 m research vessel or recreational fishing vessels. For a fish to be considered an ‘eligible’ sample a member of the research team was required to be on the fishing vessel at the time of “landing”; in some cases, when a fish was hooked from a recreational vessel, an at sea boat-to-boat transfer of a researcher was required, with the time of hook-up confirmed via radio.

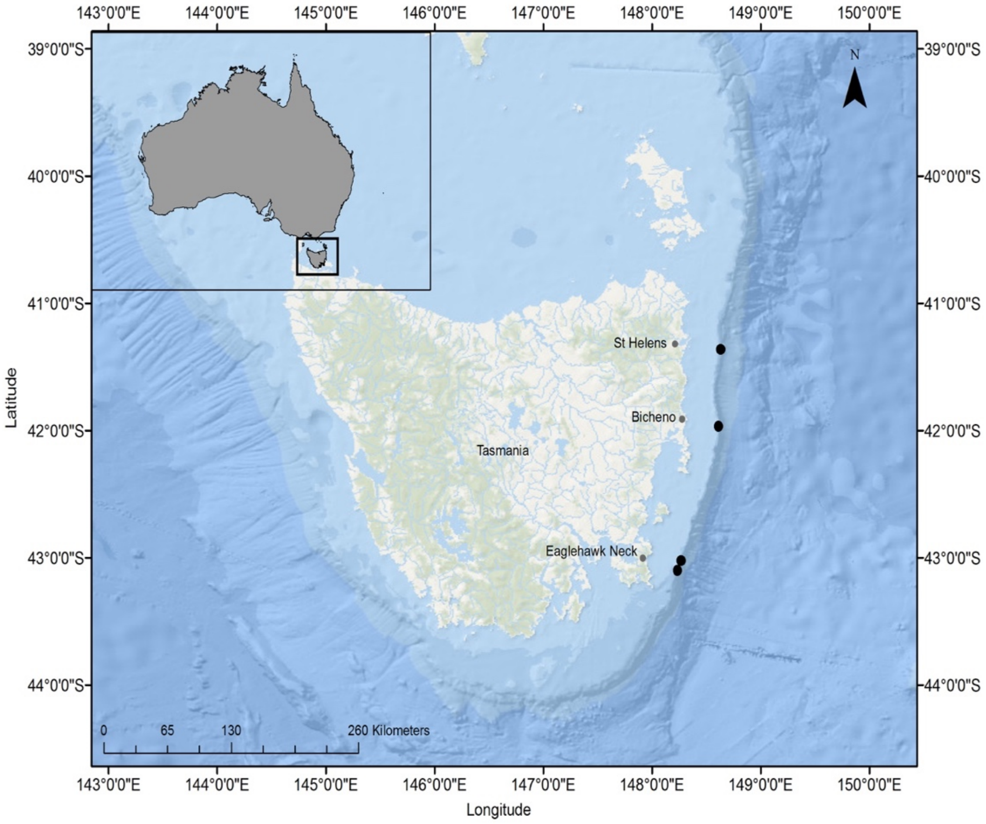

Figure 1. Sampling locations adjacent to the east coast of Tasmania (black dots).

All fish recorded in this study were landed (or at least hooked) using the daytime deep-dropping method, with baits being set on the seafloor at between 350 and 650 m, before being allowed to slowly drift up through the water column.

The standard method used to catch Swordfish was on rod-and-reel with fish fought with the angler standing up (rather than fishing from a game chair). Fishing tackle consisted of a length of braided line (24 – 100 kg breaking strain) with a monofilament 'top-shot' of between 50 – 300 m (24 – 60 kg breaking strain). The terminal tackle consisted of a length of monofilament leader between 5 – 20 m in length (200 – 400 kg breaking strain) with either a circle, a single J-hook or two J-hooks attached to the end with a dead bait affixed; either a whole squid or fish (in some cases strips of fish were used). Lines generally had between one and three lights affixed near the terminal tackle. A break-away weight system was used in all cases. On the research vessel, the tackle consisted of an 80w Shimano Tiagra reel attached to a 37 kg Wilson texalium bent-butt game rod. The reel was spooled with 800 m of 100 kg hollow core braid with a 100 m length of 60 kg monofilament top-shot attached using a PR knot. A 5 m, 400 kg breaking strain wind-on leader was attached to the top-shot via a one-metre plaited double. A heavy-duty snap swivel was attached to the end of the wind-on leader. A 3 – 4 m, 400 kg leader was clipped to the snap swivel with the terminal end fitted with an owner 16/0 non-offset circle hook. One large format light was attached at the swivel and two small format 'diamond' lights were attached with rubber bands to the leader.

Figure 2. (left) Example of rigged bait and break-away weight, with two J hooks embedded into the bait used by a recreational fisher. (right) bridle rigged bait attached to a circle hook, typical of the rig used on the research vessel.

On the research fishing equipment, a G6a electronic data logger (Cefas Technology; dimensions: 400 mm x 28 mm x 16.3 mm, 18.5 g in air, 6.7 g in water, pressure sensor rated to 1000 m) was securely attached via two cable ties directly above the snap swivel on the wind-on leader (Figure 3) from the 10th March 2016 to the 2nd June 2016, the logger was lost on this date when a Swordfish pulled the line through the leaderman's hands breaking off the accelerometer. The logger was pre-programmed prior to each day's fishing to record acceleration, temperature and pressure (depth) data at 10Hz. The logger recorded raw acceleration in three planes of motion with the data providing insight into the fight behaviour of Swordfish once hooked, including high resolution depth and temperature profiles.

Figure 3. Accelerometer attached to the terminal tackle of the research fishing gear.

For each Swordfish released, a pop-up satellite archival transmitter (PSAT) (MiniPAT; Wildlife Computers, Redmond, WA, USA) was attached. The tags were 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 PSAT tag.

Figure 4. Photo showing the attachment location of the PSAT tag in the musculature below the dorsal fin of a Swordfish.

Each tag was deployed in ‘standby’ mode and programmed to activate when wet and at a depth of greater than 2.5 m. The tags recorded pressure (depth), temperature (°C), and light level (lumens). All tags deployed from 2015 onwards were programmed to detach from the fish after 250 days with a sampling interval of 10 minutes. The tag deployed in 2014 was programmed to detach after 180 days with a sampling interval of 7.5 minutes. The tags were delivered with the on-board light attenuation coefficients set as constant (0.25). Wildlife Computers PSATs release from the anchored tether at the conclusion of the programmed period by means of a current passed through a corrodible release pin. Alternatively, if the tag sinks to a depth greater than 1800m or the depth of the tag does 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 would also 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 after 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.

Each PSAT was affixed in the musculature just below the dorsal fin using a purpose-made tagging pole, with the aim of inserting the anchor between two pterygiophores (Figure 4). Tags were attached immediately prior to an assessment of condition and suitability for release. Tagging was done at the first opportunity when the fish was boat-side due to the large size of Swordfish and their potential ability to fight hard which may have required an early release to avoid damaging the boat, the fish or injuring the crew. If this was the case, the line was cut as close to the hook as possible.

After the tag was affixed the weight of the fish was estimated, the location of the hook (categorised as mouth, internal gill area, deep-hooked, eye orbit or externally foul hooked) and severity of bleeding were recorded (categorised as nil, minor external, minor internal or major bleeding), and the hook removed where possible, if removing the hook was not possible the line was cut close to the hook. During assessment, the fish were held alongside the vessel which was moving forward at approximately 1-2 knots allowing water to flow over the gills until the fish freely kicked from the grip of the handler. This time was recorded as 'recovery time'. Release location GPS coordinates were then recorded.

A modified "ACESS" scale (see Kerstetter et al. 2003) was used to evaluate the condition of the fish at landing and again immediately prior to release if the fish was in a condition to be released. The assessment had nine criteria. Criteria A – E relate to signs of physical trauma caused by the capture. Criterion F related to whether the fish had been retrieved tail first. While criteria G – I are indicators of moribundity. For each of the criteria, a value of 0, 1, or 2 was assigned (Table 1). A fish can score a maximum value of 18, indicating minimal damage (Kerstetter et al., 2011, Kerstetter and Graves, 2006, Kerstetter et al., 2003). This method of evaluating the candidacy of a Swordfish for tagging was implemented to qualitatively assess the fish's likelihood of survival and to minimise assumptions or biases on the part of the researcher. The standard for determining whether a fish was suitably alive for release or moribund or dead was a lack of movement indicated by criteria G, lack of response to having an eye shaded by hand (criteria I) and deteriorated skin colour (criteria H). All qualitative categorical assessments were undertaken by a single researcher to facilitate standardisation.

Table 1. Modified ACESS score table to assess condition of Swordfish at landing.

ID	Criteria	Level 0	Level 1	Level 2
A	**Stomach eversion**	Everted and lacerated	Everted, not lacerated	Not everted
B	**State of body musculature**[1]	Obvious deep lacerations	Some shallow lacerations	No obvious lacerations
C	**Bleeding internal**[2]	Extensive bleeding	Light bleeding	No/almost no bleeding
D	**Gill damage or deep hooking**	Observed gill damage or deep hooking	Expected gill damage or deep hooking	No signs of gill damage or deep hooking
E	**Barotrauma**	Severe barotrauma	Mild barotrauma	No sign of barotrauma
F	**Retrieved backward or forward**	Tail hooked or wrapped, retrieved backwards	Evidence of being retrieved backwards	Forward retrieval
G	**Activity**[3]	Inactive	Slightly moving	Very active
H	**Skin colour**	grey-bronze	blue-grey-bronze	blue-purple
I	**Eye status**	Non-responsive	lacerated	responsive and undamaged

[1] damage from hook or capture considered, not cookie cutters, etc.

[2] considers internal bleeding from gills, internal mouth, deep hooking, etc. Not external bleeding from lacerations (this is covered above)

[3] includes tail beats, although there was some thought that this was sometimes caused by water movement across the fish's body when the boat was moving forward; active - was assigned when there was head movement.

Data analysis

Accelerometer tag data

Acceleration data recorded by the G6a electronic data loggers is comprised of both a static component, a gravitational component related to the tags inclination to earth's gravitational field and a dynamic component, relating to changes in velocity resulting from the fish's movement and behaviour (Wright et al., 2014). Given the tags were fixed to the fishing line and would not necessarily be aligned with respect to the vertical, the vectorial sum of dynamic acceleration (VeDA) values were calculated as a proxy of activity of the fish while they were hooked to the fishing line. Prior to calculating the VeDA the static component of the acceleration time series was removed by identifying an optimal smoothing algorithm (running mean). A range of smoothing intervals were tested; a four second interval was identified as appropriate to separate the static from the dynamic acceleration components by subtracting the running mean from the raw data (Shepard et al., 2008). Data were converted to absolute values to reflect magnitude irrespective of the direction of acceleration. The VeDA was then calculated as:

$$VeDA = \sqrt{A_x^2 + \mathrm{A}_y^2 + \mathrm{A}_z^2}$$

Where A_x, A_y and A_z are the absolute dynamic acceleration values measured for each of the three acceleration axis of the G6a logger respectively (Qasem et al., 2012).

Post-landing and 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 (Tracey et al., 2016). Mortalities beyond this point were considered to be from natural causes. A Kaplan-Meier survival function 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. Although the fishing and handling techniques replicated 'best practice' recreational fishing methods, the application of tags may bias the post-release survival estimate downward.

In addition to post-release mortality a number of fish were identified as moribund at landing and were physiologically assessed as not suitable for release. This mortality at landing was added to post-release mortality to provide an overall estimate of capture related mortality for Swordfish caught using the recreational deep-dropping method.

Horizontal movement and behaviour

Daily position estimates were calculated using a state-space model accessed through the WC proprietary software, Global Position Estimator 3 (GPE3) (Wildlife computers, WA, USA). The state-space model uses the timing of dawn and dusk as identified by the temporal profile of luminosity intensity recorded on board the tag, the depth recorded on the tag in association with a bathymetric profile at the estimated position and in situ temperature observations with corresponding remotely sensed reference data (SST) into a diffusion-based space state movement model to generate time-discrete gridded probability surfaces. Grids are produced at a resolution of 0.25 degrees. To reduce the number of unrealistic positions, an estimate of maximum sustained animal speed was input to constrain the model. A maximum sustained speed of 2 $\mathrm{m/s^{-1}}$ was used, this is slightly faster than the maximum speed (1.5 $\mathrm{m/s^{-1}}$) observed by Carey and Robison (1981) while actively tracking Swordfish fitted with acoustic tags. Given the short nature of the tracking by Carey and Robinson (1981) - maximum five days, allowing the model to accommodate a higher maximum speed is reasonable.

Behavioural states were inferred from the movement data using a hierarchical-joint estimation state-space switching model (hSSSM). A joint estimation model is preferred over a non-hierarchical (individual) model for simulated data with Argos location errors (Jonsen, 2016). The hSSSM model code is available (Jonsen et al., 2017) for *R* software (Team, 2016) and was fit to the estimated movement data using the JAGS software (Plummer, 2016) within *R*. Two Markov chain Monte Carlo (MCMC) chains of 60,000 samples were run and the first 40,000 samples from each chain were discarded as burn-in. Posterior inference was performed from the remaining 20,000 samples per chain after thinning by a factor of 5 to reduce within-chain sample autocorrelation, yielding a final sample of 4,000 from the joint posterior. The behavioural states are estimated by the posterior means of the model at a given time (b_t) which range between 1 (transient state –

directed traveling) and 2 (Area Restricted Search – resident behaviour); with estimates close to 1 or 2 having low uncertainty in the behavioural state where estimates close to 1.5 have high uncertainty. To reduce uncertainty in subsequent kernel utilisation density estimation to assess activity space for each behavioural state, cut off values of the posterior means were set at $b_t < 1.3$ for predominantly transient and $b_t > 1.7$ for predominately resident behaviour.

Distribution ranges of tagged Swordfish in each of the two behavioural modes were calculated using kernel utilisation distributions (KUD) in the adehabitatHR package (Calenge, 2006) in *R*. The function gives the probability that a tagged fish displaying a particular behaviour mode is found at a point according to its geographical coordinates (Worton, 1995). The model was run separately for positions categorised as transient or resident as described above. Kernel densities at 95% and 50% probability are also presented, representing 'core range (CR)' and 'activity space (AS)' of tagged animals respectively.

To determine factors driving the vertical habitat preference of Swordfish generalised additive mixed models (GAMMs) were used. Two separated GAMMs were fitted, one to assess the median depth (MD) at night and the other to assess MD during the day. Where median depth was aggregated daily based on depth data recorded on-board the satellite tags. Data one hour each side of dawn and dusk were removed to reduce the influence of the crepuscular dive behaviour on the results. Environmental factors including Chl_a, sea surface temperature (SST), dissolved oxygen at the surface (DO_0) and at 500 m (DO_{500}), mixed layer depth (MLD), eddy kinetic energy (EKE), lunar phase in radians and location (longitude-latitude pair) derived from the most probable track were included as fixed explanatory variables. GAMMs were constructed based on the same approach undertaken by Lam et al. (2015) and Williams et al. (2017). Analysis was run using the package 'mgcv' in *R* and after visual assessment of the error distribution, a Gaussian family with an identity link function was applied. All explanatory variables were modelled as continuous variables and smoothed, with the *k* spline value set at 5 (Zuur et al., 2009). Tag-id was included as a random effect to account for multiple observations from the same tagged fish. Correlations between variables was assessed using the variance inflation factor (VIF), with VIF scores greater than 3 indicating collinearity. Variables with a VIF higher than 3 were sequentially removed until all variables were less than the threshold (Zuur et al., 2009). The initial, full factorial models were:

$$R_i = s(location) + s(MLD) + s(EKE) + s(SST) + CHl_a + s(DO_0) + s(DO_{500}) + lunar + Tag_i + \varepsilon$$

Where R_i is the response variable median depth (MD) for Tag_i, and $i = 1,\ldots,$ number of individual tags. The environmental variables are described above and ε is the Gaussian error term. The selection of an optimal model was performed using a backward selection process, whereby non-significant explanatory variables were removed sequentially until a final model containing only significant predictors was reached at a level of $\alpha = 0.05$.

Environmental data

Sea surface temperature (SST) was sourced as the Daily Optimum Interpolation SST (OISST) 1/4° spatial resolution data product, Chl_a was sourced as MODIS NPP at a 0.05° spatial resolution both from NOAA Coastwatch and Monthly 1°-grid climatology data, DO at the surface and 500 m depths and mixed layer depth (MLD) were sourced from the World Ocean Atlas 2009, all using *xtractomatic* routines in *R* as described by Lam et al. (2015). Eddie kinetic energy (EKE) was derived from altimetry at a 0.2° spatial resolution and extracted using the Spatial Dynamics Ocean Data Explorer (Hartog *et al*., 2011). An estimate for each oceanographic product was extracted at each geolocation position at daily intervals. Lunar phase in radians was calculated in *R* for each day using the package 'lunar'.

Results

Recreational catch summary

A total of 89 individual Swordfish landings were identified between 2014-16 in Tasmania, of which 74 were attributed to the recreational fishery and 15 were caught either by the research team or a recreational fisher with a member of the research team on board (Table 2). The recreational catch was not monitored in 2017, however, two fish were caught as part of the tagging study in this year. Whilst we can't be certain if this was all fish caught over the period 2014-16, we believe that our coverage of sources of catch information resulted in this being close to the total number. Of the 74 captures identified from the recreational fishery informal interviews were conducted for 52 of the captures, 3 fishers declined to be interviewed and 19 fishers could not be contacted. For the 22 that could not be contacted or declined, some information was collected on their catch from social media, including date of capture and in some cases the weight of the fish. Of the 74-fish recorded landed by recreational fishers eight (11%) were released.

Table 2. The number of Swordfish landed in waters adjacent to Tasmania from 2014 - 2016.

Year	Recreational catch retained*	Number (%) released recreational catch	Research catch retained	Number (%) released research catch	Total catch
2014	4	1 (20%)	0	1 (100%)	6
2015	25	1 (4%)	2	0 (0%)	28
2016	37	6 (14%)	5	7 (58%)	55
Total	66	8 (11%)	7	8 (53%)	89
2017	nm*	nm*	1	1 (50%)	nm*

*nm: not monitored.

A total of 35 boats/skippers were reported to have landed Swordfish from 2014-16, including the IMAS research vessel but often with different fishers actually performing the angling role. Two of these boats/skippers accounted for almost 30% of all fish landed, while the top six boats/skippers accounted for 52% of fish landed. There were 19 boats/skippers who only reported catching one fish and a further seven boats/skippers who reported landing two fish over the period (Figure 5).

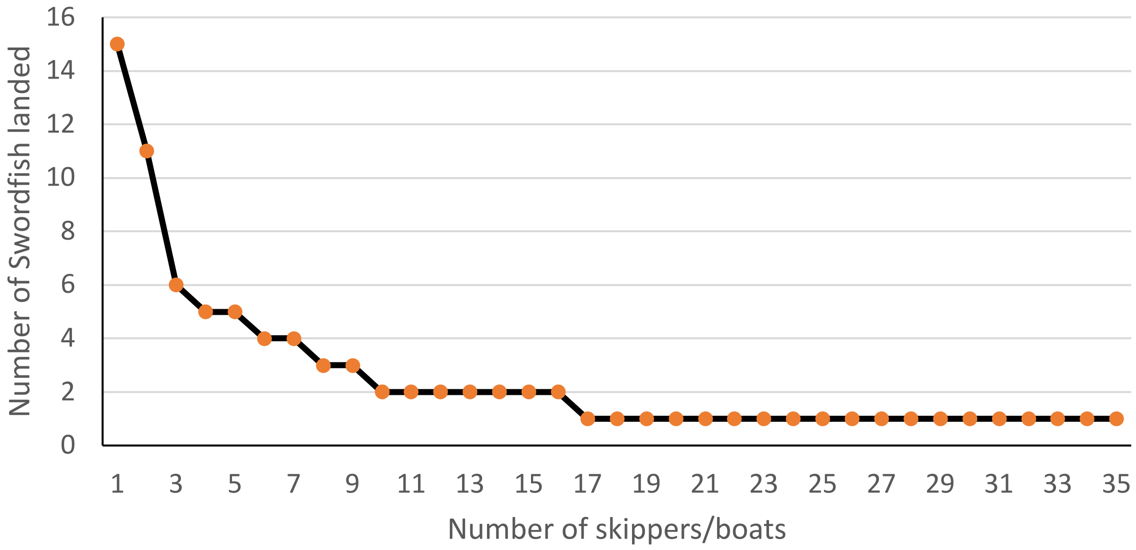

Figure 5. The number of recreationally caught Swordfish per skipper/boat from 2014-2016 in Tasmania.

A total of 44 Swordfish caught by the recreational fishery were weighed whole. These fish ranged in weight from 60 – 354 kg, with an average weight of 177 kg. Weight was estimated for a further 30 fish, including those caught and released by the research team. These estimates ranged from 50 – 350 kg, with an average weight of 139 kg. Four fish caught by recreational fishers were weighed gutted, with the weights reported as 140, 207, 220 and the largest fish reported to date at 356 kg. The distribution of fish weights was right skewed with a longer tail of larger fish being caught (Figure 6).

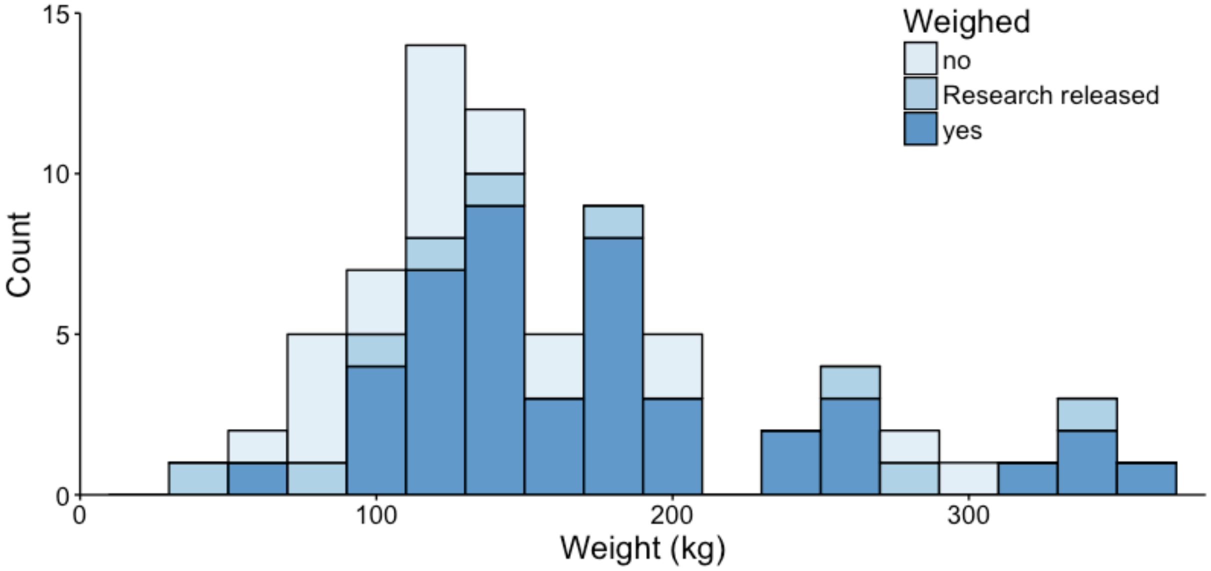

Figure 6. The weight frequency composition of recreationally landed Swordfish from 2014 – 2016 in Tasmania (*n* = 44 weighed, 21 weight estimated and nine released with satellite tags with weight estimated).

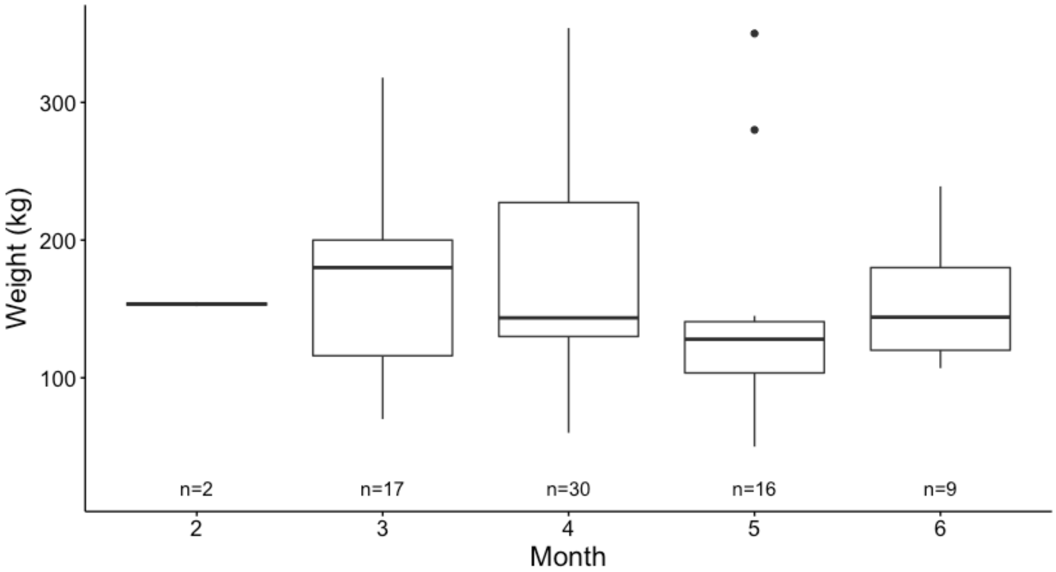

Figure 7. Box plot illustrating variation around the median size of all Swordfish by month reported from 2014 - 2016, plus two individuals caught by the research team in 2017.

Although there was no significant difference between the size of fish caught each month there was a trend where the median weight of fish peaked in March and then declined through April and May before a slight increase in June (Figure 7).

A total of 71 individual fish, including those caught with the research team present, had a weight measurement (or estimate) and the angling duration recorded (time from hook up to landing). Angling duration ranged from 15 – 490 minutes, with an average time of 118 minutes (*n* = 71). There was a significant positive relationship between fish weight and angling duration ($r^2 = 0.39$, $p < 0.001$), with larger fish generally having a longer angling duration (Figure 8). 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.

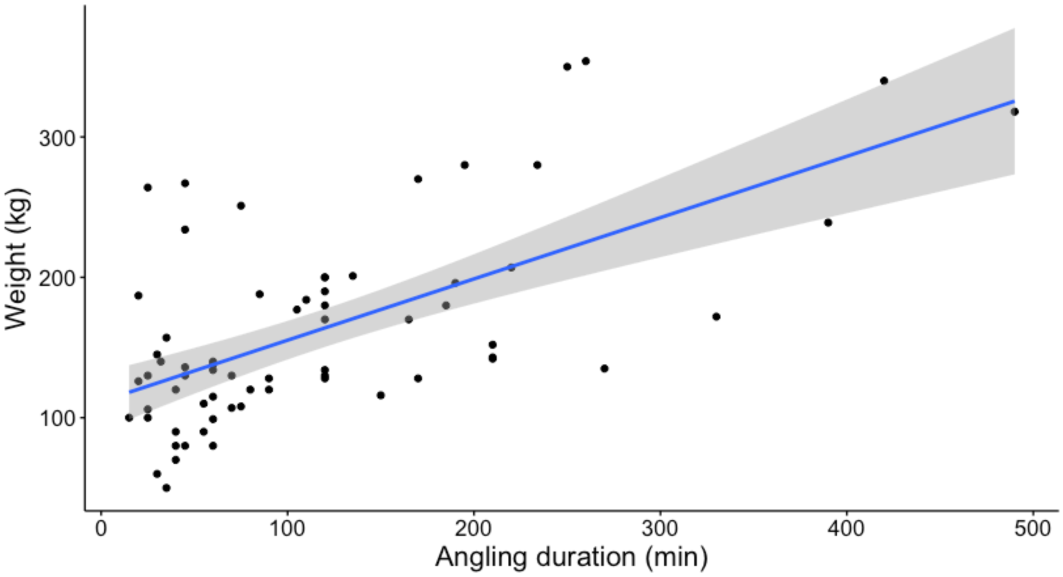

Figure 8. The relationship between angling duration and fish weight of Swordfish caught using the recreational deep-dropping method. The blue fitted line is a linear regression and the grey shading indicated the 95% confidence intervals of the regression.

The most commonly reported hook styles used were single J-hooks (37%) and single circle hooks (34%), accounting for over 70% combined for the hook types reported (Figure 9). Terminal tackle where two J-hooks (jj) were used accounted for 15% of the fish reported landed, while circle and J hook configurations (11%) and two circle hook configurations were less commonly used (3%).

Just over half (54%) of the fish caught where the hook configuration and hooking location were recorded (*n* = 67) were hooked in the corner of the mouth or lower jaw. The highest rate of a mouth hook-up was reported for single circle hooks (c) at 65%. Fish caught using single J- hooks (j) had a slightly lower, but similar percentage of mouth hook-up at 58% (Figure 9). Deep hooking (hooked deeper than the gill region) was not reported for either the single circle or double circle configurations. For the other three hook configurations that had at least one J-hook eight percent of landed fish were reported as deep hooked. The percentage of fish reported to have been hooked in the gill area was 18%, with 21% of fish landed with single J-hooks and 14% of fish landed with single circle hooks reported to be hooked in the gill area respectively. The percentage of fish landed foul-hooked was 22%, with 14% foul hooked in the body, commonly in close vicinity to, or in, a fin (caudal, pectoral and anal fin reported). Eight percent were reported hooked externally in the vicinity of the head (eye, bill and operculum reported).

The two hooking locations considered here to be the most detrimental to the fish, and its subsequent chance of survival if the intention was to release it were 'deep hooked' and 'internal gill area', however, it needs to be noted that release was not the intention for many of these landings with the intention to retain the fish for consumption. When combining the hook configurations to either circle hooks only or a configuration with at least one J-hook, the former had a 17% reporting rate of being hooked internally in the area of the gills, while the latter had a 32% reporting rate of being hooked in the gill area or deep hooked.

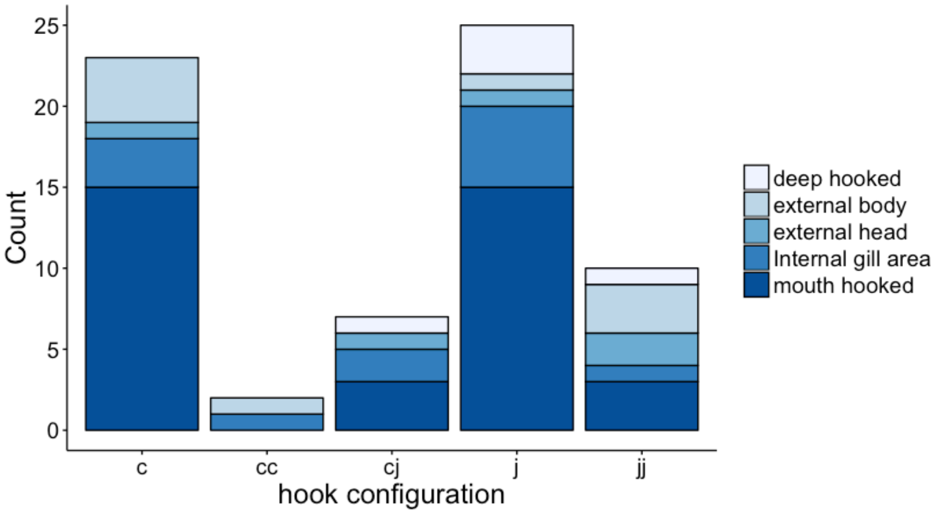

Figure 9. The number of Swordfish landed using each hook configuration reported with the hooking location for each fish identified in the figure legend. Hook configurations are as follows: single circle hook (c), two circle hooks (cc), a circle and J hook (cj), a single J-hook (j) and two J-hooks (jj).

Research catch summary

A total of 17 Swordfish were landed between June 2014 and May 2017 with at least one member of the research team on board (Table 3). All fish were caught on the east coast of Tasmania. Fishing was focused in the areas most frequented by recreational fishers when targeting Swordfish in Tasmania; St. Helens, Bicheno and the Tasman Peninsula.

Table 3. Capture details for Swordfish caught by the research team or recreational fishers with a member of the research team on-board. All weights are estimated apart from those with a '#'. Hook types were either single J-hook (J), two J-hooks (JJ) or circle hooks (C). A '*' indicates the fish was landed by a recreational fishing vessel with a member of the research team on board.

Fish ID	Capture date	Estimated weight (kg)	Angling duration (Hour : min)	Hook type	Hook location
SC0001*	21/06/14	180	2:10	J	Deep hooked
SC0002*	13/06/15	196#	3:10	JJ	Foul hooked
SC0003*	13/06/15	120	1:30	J	Mouth
SC0004*	10/03/16	100	0:25	C	Mouth
SC0005	10/03/16	318#	8:10	J	Mouth
SC0006	21/03/16	130	1:10	J	Internal gill
SC0007	08/04/16	280	3:15	C	Mouth
SC0008*	12/04/16	140	0:32	J	Foul hooked
SC0009*	12/04/16	110	0:55	JJ	Deep hooked
SC0010*	12/04/16	270	2:50	C	Mouth
SC0011*	31/05/16	80	1:00	C	Internal gill
SC0012	31/05/16	80	0:40	C	Foul hooked
SC0013	31/05/16	50	0:35	C	Mouth
SC0014	02/06/16	115	1:00	C	Mouth
SC0015*	03/06/16	120	1:20	C	Foul hooked
SC0016*	05/04/17	350	5:00	J	Mouth
SC0017	18/05/17	280	3:55	C	Mouth

Dyanamics of a fishing event and vertical behaviour of fish from hook-up

Data from the accelerometer attached to the terminal tackle was collected for 10 Swordfish (Figs 28 – 37). Three of these were dropped during retrieval, three were landed dead, three were landed and a PSAT attached and subsequently identified as surviving post-release, one was landed and a PSAT attached but was identified as a post-release mortality. Each recorded fishing event had a reasonably consistent profile (Figure 10), with the bait and break-away sinker deployed to the seafloor (average depth = 466 ± 17.5 SE m; range 340 – 510m), with deployments taking between six and eleven minutes to reach the seafloor (average time = 8 ± 0.5 SE minutes), depending on the weight of the break-away weight and the depth. The break-away sinker was then detached from the terminal tackle and the bait either remained near the seafloor or drifted up through the water column depending on the velocity of the current and the decision to either back the boat into the current or allow the drift of the boat to bring the bait up through the water column. A hook-up was identified by an increase in the vectorial sum of dynamic acceleration (VeDA) recorded by the accelerometer. If a hook-up was achieved, the average time from the bait reaching the seafloor to hook-up was 17.5 ± 2.9 SE minutes (range = 4 – 34 minutes), and the average depth from the seafloor at hook-up (bait drifted up through the water column) was 51.5 ± 12.3 SE m (range = 10 – 125 m).

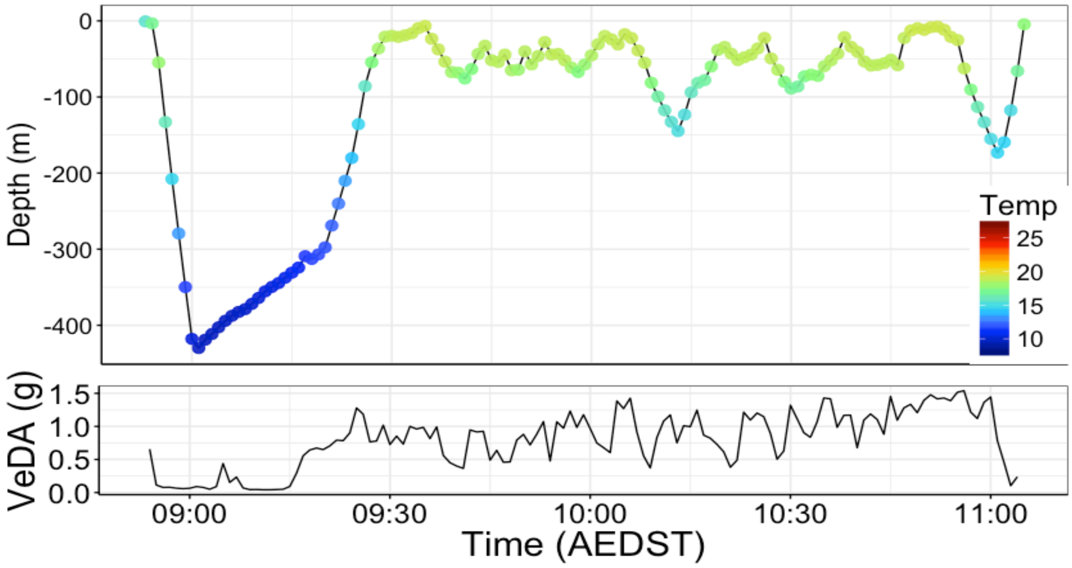

Figure 10. An example of the vertical profile of Swordfish during a fishing event. Each point represents one-minute in time and the colour of the point indicates the temperature at that point (as per the figure legend). The bottom figure shows the corresponding vectorial sum of dynamic acceleration (VeDA) response recorded by the accelerometer. A VeDA value greater than zero indicates movement of the line.

Once a Swordfish was hooked, in all cases, its immediate response was to ascend towards the surface. This took, on average, 11.7 ± 1.7 SE minutes (range = 6 – 22 minutes). For four events the fish ascended to the surface and in some cases, breached or jumped from the water. For the other six events the fish ascended to an average depth of 29 ± 12.8 SE m (range = 10 – 120 m), before changing its behaviour. During these ascents, the angler often had to wind quickly to retrieve line to ensure the hook did not dislodge due to slack line. Once the fish changed behaviour the angler would be fighting against the fish with the full weight of the drag setting on the reel. With the exception of one case, fish would then maintain a depth between the surface and 220 m (average maximum depth during ‘fight’ phase = 146 ± 18.3 SE m). The exception was one fish (Figure 34), that after ascending to approximately 30 m descended to approximately 350 m, before again ascending to maintain a depth less than 100 m. The temperature recorded on the accelerometer during the phase of the fight after fish ascended indicated that fish were remaining above the thermocline. During this phase, fish would generally pull against the line with short runs, either descending or ascending until either the fish was landed or dropped.

For each fish that was landed it was noted by the angler that the fish was 'kiting' against the weight of the line. This is described as a stalemate between the angler and the fish where the fish was not taking line off the reel, but the angler could not easily retrieve line as the drag would release line. From this point, the retrieval of the fish to the boat was slow. This was confirmed on the accelerometers, with the last phase of the fight for these fish showing a slow, but constant ascent of the fish until landing. This phase took between 20 minutes and one hour.

There were no obvious trends in the profile of the fishing event that differentiated between fish that died and survived after landing. However, after identifying the stalemate phase, anglers were encouraged to use their thumb on the reel to increase drag pressure to shorten the duration of this phase. In some cases, this was effective, in others it was more difficult, requiring significant angling skill. In no cases where this technique was employed was the fish lost due to the hook dislodging or the line breaking.

Fish condition

Peritoneal barotrauma was identified in 63% (*n* = 10) of fish caught (excluding a fish that was predated boat-side by a Mako Shark), making it the most common physical trauma related to capture (Table 4). Five of these fish (SC0002, SC0005, SC0009, SC0015 and SC0017) had severe barotrauma. Four of the fish were within the 95% confidence limits of the linear regression fitted to the fish weight vs angling duration results (Figure 8), indicating that the angling duration for these fish was not significantly longer than would be expected for the size of the fish. Fish SC0005, however, was the largest fish caught with research crew on board and had the longest angling duration recorded at just over eight hours. Fish SC0007 had a shorter fight time than would be expected for a fish of its size according to the linear regression presented in Figure 8.

Fish SC0002 had minor external wounds from the hook (three-inch tear on the exterior of the operculum). The condition of this fish was poor at landing according to ACESS criteria G – I. Resuscitation was attempted unsuccessfully for a period of 10-minutes. The fish was brought on-board and euthanised.

Fish SC0005 and SC0009 had no other signs of physical trauma, and resuscitation attempts were made for 12-minutes and one hour respectively. The latter was released several times during the resuscitation attempt, but the positive buoyancy associated with the barotrauma prevented the fish from diving. Beside the symptoms of barotrauma, the condition of this fish did not deteriorate until after almost 55-minutes after landing. Both fish were brought on-board and euthanised.

Fish SC0015 was tail wrapped and retrieved to the boat backwards. This fish was held boat-side for resuscitation for 28-minutes. Two attempts were made to release the fish within the first 15-minutes of resuscitation as the condition of the fish, assessed by criterion G – I, had not yet deteriorated. The positive buoyancy from the barotrauma, however, prevented the fish from diving. After 25 minutes the condition of the fish began to deteriorate. It was then brought on-board and euthanised.

SC0017 presented with severe peritoneal barotrauma, but was still in an otherwise healthy condition at landing according to ACESS criteria G – I. Several attempts were made to release the fish over the resuscitation period of 54-minutes, but the barotrauma prevented the fish diving to a depth where it could re-compress the expanded gases and it would float to the surface. Given the otherwise healthy appearance of the fish, a decision was made to trial a release weight to assist the fish to descend to a depth where the gases would recompress. A barbless hook was applied to the lower jaw of the fish with a length of 15 kg monofilament fishing line, attached to a ~5 kg weight. This successfully assisted the fish to descend, however the satellite tag indicated that the fish descended to the seafloor and died.

Five fish were assessed as having mild peritoneal barotrauma (Table 4). Two of these had no other signs of physical trauma (SC0007 and SC0010), both had ACESS scores at landing of 15. These were two of the larger fish tagged, estimated at 280 and 270 kg respectively, the angling duration for both was significantly shorter than predicted by the linear regression in Figure 8. The condition of both fish improved in respect to general activity and body colour after two and five-minute resuscitation periods respectively (ACESS score increased to 17). Mild peritoneal barotrauma was still evident in both but given the overall good condition of the fish the decision was made to release the fish. Both fish swam down with no significant positive buoyancy effect from the barotrauma. One fish died after six days, the other survived for the duration the tag stayed attached (196 days @ liberty).

Fish SC0008 presented with mild peritoneal barotrauma and was landed with the hook in the anal fin, indicating that the fish may have been retrieved backwards for a period. The angling duration was within the 95% confidence limits of the linear regression presented in Figure 8. After four minutes of resuscitation, however, the fish's condition improved, and it was released. It survived for the duration the tag stayed attached (186 days @ liberty).

Two fish with mild peritoneal barotrauma had additional physical trauma from the hook lodged internally in the gill arch. SC0006 had significant bleeding from the gill region, while SC0011 had less observable damage and a minor bleed from the region of the gills. The condition of SC0006 rapidly deteriorated during the resuscitation process leading to the decision to euthanise the fish. The angling duration for this individual was within the predicted confidence intervals based on the size of the fish. The condition of SC0011, also declined during the resuscitation period, albeit at a slower rate. The fish was swum boat-side for 20-minutes before the decision was made to euthanise the fish as activity, colour and eye response deteriorated after this time. The angling duration for this fish was significantly longer than predicted by the linear regression in Figure 8, however, there was substantial variation in the angling duration relative to the size of smaller fish, this one estimated at 80 kg.

Eighteen percent (*n* = 3) of fish landed were observed to have been deep hooked, including in the vicinity of the gill region, this was the second most common type of physical trauma reported (Table 4). All three fish, including SC0006 and SC0011 reported above, had bleeding associated with the internal hooking wound. Fish SC0001, had the hook lodged deep enough that it could not be seen. After 20-minutes resuscitation, however, the body colour of the fish improved markedly. A decision was made to release the fish, and it was observed swimming away. The satellite tag reported, however, that the fish swam/sank to the seafloor where it did not recover. Hence, deep hooking (or the hook lodged in the gill region) was fatal in all three cases observed.

Only one fish (SC0004) was observed with an everted stomach at landing. Other than this, the fish had no other observable physical trauma and was in generally good condition when landed. The fish was resuscitated for five minutes over which the body colour improved, and the everted stomach partially retracted. The decision was made to release the fish, which survived for the full duration of the satellite tag deployment (250 days @ liberty).

Table 4. Summary of ACESS scores for recreationally caught Swordfish where a researcher was on board at landing. Scores were recorded at landing and again immediately prior to the decision of whether to retain or tag and release the fish after a period of resuscitation (Resus. time). The score criteria are divided into categories, firstly signs indicative of physical trauma: (A) stomach eversion, (B) state of body musculature, (C) internal bleeding, (D) gill damage or deep hooking or (E) barotrauma. Details on the scoring are defined in Table 1, but generally a score of '0' is poor and highlighted in a deeper red in the assessment at landing, a score of '1' is mild, highlighted by a lighter red in the assessment at landing and a score of '2' is good. If the fish was retrieved tail first (criteria F) it scored a '0', highlighted by a deeper red in the assessment at landing, a score of '1' indicated that there was evidence that it may have been retrieved tail first at some stage during the fight, while a score of '2' indicates the fish was retrieved head first. Criteria G – I assess signs of moribundity: (G) general activity, (H) skin colour and (I) eye status. Scores shaded in light green for the assessment at the time of the decision to release or retain, indicate an improvement, while a score highlighted in light red indicates a deterioration in a criterion. The sum of all criteria are shown in the ACESS score columns. The 'released' column indicates whether the fish was released (Y) or retained (N). Rows highlighted in gold indicate the fish survived post-release, while those highlighted in grey indicate the fish died post-release. *indicates accelerometer data was collected. SC0003 was predated by a Mako Shark boat-side so no assessment could be made.

	At landing											At decision to retain or release										
Fish ID	A	B	C	D	E	F	G	H	I	ACESS score	Resus. time (min)	A	B	C	D	E	F	G	H	I	ACESS score	Released
SC0001	2	2	1	0	2	2	1	1	2	13	00:20	2	2	1	0	2	2	1	2	2	14	Y
SC0002	2	1	2	2	0	2	0	0	0	9	00:10	2	1	2	2	0	2	0	0	0	9	N
SC0003	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	N
SC0004	1	2	2	2	2	2	2	1	2	16	00:05	1	2	2	2	2	2	2	2	2	17	Y
SC0005*	2	2	2	2	0	2	1	1	2	13	00:12	2	1	2	2	0	2	0	0	0	9	N
SC0006*	2	2	0	0	1	2	1	1	2	11	00:02	2	2	0	0	0	2	0	0	0	6	N
SC0007*	2	2	2	2	1	2	1	1	2	15	00:02	2	2	2	2	1	2	2	2	2	17	Y
SC0008*	2	2	2	2	1	1	1	1	2	14	00:04	2	2	2	2	1	1	2	2	2	16	Y
SC0009*	2	2	2	2	0	2	1	1	2	14	01:00	2	2	2	2	0	2	0	0	0	10	N
SC0010*	2	2	2	2	1	2	1	1	2	15	00:05	2	2	2	2	1	2	2	2	2	17	Y
SC0011	2	2	1	1	1	2	1	1	2	13	00:20	2	2	1	1	1	2	0	0	0	9	N
SC0012	2	2	2	2	2	2	2	1	2	17	00:05	2	2	2	2	2	2	2	1	2	17	Y
SC0013*	2	2	2	2	2	2	1	1	2	16	00:02	2	2	2	2	2	2	2	1	2	17	Y
SC0014	2	2	2	2	2	2	2	1	2	17	00:01	2	2	2	2	2	2	2	1	2	17	Y
SC0015	2	2	2	2	0	0	1	1	2	12	00:28	2	2	2	2	0	0	0	0	0	8	N
SC0016	2	2	2	2	2	2	2	1	2	17	00:08	2	2	2	2	2	2	2	2	2	18	Y
SC0017	2	2	2	2	0	2	1	1	2	14	00:54	2	2	2	2	0	2	1	1	2	14	N

Tag retention

A total of nine fish were released with a PSAT attached (Table 5). Three PSATs (43% of tags that were on fish that survived) stayed attached to the fish for the full-program duration of 250 days. The remaining four detached from the fish prior to the programmed release date (127 – 196 days). The mean attachment duration was 203 ± 18 S.E. days (Figure 11).

Table 5. Deployment and transmission information from pop-up satellite archival tags deployed on Swordfish caught adjacent to the east coast of Tasmania by recreational fishing methods.

Deployment						Pop-up transmission			
Fish ID	Location	Date	Latitude	Longitude	Programmed duration (d)	Date	Latitude	Longitude	Actual duration (d)
SC0001	TAS	21/06/14	-43°01	148°15	180	23/06/14	-43°56	152°47	2
SC0004	TAS	10/03/16	-43°03	148°16	250	15/11/16	-18°54	152°15	250
SC0007	TAS	08/04/16	-41°20	148°37	250	21/10/16	-29°44	154.08	196
SC0008	TAS	12/04/16	-41°19	148°40	250	15/10/16	-25°29	173°42	186
SC0010	TAS	12/04/16	-43°01	148°39	250	18/04/16	-41°54	148°43	6
SC0012	TAS	31/05/16	-43°01	148°17	250	05/02/16	-43°58	149°04	250
SC0013	TAS	31/05/16	-43°01	148°17	250	11/11/16	-40°50	156°33	164
SC0014	TAS	02/06/16	-41°17	148°40	250	07/02/17	-36°26	152°36	250
SC0016	TAS	05/04/17	-43°03	148°16	250	10/08/17	-38°48	148°24	127

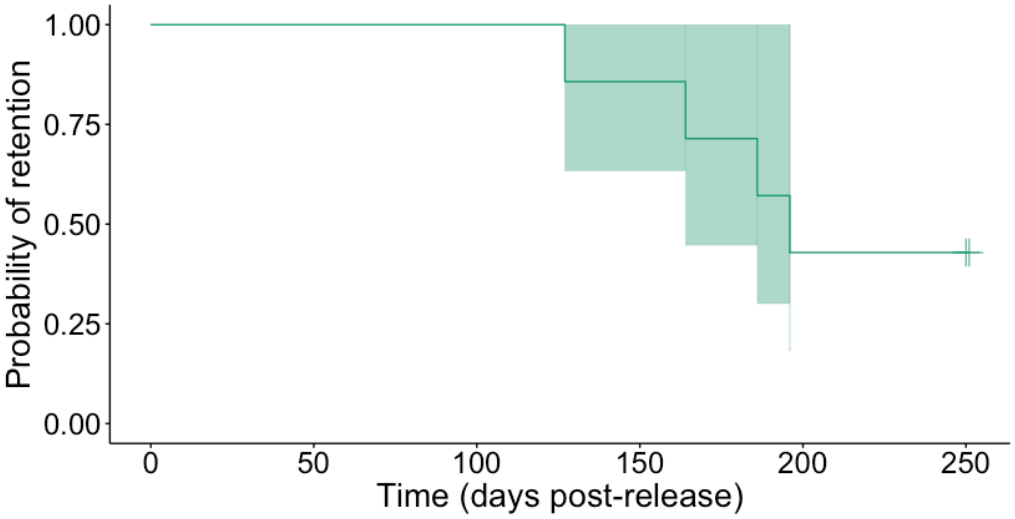

Figure 11. The probability of a PSAT tags remaining on a Swordfish on a given day post-release as estimated using a Kaplan-Meier survival function (*n* = 7). The shaded area indicates the 95% confidence intervals. All PSAT tags considered in this analysis were programmed to stay attached for 250 days. Individuals that were determined to have succumbed to mortality were excluded from the analysis.

Post-landing and post-release survival

Of the 17-fish caught, nine (53%) were assessed as in a condition suitable for release based on their ACESS score post tagging and resuscitation, seven of the remaining fish were assessed as moribund and were euthanised. A release weight system was trialled for one individual (SC0017) that presented with significant barotrauma. The trial was successful in assisting the fish to descend against the effects of the barotrauma, but the satellite tag identified that it did not survive. Based on the primary physiological assessment of severe barotrauma, the tag data was excluded, and this fish was considered a post-landing mortality.

Of the nine fish that were assessed as in a condition suitable for release, the PSAT data indicated that two died shortly after release, and as such these fish were categorised as post-release mortalities related to their capture. Therefore, the total capture induced mortality including fish that were assessed boat-side as moribund and those that were identified as dying within days after release was estimated at 59%, while the post-release survival of fish that were assessed as healthy enough to release based on the ACESS score was estimated at 78% (60 – 100% 95% CI). Given the small sample size of PSATs deployed, the confidence intervals are broad. For the given release mortality estimate a power analysis indicated that deploying 80 tags would reduce the confidence interval to within 30% of the estimate, and beyond this a prohibitively large sample size would be required to further reduce the confidence intervals (i.e. 320 tags to reduce the CI to within 20% of the release mortality estimate (Figure 12)).

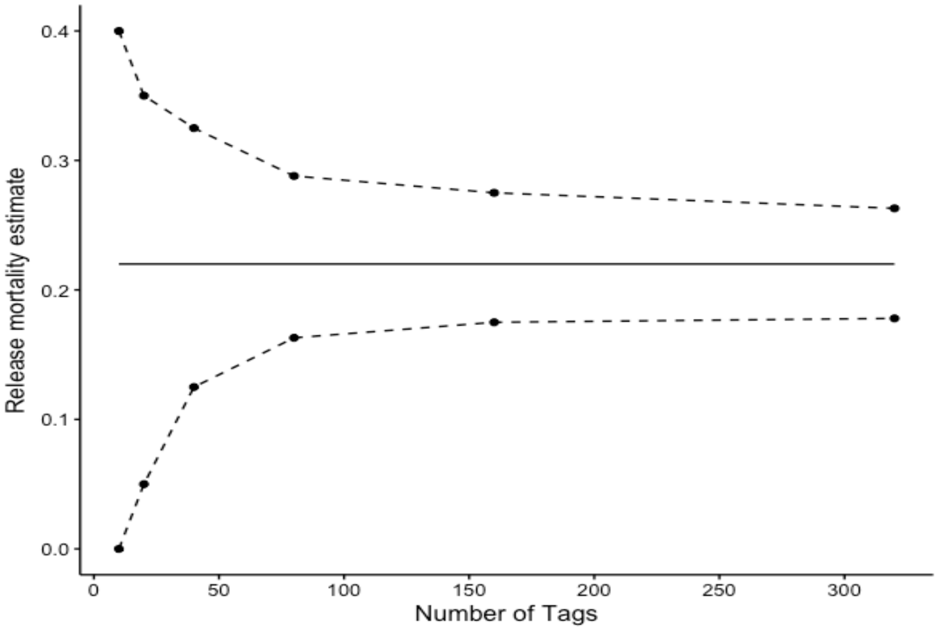

Figure 12. The predicted 5th and 95th percentile values around the post-release mortality estimate (22%) of Swordfish assessed as in a condition suitable for released based on their ACESS score (Table 4) for a given number of tags deployed.

Fish SC0001 sank straight to just over 600 m, presumably the seafloor, and remained there for two days prior to the tag detaching as programmed if depth remained constant for this period of time. Fish SC0010, displayed normal crepuscular dive behaviour for three nights after release, although the average depth reported during the days over this period was shallower relative to the remaining seven fish. On the fourth night, the fish's behaviour changed dramatically with multiple bounce dives (or possibly sinking and burst return to near the surface) to approximately 400 m before sinking to approximately 1,100 where the tag detached.

There are indications that one fish may have died well after release. Fish SC0013 was at liberty for 164 days and displayed normal crepuscular dive behaviour over this period. Just prior to release, however, the tag descended to 1,800 m before surfacing. It is most likely that the fish sank to this depth and then the tag detached as programmed to avoid damage to the tag from extreme pressures beyond this depth.

Angling duration was not identified as a significant factor leading to mortality of Swordfish. An ACESS score of 1 for barotrauma was not a significant predictor of mortality, however a score of 0 was a highly significant predictor of mortality (Table 6). An ACESS score of both 1 and 0 for hook damage were significant predictors of mortality (Table 6).

Table 6. Mulitple linear regression results assessing a suite of predictor variables against survival of recreationally caught Swordfish (*F*-statistic: $9.285_{d.f.=5,10}$, $P = 0.002$; Adjusted $R^2 = 0.73$). ACESS scores for barotrauma and hook damage were treated as ordered nominal factors.

Predictive variable	Estimate	Standard error	*t*-value	*p* value
Intercept	-0.99	0.13	7.80	<0.001***
Angling duration	-0.00	0.00	-0.43	0.679
f (barotrauma 1)	-0.26	0.17	-1.50	0.165
f (barotrauma 0)	0.95	0.17	5.35	<0.001***
f (hook damage 1)	-0.73	0.30	-2.40	0.037*
f (hook damage 0)	-0.85	0.21	-4.03	0.002**

Horizontal movements and behaviour

General movement summary

Movement data was collected for seven Swordfish caught off the east coast of Tasmania and released with a PSAT attached (Figure 13). During the period for which the PSATs stayed attached, fish dispersed as far north as 11°S, some 3,762 km from the capture location and 174°E, 1,971 km from the capture location. All fish however, remained in the Tasman or Coral Seas. Fish were caught and tagged off the east coast of Tasmania in the months March to July. During this period, the PSATs identified that the fish had a probability of being located in waters off southeast Australia, but that several fish also left these cooler waters and were located in tropical waters as far north as 11°S (Figure 14). From August to September there was still a probability of locating a tagged Swordfish in southeast Australian waters, but by October the fish had either moved north or east (outside the Australian EEZ). During November and December there was no evidence of the fish being located in southeast Australian waters south of 38°S, with all fish with tags still attached dispersed through the northern Tasman Sea and the Coral Sea (Figure 14). In December however, there was evidence of fish either inhabiting, or moving towards the east coast of NSW. In January, fish with tags still attached were located close to the Australian coastline between southern Queensland and along the coast of NSW. By February one fish had returned to the east coast of Tasmania, and two were located within the EEZ adjacent to NSW (Figure 14).

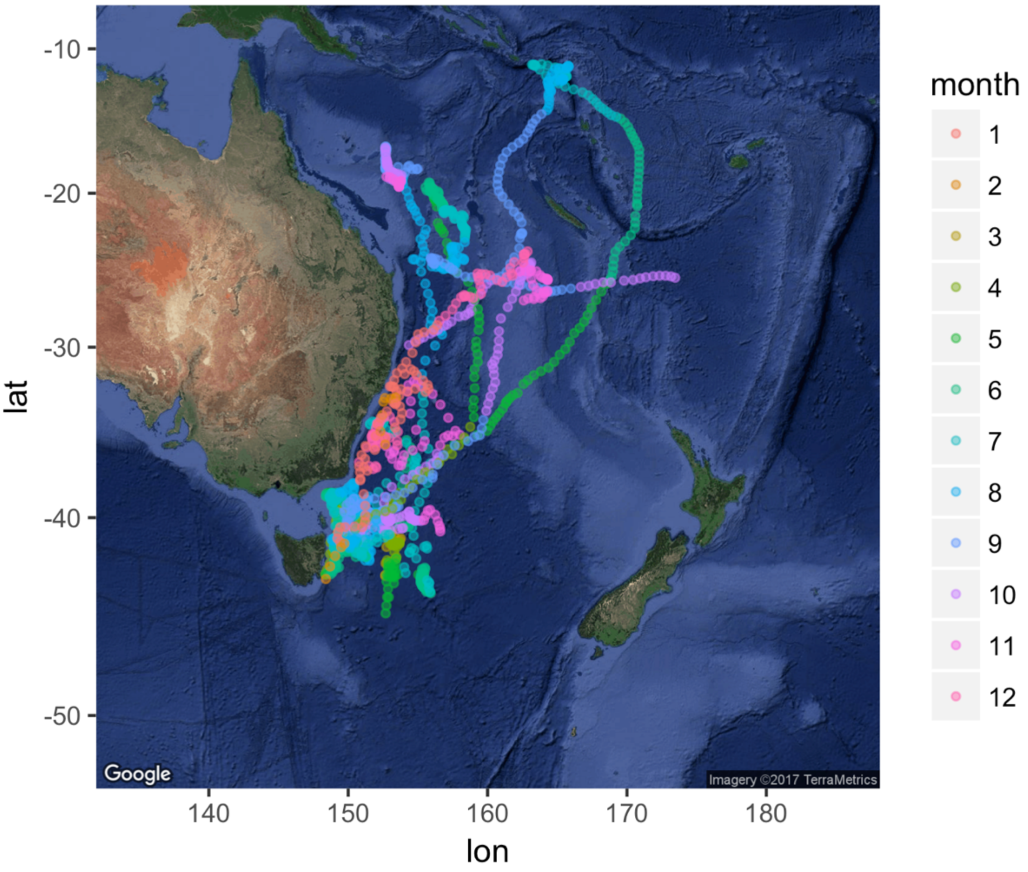

Figure 13. Most probable tracks estimated for seven Swordfish caught off the east coast of Tasmania and released with pop-up satellite tags. The colour of each point indicates the month corresponding to each position estimate.

Detailed movement summary

Four of the six Swordfish tagged in 2016 displayed protracted equatorward migrations, all moving to waters north of 25°S, at least 15 degrees north of the locations they were tagged. Each migration was characterised by a period of rapid, directed travel prior to an apparent change in behaviour to a more area restricted mode once the fish arrived in the Coral Sea. Individuals SC0007 (Figure 43) and SC0008 (Figure 45) began their migrations soon after being tagged adjacent to Tasmania in April, with the former taking four and the latter taking three months to arrive at the location where they switched behaviour mode. Individuals SC0004 (Figure 41), tagged in March, and SC0012 (Figure 47), tagged in May displayed an area restricted state of behaviour remaining in the vicinity of southeast Australia (below ~38°S) for four and three months respectively prior to their northward migrations. For these two fish, their migration north took approximately two months prior to again switching to an area restricted state of behaviour Three of the individuals undertaking these long migrations headed away from the coastline of Tasmania in a roughly north-easterly direction, SC0008 (Figure 45) and SC0012 (Figure 47) headed in a more northerly direction once reaching the Lord Howe Rise, while SC0007 continued in a north-easterly direction until reaching~22°S, where it travelled north until reaching ~18°S, it then headed northwest until it changed to an area restricted behaviour state at ~12°S (Figure 43).

The period of area restricted behaviour in the Coral Sea and northern Tasman Sea was unique for each fish, both in terms of timing and location. Individual SC0004 spent approximately three months (September – November) in an area east of the Great Barrier Reef (~18°S, ~153°E) (Figure 41). Individual SC0012 spent November and the beginning of December in an area on the eastern edge of the Lord Howe Rise, approximately adjacent to Brisbane (~26°S, ~164°E) (Figure 47). The timing of the area restricted behaviour of SC0007 and SC0008 was similar with both spending approximately one month over July and August in this mode, however the locations differed. Individual SC0007 spent time in an area east of the Solomon Islands (~12°S, ~165°E) (Figure 43), while SC0008 spent time in a broader region than the other three fish, adjacent to Queensland, between 20°S and 25°S, and between 155°E and 160°E (Figure 45).

After the periods of area restricted behaviour, three individuals switched back to a mode of directed travel, the tag detached from the fourth fish whilst it was still in an area restricted behaviour state. SC0007 headed in an approximate south-westerly direction beginning in late August, with the most probable track suggesting that it may have traversed along the north-eastern edge of the Lord Howe Rise for a short period of time in mid-September before again tracking southwest. The directed travel led the fish back to the continental shelf break adjacent to northern NSW, where the tag then detached (Figure 43). SC0012 also migrated in a south-westerly direction from its period of area restricted behaviour beginning in December 2016. The most probable track for this individual suggests that the fish intersected with the continental shelf break of Australia at a similar latitude to fish SC0007. From here however, the fish migrated south following the continental shelf break until reaching approximately 37°S, the southeast corner of mainland Australia. The fish then continued South, but not tracking as closely to the shelf break, before returning to the continental shelf break adjacent to Tasmania in February 2017, migrating as far south as 44°S before the tag detached (Figure 47). Individual SC0008 began directed travel after its period of area restricted behaviour in September 2016. Unlike the other two fish that travelled south, this fish migrated east for almost two months before the tag detached approximately 400 nm east-northeast of Norfolk Island at 172°E (Figure 45).

The other two PSAT tagged fish (SC0013 and SC0014) that survived post-release did not undertake long migrations akin to the four fish previously described. Both fish were tagged late in the season where Swordfish were caught off Tasmania and were substantially smaller than the four fish whose migrations were previously described Individual SC0013 was tagged in late May and soon after migrated north adjacent to Tasmania over the course of June. The most probable track indicates that the fish moved into Bass Canyon off southeast Victoria before moving east along the shelf break arriving in waters adjacent to the southeast corner of mainland Australia in August. From here the fish moved east during September and November (Figure 49). The depth profile recorded on the tag indicated the fish died after 164 days with the tag descending to a depth that activated the release of the PSAT from the fish (Figure 48). According to the most probable track the fish did not migrate further north than -38°S. Individual SC0014 was tagged in early June and spent the next 250 days moving throughout the Tasman Sea, but not migrating further north than 31°S or further east than 157°E (Figure 51).

Fish SC0016, was tagged adjacent to southeast Tasmania in April 2017. It followed the shelf break north during April, arriving in the Bass Canyon in late April-early May. It remained in this area until the tag detached in August 2017. This was a large fish estimated at 350 kg. Whilst it was not observed to migrate north while the tag was attached, the tag did detach earlier than the months that some of the other tagged fish began their equatorward travel (Figure 53).

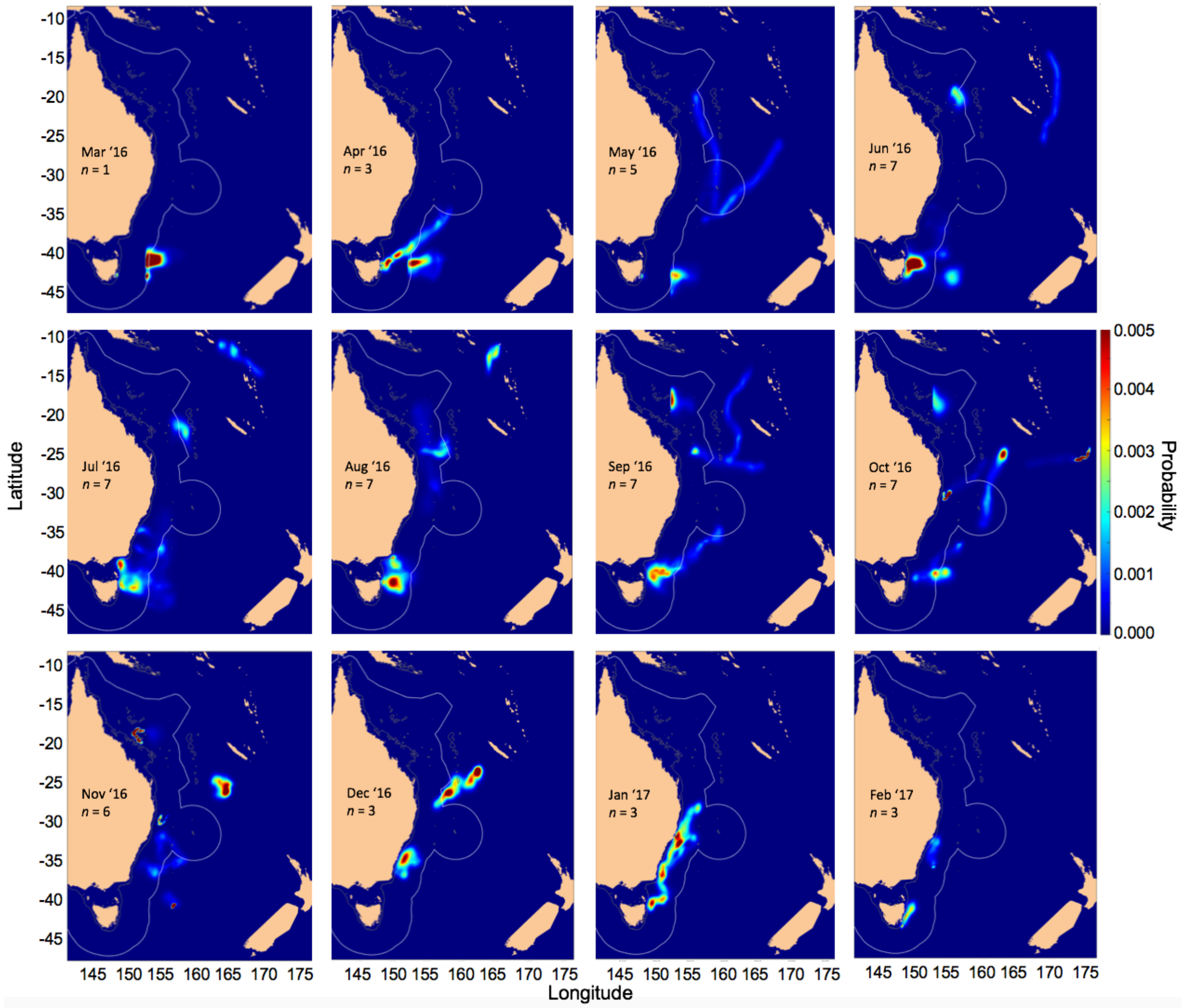

Figure 14. The probability of a satellite tagged Swordfish from this study being located in a given region, pooled each month from March 2016 to February 2017 (excludes fish tagged in April 2017). The probability densities are a cumulative estimate from the daily probability estimates, so contain both the estimates of the geo-location model error and movement within a month for all tags at liberty at that time (*n* indicates the number of tags at liberty in a given month).

Transient and area restricted behaviour

As described previously, the most probable tracks of Swordfish movement indicated periods of both directed travel (transient) behaviour and area restricted behaviour. To explore this further a state-space model was fitted to the movement data to quantify these two behaviour modes based on the step length and turn angle between each location estimate. The model successfully identified these two behavioural states with varying degrees of confidence (Figure 15; left). With posterior mean values (b_t) closer to one indicating a transient behavioural state and values closer to two indicating an area restricted behavioural state. When converted to a binary response with a cut-off value of 1.5, the two behavioural modes could be clearly identified (Figure 15; right). The geo-located behavioural state data was then fitted to a kernel utilization distribution (KUD) analysis, with the b_t values limited to less than 1.3 for transient behaviour and greater than 1.7 for area restricted behaviour to remove data points that had a higher degree of uncertainty in the classification of behavioural state. The KUD analysis identified a high proportion of area restricted behaviour in the waters adjacent to southeast Australia, including Tasmania, and to a lesser extent, southern NSW. There was also a region ranging diagonally from approximately 17°S, 152°E to 28°S, 165°E where there was a higher probability of finding the tagged fish in an area restricted behavioural state (Figure 16; left). Two smaller areas with a 95% probability of a tagged fish being in an area restricted behavioural state were also identified in the Pacific (Figure 16; left).

There was a high probability of a tagged fish being in a transient behavioural state for a broad area within the Tasman Sea between the coast of Australia and the Lord Howe Plateau (Figure 16; right). There were two other areas further north where fish had a higher proportion of time in a transient state, one adjacent to the mid-Queensland coast and the other southeast of the Solomon Islands. Overall, the 95% contour ellipse of a transient state probability covered the range of all geo-located positions (Figure 16; right).

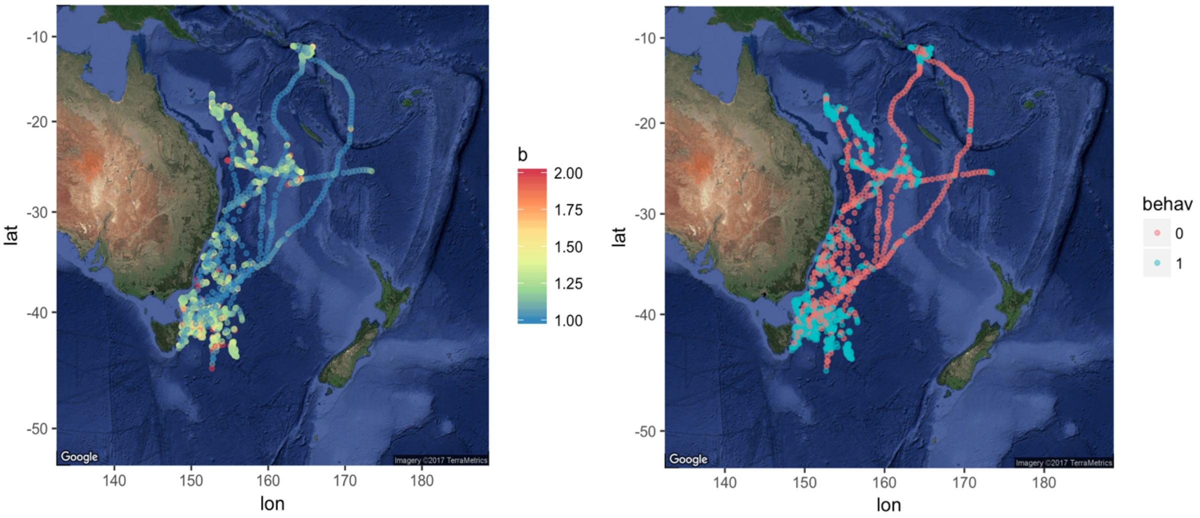

Figure 15. (Left) Posterior mean values (b_t) calculated by a hierarchical-joint estimation state-space switching model for each most probable location estimate of seven Swordfish caught off the east coast of Tasmania and released with a PSAT attached. Values tending towards 1 indicate a higher certainty of a transient behaviour state, while a value closer to 2 indicates a greater certainty of an area restricted behaviour state. (Right) Posterior means converted to binary behaviour modes; transient (0) where $b_t <= 1.5$ or area restricted (1) where $b_t > 1.5$.

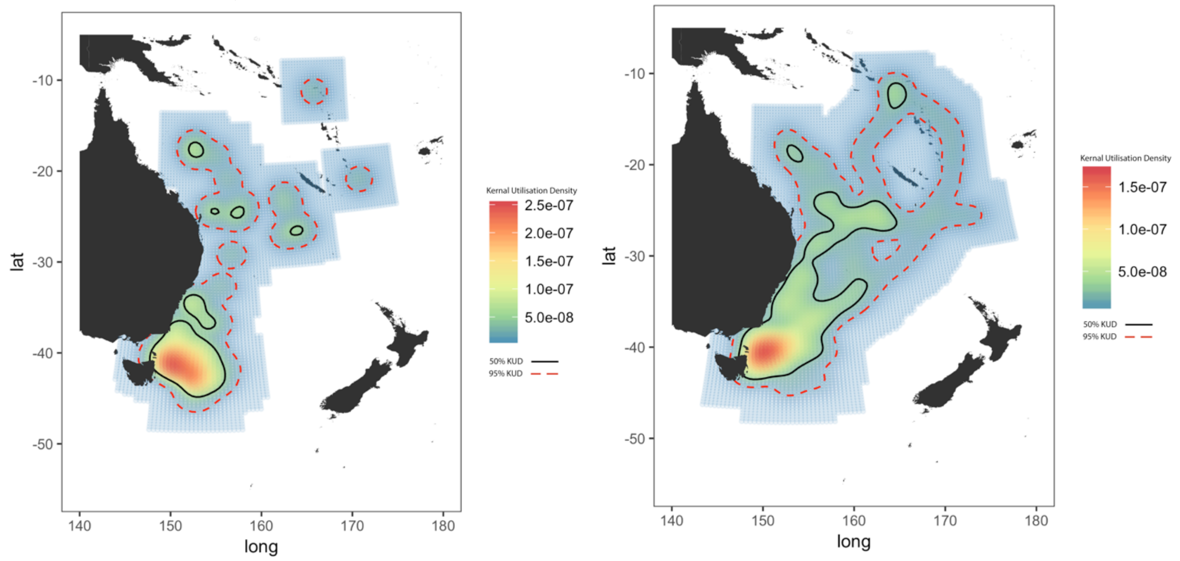

Figure 16. Kernel utilisation distribution (KUD) plots calculated for the most probable position estimates of seven Swordfish caught off the east coast of Tasmania and released with PSATs attached. (Left) KUD probabilities calculated on positions where the fish were predicted to be in an 'area restricted' behaviour state ($b_t > 1.7$). (Right) KUD probabilities calculated on positions where the fish were predicted to be in a 'transient' behaviour state ($b_t < 1.3$). 50% (black solid line) and 95% (red dashed line) utilisation distribution contours are shown.

The behaviour states identified by the movement paths were further explored by considering sea surface temperature (SST) at each geo-location point (Figure 17). To isolate warm water area restricted (WAR) behaviour from cool water area restricted behaviour (CAR) geo-location estimates with a $b_t > 1.7$ and an SST >24°C were assigned as WAR behaviour and with a $b_t > 1.7$ and an SST <24°C assigned as CAR behaviour. Swordfish are thought to spawn in water temperatures greater than 24°C SST.

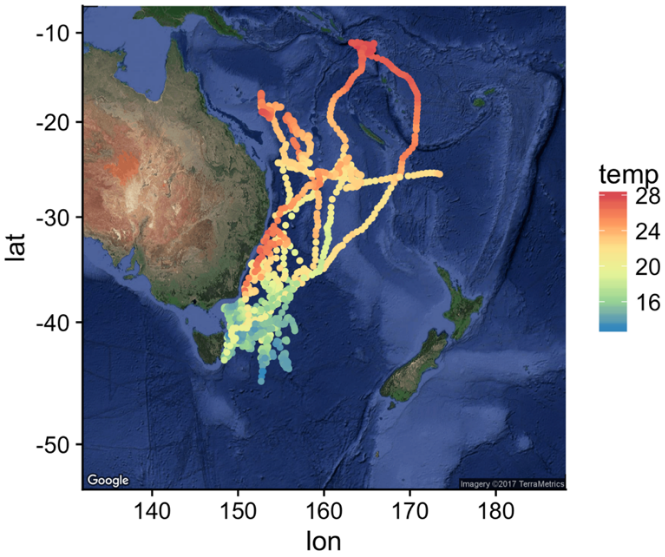

Figure 17. Most probable location estimates of seven Swordfish caught off the east coast of Tasmania and released with a PSAT attached. Colour points indicate the sea surface temperature (°C) at each point.

The greatest proportion of CAR behaviour relative to transient behaviour occurred in latitudes ranging from 39°S to 43°S, transpiring between Julian days 80 – 300 (mid-March – late-October) (Figure 18). The greatest proportion of WAR behaviour relative to transient behaviour occurred in latitudes ranging from 10°S to 38°S, with peaks at 10°S to 11°S, 18°S to 20°S and 24°S to 27°S, transpiring between Julian days 100 – 365 (mid-April – late-December, with the highest proportions from Julian day 200 (Figure 18).

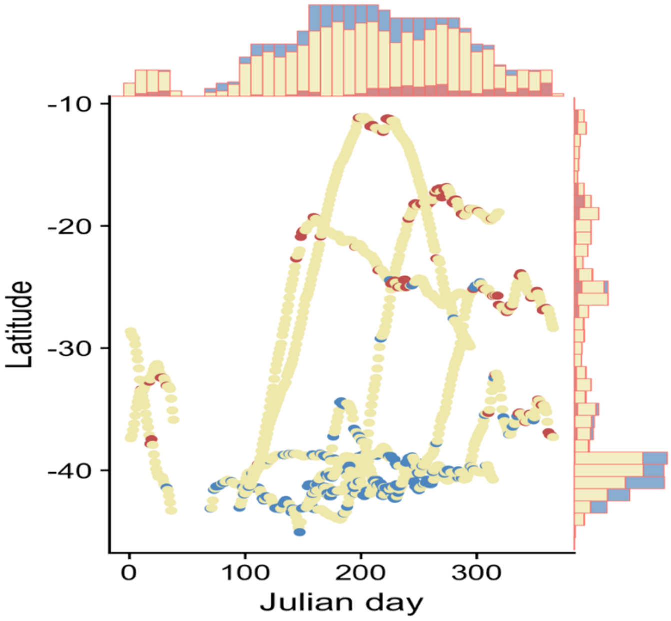

Figure 18. The latitudinal component of the most probable geolocation estimates for seven Swordfish caught off the east coast of Tasmania and released with a PSAT plotted against Julian day (day of year). The points are coloured to indicate three behavioural states: 'warm area restricted' (Red) behaviour state ($b_t > 1.7$ and temperature > 24°C), 'cool area restricted' (Blue) behaviour state ($b_t > 1.7$ and temperature < 24°C) and transient (yellow) behaviour state ($b_t < 1.3$). Marginal histograms for Julian days are shown on the top of the figure (bin size = 10 days) and for latitude on the right of the figure (bin size = 1°).

Vertical habitat preference and behaviour

All surviving satellite tagged fish displayed consistent crepuscular behaviour, with evidence of occasional daytime basking behaviour (Figure 19). At dawn, fish descended to deeper waters, spending daylight hours at a median depth of 530 m (inter-quartile range: 418 – 606 m), and a maximum depth reported at 1,100 m (Figure 20). During daylight hours there was a trend for the depth to increase until approximately midday before a decrease until dusk when fish moved relatively rapidly to near surface depths (Figure 21). There was some evidence of fish occasionally spending time in surface waters during daylight hours, although these were rare events. At dusk, fish ascended to shallower waters, spending night time hours at a median depth of 35 m (inter-quartile range: 20 – 77 m). There was also evidence of fish spending time in deeper water during the night (maximum night time depth recorded = 815 m), again however, these were rare events (Figure 20).

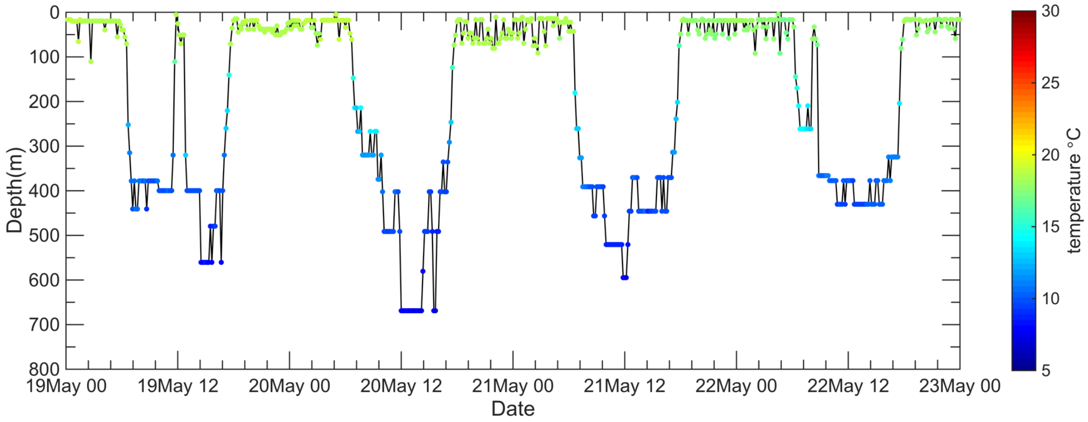

Figure 19. Example of diel crepuscular dive behaviour recorded on a PSAT attached to a Swordfish in 2017 adjacent to the coast of Tasmania. The colour of the points indicates the water temperature as per the figure legend. The dates on the x-axis are shown at both midnight (00) and midday (12). A basking event is evident around midday on the 19th May.

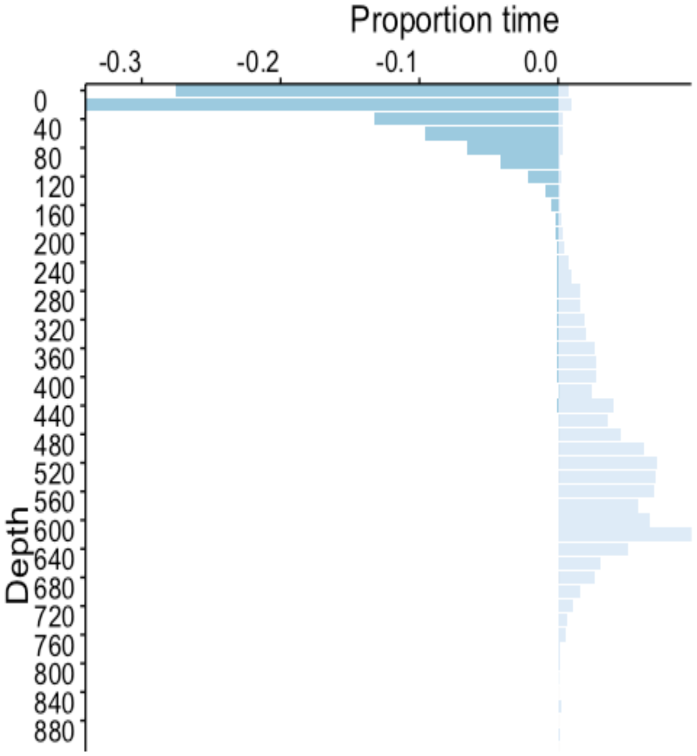

Figure 20. Depth preferences of all Swordfish combined during the night (dark blue bars) and the day (light blue bars) inferred from the proportion of time at 20 m depth bins. Data one hour either side of dawn and dusk have been removed.

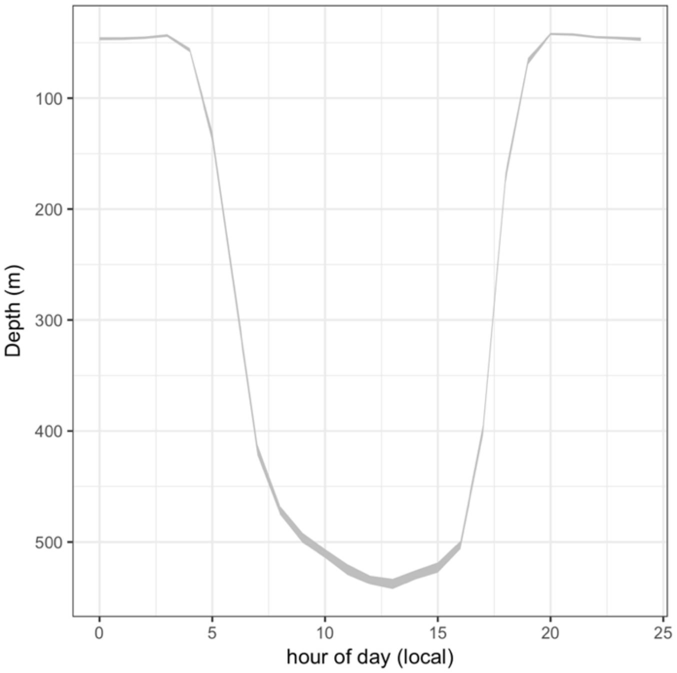

Figure 21. 95% confidence intervals of the depth reported by PSATs attached to Swordfish for each hour of the day.

During daylight hours, when the Swordfish were spending time in deeper waters, the median temperature experienced was 9.9°C (inter-quartile range: 8.8 – 12.1°C). The minimum temperature recorded for any fish was 5.3°C. During the night, when fish were inhabiting near surface waters, the median temperature experienced was 19.1°C (inter-quartile range: 15.4 – 23.0°C). The maximum temperature recorded was 28.8°C (Figure 22). The broader range of temperatures experienced whilst the fish were near surface waters was reflective of the broad latitudinal gradient the fish covered when migrating north to the Coral Sea from the cooler surface waters adjacent to Tasmania. The overall depth – temperature profile of all PSAT data can be illustrated by a habitat envelope plot with the highest proportions of time spent in a broad range of temperatures depending on geographic location shallower than 100 m and a within a narrower range of cooler temperatures between 400 and 700 m (Figure 23).

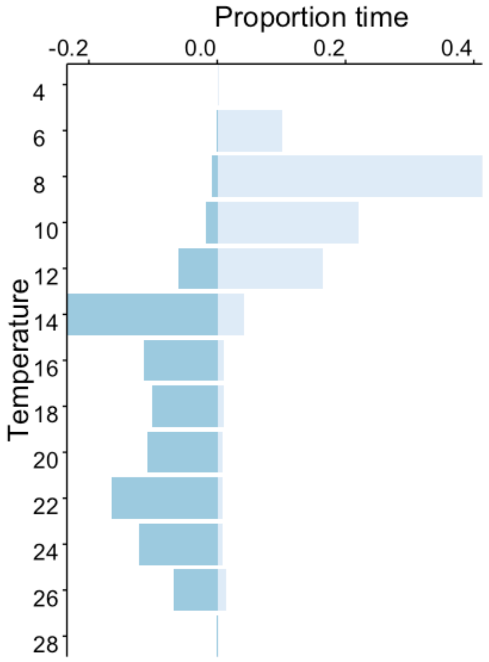

Figure 22. Water temperatures (°C) experienced by Swordfish during the night (dark blue bars) and the day (light blue bars) inferred from the proportion of time at 2°C depth bins.

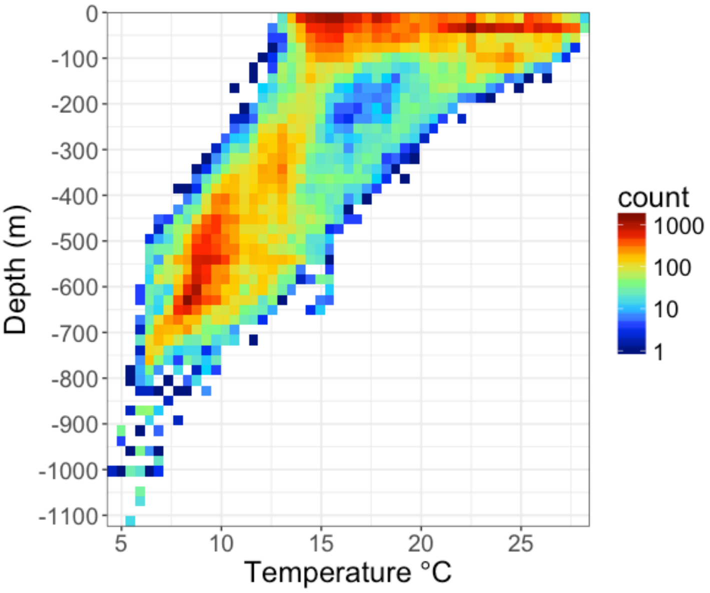

Figure 23. Vertical habitat envelope of Swordfish in the Tasman and Coral Seas with temperature and depth reported from PSATs. Temperature and depth are binned by 1°C and 20 m, respectively. Frequency of occurrence is displayed on a $\log_{10}$ scale.

The GAMM model assessing the effects of location, environmental factors and lunar cycle on the median depth of Swordfish during night-time hours identified only Chl_a had a significant effect (Table 7). A low value of Chl_a led to fish spending more time in deeper water during the night, moving to a shallower depth as Chl_a increases before plateauing (Figure 24).

Table 7. Summary of GAMM results of median depth of Swordfish in night-time hours.

	Value	Standard error	DF	t-value	p-value
Intercept	44.47	2.30	276	19.36	<0.001
Log_{10} Chl-a	-15.05	6.60	276	-2.28	0.023
Lunar phase	7.87	8.57	276	0.92	0.35
Lat, lon (Fx1)	-1.88	2.88	276	-0.65	0.51
Lat, lon (Fx2)	-2.28	3.89	276	-0.59	0.56

While lunar phase was not identified as a significant factor in regard to median depth of Swordfish during night-time hours, the individual effect shows an interesting trend with median depth increasing as lunar phase approaches and departs π which represents the full moon (Figure 24).

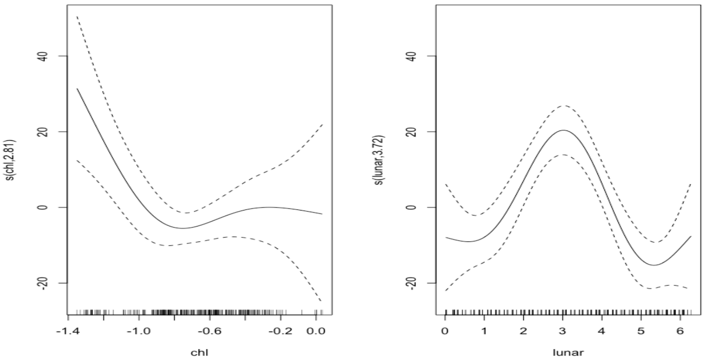

Figure 24. Estimated individual effects (solid line) of log_{10} Chl_a and lunar cycle from the GAMM testing effects on median depth of Swordfish during night-time hours. Dashed lines show 95% confidence limits. The rug plot (dashes along the x-axis) indicate sample distribution.

Shallower median depths of Swordfish during night-time hours were predicted at the mid-latitudes of the Tasman Sea, and increased sequentially moving both equatorward and poleward. The deepest median depths during night-time hours were predicted in the Coral Sea, adjacent to north Queensland and in the region of the Pacific Islands (Figure 25).

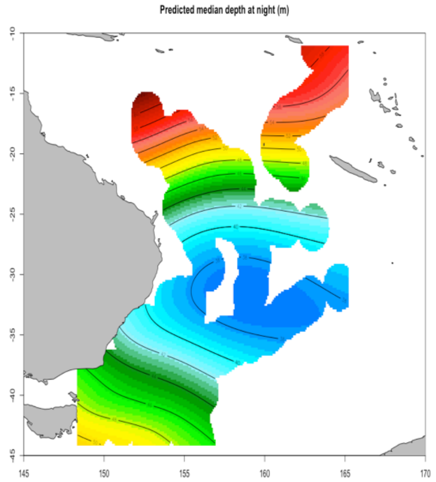

Figure 25. Model predictions from the best fitting GAMM of median depth of Swordfish during night-time represented by depth contours and plotted in false colour.

The GAMM model assessing the effects of location, environmental factors and lunar cycle on the median depth of Swordfish during day-time hours identified only SST as a significant predictor (Table 8). With median depth during the day increasing as SST increases, the rate of increase slows above 20°C (Figure 26). This is shown spatially with shallower median depths predicted adjacent to Tasmania and southeast Victoria with median depth increasing as the fish move equatorward. There was a slight decrease in median depth for the individual that displayed area restricted movement adjacent to the Solomon Islands (Figure 27).

Table 8. Summary of GAMM results of median depth of Swordfish in day-time hours.

	Value	Standard error	DF	t-value	p-value
Intercept	515.30	19.08	480	27.00	<0.001
SST	69.22	21.54	480	3.21	0.014
Lat, lon (Fx1)	11.14	25.65	480	0.43	0.66
Lat, lon (Fx2)	9.36	23.10	480	0.41	0.68

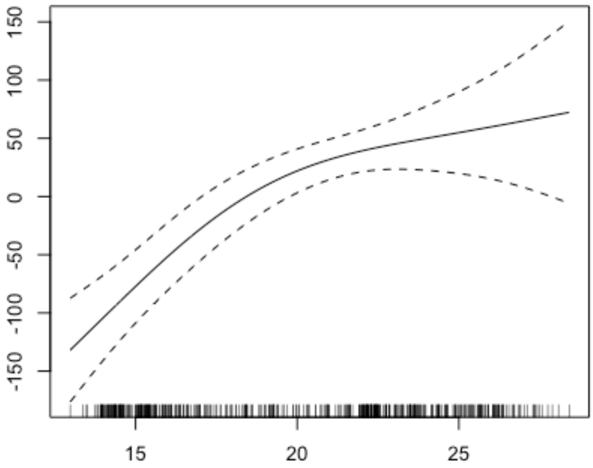

Figure 26. Estimated individual effects (solid line) of SST from the GAMM testing effects on median depth of Swordfish during day-time hours. Dashed lines show 95% confidence limits. The rug plot (dashes along the x-axis) indicate sample distribution.

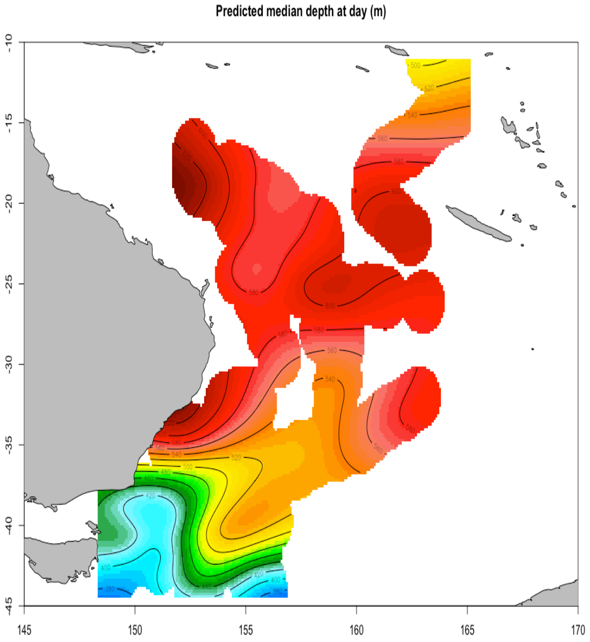

Figure 27. Model predictions from the best fitting GAMM of median depth of Swordfish during day-time hours represented by depth contours and plotted in false colour.

Discussion

Development of the recreational fishery in Australia

While there have been several recreational fishers that have invested time in attempting to catch Swordfish in Australia with limited success the contemporary development of the fishery occurred in Tasmania in 2014, with the reporting of several successful dedicated trips using the deep-dropping method during daylight hours. The fishery in Tasmania experienced a rapid increase in participation, and concurrently catch from 2014, however, it should still be considered relatively niche compared to other recreational fishing activity in the state. From 2014-2016 approximately 35 boats reported catching a Swordfish in Tasmania with six boats accounting for 52% of the fish landed with the other boats reporting only catching one or two fish over this period. In 2015 there was an expansion of the fishery to the waters off the southeast coast of Victoria with anecdotal reports of a similar number of fish being caught as in Tasmanian waters. There were also reports of a small number of Swordfish caught in Western Australia, New South Wales and Queensland using the same methods proven to be successful in Tasmania.

There are several likely factors limiting a greater amount of effort, including the need to travel a long distance offshore, particularly from mainland Australia, combined with limited opportunities due to inclement weather, a need for appropriately equipped vessels – ideally with high quality depth sounders, a requirement for heavy duty fishing tackle and a degree of patience and knowledge on how to target the species.

Whilst the recreational fishery for Swordfish is still relatively niche in southeast Australia it has attracted significant attention from within the recreational fishing community in Australia and internationally, being showcased in several popular fishing magazines, television shows and broadly across social media platforms. This is primarily due to it being a new targeted fishery, but also due to the relatively large size of the fish being caught. Swordfish are sexually dimorphic in regard to body size, with females growing significantly larger than males (Young et al., 2004). It has been reported from several regions across the globe than larger female Swordfish are more likely to migrate further poleward into cooler temperate waters than the smaller males (Neilson et al., 2014). The Australian recreational fishery has developed on what would be considered the southern range edge of Swordfish on continental Australia, probably explaining the large size of the fish reported, with an estimated average weight in Tasmania of 177 kg and a maximum weight greater than 356 kg (which was the weight of one fish weighed after it had been gutted). This is considerably larger than the average size of fish caught by the commercial longline fleet in the northern Tasman Sea and Coral Sea, estimated at 60-80 kg depending on season. The few fish caught and reported by recreational fishers in New South Wales and southeast Queensland, where the warm water East Australian Current has a far greater impact have also been significantly smaller that the fish caught in southeast Australia.

The size of fish caught off Tasmania and Victoria are also significantly larger than fish caught in other areas where a recreational fishery for Swordfish is well developed. For example, off Florida, which has one of the best developed recreational fisheries for the species globally. Kerstetter and Fenton (2012) engaged with this fishery to assess post-release survival of juvenile Swordfish using satellite tags and reported fish sizes ranging from 85 – 129 cm (LJFL), which converts to 7 – 27 kg[1], although larger fish are also caught (20 – 100 kg)[2] . New Zealand, however, appears to provide an opportunity for recreational anglers to target larger Swordfish with a reported size range of between 100 – 300 kg, but bigger fish have also been landed (http://www.primetimecharters.co.nz/broadbil.htm). A PSAT study to assess the movement of Swordfish conducted in New Zealand where fish were caught by the commercial fleet between ~30 and 37°S reported an average estimated size of 86 ± 8 s.e. kg, with a maximum estimated weight of 160 kg (Holdsworth et al., 2010).

The large size of fish caught in southeast Australia create an attraction for game fishers and given the regional locations from where most fishing for Swordfish occurs, the development of the fishery has the potential for a significant socio-economic boost in these regions. As a comparison, the recreational fishery for large black marlin on the Great Barrier Reef in Australia has a long history dating back to the early 1960s (Gunn et al., 2003, Pepperell and Davis, 1999). Given the size of the fish and the exciting experience of catching a large billfish, that fishery tends to attract wealthy fishers from both Australia and internationally willing to invest heavily in the opportunity.

The development of the recreational Swordfish fishery off southeastern Australia has been the source of much emotive discussion, both within the general community and the recreational fishing sector. Predominantly, the discussion has focussed on whether the fish should be targeted, how they should be handled, and whether they should primarily be released or retained. Swordfish, to some degree resemble istiophorid species, such as marlin and sailfish, primarily due to their prominent rostra (bill). In Australia, there has been a long history of promoting catch and release for istiophorid species, which have been shown to have relatively high post-release survival rates from recreational fishing events (Musyl et al., 2015, Gunn et al., 2003, Pepperell and Davis, 1999, Domeier et al., 2003). While a small number of marlin and sailfish are occasionally landed to be weighed for sanctioned competitions or record claims, the vast majority are released – often with spaghetti tags attached (Ghosn et al., 2015). The perceived similarities between marlin and Swordfish have led to an opinion from some within the recreational community that Swordfish should also be predominately catch and release only.

Swordfish, however, are not directly related to the family Istiophoridae, but in fact, constitute the only species in the family Xiphiidae. The species also has many morphological and physiological distinctions to istiophorid species (Beckett, 1972, Nakamura, 1985). Swordfish also behave quite differently to marlin and sailfish, migrating in much cooler waters and regularly diving to depths much deeper and temperatures much lower than recorded for istiophorid species. This is reflected in the differences in recreational fishing methods to capture the species. Marlin and sailfish are nearly always targeted by trolling surface lures or baits, and whilst Swordfish are caught in some regions at the surface during the night, the development of the new fishery in southeast Australia has exploited their unique crepuscular dive behaviour to target the fish using set baits at relatively extreme depths (~400 – 700 m).

Further contributing to the debate on whether Swordfish should be predominately a catch and release species is the eating quality of the fish. In the developing period of game fishing in Australia, marlin and sailfish, particularly larger specimens, were considered to be relatively poor in regard to the eating qualities of their

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[1] http://www.fishweights.net/newzealand.aspx

[2] http://budnmarys.com/daytime-nighttime-Swordfishing.html

meat, an attitude that contributed to a higher willingness to release fish. The eating qualities of Swordfish on the other hand are highly regarded, the oily, yet firm flesh of Swordfish making them highly desirable for human consumption. The demand for Swordfish meat for consumption offers a counter argument to the concept of a catch and release ethos, with many recreational Swordfish fishers preferring to retain their catch for this reason. This is shown by the fact that only 11% of fish caught by recreational fishers in Tasmanian waters from 2014 – 2016 were released. In some of these cases, the fishers had previously caught and retained a Swordfish and still had meat available. It is important however, to consider that Swordfish often have an elevated concentration of methylmercury within their flesh. Food Standards Australia and New Zealand recommend that pregnant women, women planning pregnancy and young children under six years of age only have one serve of Swordfish (150 grams for adults and 75 grams for children) per fortnight and for the rest of the population, one serve per week (150 grams)[3]. While these recommendations are reasonable for a consumer purchasing smaller portions of Swordfish from a commercial source or at a restaurant, the large size of a recreationally caught Swordfish equates to a significant yield of meat. Fishers will need to be informed and be made aware of the potential for over-consumption when retaining large amounts of meat for themselves or sharing their catch.

As previously discussed, large marlins are sometimes retained by an angler to be weighed. This is defined as ‘trophy fishing’, where the angler may want the weight recorded for their personal records, to be considered as part of a fishing competition or for submission as a record claim. Trophy fishing is also highly relevant to anglers participating in the recreational capture of Swordfish. As the fishery is relatively new, many people are catching a Swordfish for the first time and would like a personal memento of the capture, generally including, a whole weight measurement, a photo and sometimes, a fibreglass cast of the fish. There has also been significant scope for state, national and international game fishing records to be claimed as the new fishery develops, since many such record categories were vacant, or held by much smaller fish prior to the development of the recent deep-dropping fishery.

Another consideration that has been raised is whether the removal of large breeding females by the recreational fishery is likely to negatively impact the population of Swordfish. Given the current size of the recreational fishery relative to the commercial fishery (tens of fish versus tens of thousands of fish per annum) it is unlikely that there would be any adverse impact on the stock. If the recreational fishery was to increase significantly however, a quantification of the recreational harvest would be beneficial for inclusion in stock assessment models and for consideration of sustainable management.

Ultimately, we would suggest that the pragmatic approach to whether a Swordfish should be retained or released should be based on a scientific understanding of the likelihood of an individual to survive after release, and a common-sense approach to whether the fisher chooses to retain the fish if they are within fisheries management regulations and with prior consideration and preparation to ensure that if a fish is retained, it is done so to maximise animal welfare and minimise meat wastage.

Survival from capture

Excluding fish retained, the effects 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). This is the first study to assess the survival rate of Swordfish after landing caught using the recreational daytime deep-dropping method. The reported post-release survival estimate should be considered conservative, however, as the effects of attaching satellite tags are unknown and may have biased the results towards a higher mortality rate (Cooke and Schramm, 2007).

Of the 17 fish caught, eight (47%) were deemed not in a condition to be released. They were landed in either a moribund state, or their condition deteriorated to a moribund state during the boat side resuscitation process. The remaining nine fish were released successfully with a satellite tag attached, and with all tags successfully transmitting data after they detached from the fish. Two of these fish died shortly after release, one immediately and the other on the fourth day after release. The duration to a mortality event was similar

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[3] http://www.foodstandards.gov.au/consumer/chemicals/mercury/Pages/default.aspx

to that reported by Kerstetter and Fenton (2012) who caught and released with PSATs small recreationally and commercially caught Swordfish in Florida. They reported two mortalities immediately after release (one observed to have barotrauma – as it floated at the surface), and further mortalities after 6, 24 and 28 hours. Abascal et al. (2010) also found that mortality generally occurred within the first few days after tagging for Swordfish caught using commercial methods in the southeast Pacific. Post-release mortality within hours or days after release is also consistent with other studies on large pelagic fish (Domeier et al., 2003, Horodysky and Graves, 2005, Kerstetter and Graves, 2008, Kerstetter and Graves, 2006, Tracey et al., 2016).

The remaining seven fish were deemed to have survived the catch and release event. The tags reported normal crepuscular behaviour and migrations away from the locations of capture for the duration that the tags were attached (127 – 250 days – noting that 250 days was the maximum programed attachment period). A post-release survival rate of 78% for fish that were identified by physiological assessment as suitable for release was estimated. One fish was discerned as dying after 164 days, but given the protracted duration after release, it is unlikely that its death was related to the capture event. Rather, it is far more likely that this was a natural mortality.

Considering post-landing mortality combined with post-release mortality a total capture survival rate for all 17 fish of 41% was estimated. This is lower than the reported post-release survival rate of small recreationally and commercially caught Swordfish in Florida – where a rate of 64.3% survival was estimated based on five of fourteen reporting tags indicating a mortality (Kerstetter and Fenton, 2012), fish tagged opportunistically aboard commercial longline vessels in the southeast Pacific (60%) (Abascal et al., 2010) and in the western North Atlantic and in the eastern Pacific where fish were caught using a combination of recreational, commercial longline, research longline and harpooning, at 78% and 62% respectively (Dewar et al., 2011).

There are several possible reasons for the difference in survival rate between this and other studies. Abascal et. al. (2010) report that they only tagged fish in ‘prime condition’. This is considered akin to the assessment here of fish that were identified by physiological assessment as suitable for release. Hence, the survival rate of 60% that they report is less than the post-release survival rate reported here of 78%. They postulate that the mortalities were most likely attributed to the long set duration of the commercial longline gear, which could last more than 8 hours. Each fish mortality in their study was identified by the fish sinking to greater than 1800 m. This would suggest that barotrauma was not linked to post-release mortality. It is not clear however if the fish that were considered in less than prime condition and excluded from the tagging experiment had suffered barotrauma. The mean size of Swordfish hooked in the Abascal et. al. (2010) study was166 cm (LJFL), which converts to 60 kg[4]. Much smaller than the average size of fish caught in this study.

It is not clear in the study by Dewar et. al. (2011) whether researchers selected for fish in ‘good condition’, however, given the objective of their study was to assess movement rather than post-release survival, it is likely they did. The survival rates they report are very similar to the post-release survival rate we report here. They do not discuss whether they observed fish with barotrauma, but again the size of the fish they were tagging was smaller than in this study with mass estimates ranging from 45 – 114 kg in the Eastern Pacific, 20 – 135 kg in the Central Pacific and 11 – 77 kg in the western North Atlantic (Dewar et al., 2011). They did not describe which methods were used to catch each fish and whether there was an effect of fishing method on survival, all of which make direct comparisons with this study difficult.

Kerstetter and Fenton (2012) also indicated that they selected for healthy fish assessed by an ACESS score, as well as deploying tags on fish that were caught during night-time hours, and therefore presumably caught near the surface, whereas in this study, we deployed tags on fish that had been caught at depths between 350 – 600 m during the daytime. They report that only one fish was observed floating at the surface, presumably due to barotrauma. Angling durations in their study ranged from 5 – 25 minutes, far shorter than the fight times for the large fish reported here but they did not find a common predictor in the fish that died after release (Kerstetter and Fenton, 2012).

The survival rate reported here for Swordfish caught by recreational fishers using the daytime deep-dropping method is lower than reported for other large pelagic species caught by recreational fishing methods. These

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[4] http://www.fishweights.net/newzealand.aspx

include billfish –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) and also tunas – Atlantic Bluefin Tuna, *Thunnus thynnus* (100%) for juveniles (Marcek and Graves, 2014) and 94-97% for adults (Stokesbury et al., 2011) and Southern Bluefin Tuna (83%) (Tracey et al., 2016). It is important to note however, that all the species listed here were caught using either surface trolling or surface drift baits, and in no reported cases is barotrauma indicated as a symptom of capture.

Currently, the use of PSATs is the only effective method to assess post-release survival (PRS) of large pelagic species. The application of PSATs provides a detailed profile of the behaviour of the fish immediately after release and depending on how long the tags are programmed to stay with the fish, longer term movements and vertical behaviour. There are several considerations when using PSATs to assess PRS. Primarily, the tags are expensive and without significant funding the sample sizes can be limited. While the results of a study with limited sample size are still informative they will generally have broad confidence intervals. In this study, the sample size of tagged fish was limited to nine. The confidence intervals estimated by a standard bootstrapping routine were close to 100% of the PRS estimate. A power analysis indicated that to reduce the confidence intervals to 20% of the PRS estimate would require 320 tags to be deployed. The cost to achieve such sample size would be prohibitive. So, whilst there are no other methods currently available to assess PRS of large pelagic fish the broad confidence intervals resulting from small sample sizes need to be taken into consideration when reporting on PRS.

Another important consideration when using PSATs to assess PRS is the reliability of the tags. Given that studies are often dealing with limited sample sizes, tag failure can significantly affect the assessment of PRS. Several studies assessing PRS and fish movement of Swordfish using PSATs have reported multiple tag failures, e.g. 8% from Neilson et al. (2009), 10% from Abascal et al. (2010), 39% from Abascal et al. (2015), 21% from Abecassis et al. (2012), and 13% from Kerstetter and Fenton (2012). The only way to effectively consider tag failures in the analysis of post-release survival data is to remove these tags from the study, further reducing sample size. For example, Kerstetter and Fenton (2012) excluded the non-reporting tags from their analysis. If these tag failures were in fact mortalities, it would greatly affect their post-release survival rate estimate given the small sample size. In this study, we had 100% of the tags deployed report data. There are several companies that produce PSAT tags, with varying tag sizes, technological innovations and price points. We would suggest that tag reporting reliability is key in PRS studies. To date, we have had 100% reporting success using Wildlife Computers MiniPATs in both this study and a previous study on southern bluefin tuna where 59 PSATs were deployed to assess PRS (Tracey et al., 2016). A recent review of reporting performance of Wildlife Computer tags estimated an overall reporting rate of 86% (Musyl et al., 2011). However, as the technology is being further developed the reliability of tags is greatly increasing.

Factors predicting mortality

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).

In this study, one individual was predated boat-side by a Shortfin Mako shark, and one died due to the fish becoming tail-wrapped in the line during the fight and being retrieved to the boat backwards all contributing to mortality at landing – i.e. prior to an opportunity to release. Tail wrapping has been reported to lead to mortalities for Southern Bluefin Tuna (Tracey et al., 2016) and Atlantic Bluefin Tuna (Stokesbury et al., 2011) caught using recreational fishing methods.

Angling duration

Longer angling time has been shown in many studies to increase physiological disturbance and the time required for recovery (Cooke et al., 2008, Cooke and Suski, 2005). 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), Striped Marlin (Domeier et al., 2003) and Southern Bluefin Tuna (Tracey et al., 2016). Our results were consistent with this, indicating that longer angling durations did not relate to the fate of Swordfish. While these results do not indicate that angling duration affects survival of Swordfish, extended durations such as those reported here do increase the physiological effects on the fish and contribute to exhaustion which can impair the fish's reflexes making them more susceptible to predation post-release. Consideration should be given to using appropriate tackle relative to the likely size of the fish to minimise the angling duration, subsequently improving the welfare of the animal (Cooke and Suski 2005, Iwama 2007). However, given the potential to catch very large Swordfish in southeast Australia, even the heaviest standard game fishing tackle is unlikely to reduce the angling duration significantly.

Barotrauma

Physostomous fish caught at depths beyond one atmosphere experience a change in pressure on retrieval that can often result in physical trauma, commonly referred to as barotrauma (Gotshall, 1964). This is due to the gases in their swim bladder rapidly decompressing, potentially rupturing the swim bladder which allows gasses to enter the viscera and cranium (Gotshall, 1964, Rummer and Bennett, 2005). Tears of the swim bladder and haemorrhaging of circulatory components can result in mortality soon after the fish is landed (Rummer and Bennett, 2005). Beyond the physical trauma of barotrauma, the fish often become positively buoyant and cannot return to depth, leaving the fish vulnerable to predation and often leading to mortality (McLennan et al., 2014). It has been reported that slow retrieval speed does not reduce the effects of barotrauma (Butcher et al., 2013). Barotrauma was the most common physical trauma observed in the 16 Swordfish (excluding the fish that was predated boat-side at landing) that were assessed during this study with five fish presenting with mild barotrauma and five with severe barotrauma, equating to 63% of fish assessed. Barotrauma was identified as a significant predictor of mortality in this case.

Observable symptoms of barotrauma can be a strong indicator of fish condition and mortality risk (Campbell et al., 2010, Brownscombe et al., 2017). This was the case here for Swordfish, with observable symptoms of barotrauma, primarily distention of the ventral surface of the fish and an inability to descend significantly related to post-capture mortality (when categorised using the ACESS score). All studies to date on the effects of barotrauma on fish have been conducted on smaller fish, such as Red Snapper *Lutjanus campechanus* (Rummer and Bennett, 2005), Coral Trout *Plectropomus leopardus*, Crimson Snapper *Lutjanus erythropterus*, Saddletail Snapper *Lutjanus malabaricus*, Red Emperor *Lutjanus sebae*, Red-throat Emperor *Lethrinus miniatus*, Grass Emperor *Lethrinus laticaudis* (Sumpton et al., 2010) and Smallmouth Bass *Micropterus dolomieu* (Nguyen et al., 2009) among others. Swordfish are a much larger species and while the principles are the same, there are other factors that need to be considered in relation to the effects of barotrauma in Swordfish.

Primarily, the large size of Swordfish leads to extended angling durations, as seen in this study, often several hours and in one case, over eight hours. While angling duration was not related to mortality here, the long durations will contribute heavily to exhaustion. It was observed in two cases where fish presented with mild barotrauma (ACESS score 1) but no other evidence of physical trauma according to the ACESS score, the fish were retrieved to the boat ventral side up, but after a short-period of resuscitation boat-side the fish would right itself and had sufficient energy to descend, where presumably the expanded gases were recompressed. The satellite tags indicated that these fish survived. One fish, however, presented in a similar manner, and after a resuscitation period of five minutes righted itself and descended. This fish was identified as dying approximately four days post-release. It is possible, in light of no other obvious physical damage that the internal damage to the swim bladder or other organs led to the mortality. Four fish presented with severe barotrauma (and no other signs of physical damage). All of these fish were ventral side up when they surfaced prior to landing and after extended periods of resuscitation the fish were not able to descend due to the effects of the barotrauma. In each case the fish were observed attempting to descend but it appeared that they were too exhausted from the retrieval process to descend to a depth that would facilitate re-compression of the gasses and they would float back to surface. In each case the fish became moribund and were dispatched. It is worth noting that each of these fish was large (>100 kg). A Swordfish charter operator from Florida reported very few cases of barotrauma for fish caught at similar depths using the same rod-and-reel methods employed here (Nick Stancyk *pers. comm.*). The fish he catches, however, are predominately smaller than 100 kg, and generally have shorter angling durations and are thus likely to be less exhausted by the experience. The ability of a fish to survive the effects of barotrauma depends on the physical damage caused by the initial trauma, subsequent treatment and by its capacity to heal the damage to affected organs (McLennan et al., 2014).

For smaller species of fish there are two treatments that are used in an attempt to ameliorate the effects of barotrauma. One is lateral venting, where a small puncture is made in the side of the fish with the intention of allowing the gases to escape from the swim bladder so the fish can descend (McLennan et al., 2014, Eberts and Somers, 2017, Campbell et al., 2009). A review study, however, identified that venting had little benefit to fish survival, and became increasingly harmful the deeper the fish was retrieved from (Wilde, 2009). There is also significant debate whether this method should be promoted as it requires a sound understanding of the technique to be effective and has significant risks associated with additional physical trauma and potential for secondary infections (Kerr, 2001, Nguyen et al., 2009, Scyphers et al., 2013). A less-invasive alternative is assisting the fish to descend to a depth where the gases recompress. This is usually performed using a descending device, such as a shot-line release rig where a weighted device is attached to the jaw of the fish to return it to capture depth (Bartholomew and Bohnsack, 2005, Sumpton et al., 2010).

We attempted to use a release weight on one fish that presented with severe barotrauma. The fish was observed swimming on the surface after an attempted release but could not descend. The fish was estimated at 280 kg. A release weight of approximately 5 kg was attached to the terminal tackle of the capture fishing rod along with a barbless J-hook. The hook was inserted in the lower jaw of the fish and the fish was slowly descended to approximately 40 meters before weight on the line reduced, and we assume the fish removed itself from the hook. While the method was successful in assisting the fish to descend, the attached satellite tag indicated the fish descended to the seafloor and did not survive. While this was only one fish, it did indicate that using a release weight to assist a Swordfish with barotrauma could give a false perception that the fish will survive if it can be descended to depth. Also, it is a logistically challenging procedure given the size of the fish. Although, there could be scope to explore this option further as the tag technology reduces in price and a sufficient number of tags can be applied to test this method of potentially allowing fish to recompress.

Assessing barotrauma in Swordfish is relatively simple with the fish presenting ventral side up when retrieved boat-side. The fish that were suitable for release in this study were able to right themselves after a reasonably short period of time (2 – 5 minutes), and subsequently were observed to descend and in all but one case the PSAT identified that the fish survived. Alternatively, fish that were not able to right themselves or descend after a resuscitation period of >5 minutes (up to 1 hour) did not recover and either died or could not descend. This information is useful to improve responsible fishing practices for Swordfish, indicating that if the intention is to release a Swordfish with barotrauma, immediate resuscitation should be conducted and if the fish is unable to descend on its own after approximately five minutes it should be humanely dispatched with consideration of animal welfare. If the fish in not able to descend during an attempted release it will float so the fishers can collect the fish to avoid wastage due to the fish dying and sinking.

Hook type and hooking location

Hooking injury 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, Muoneke and Childress, 1994, Cooke and Suski, 2005). When fish are deep hooked they tend to experience increased bleeding and damage to vital organs (Lyle et al., 2007, Muoneke and Childress, 1994). This often equates to high rates of immediate and short-term mortality (Lyle et al., 2007, Bartholomew and Bohnsack, 2005, Arlinghaus et al., 2007, Cooke and Suski, 2005). Studies have shown that the use of non-offset circle hook reduce deep hooking and subsequent hooking injury over J-hook or treble hooks (Cooke and Suski, 2004), including large pelagic species such as marlin where a significantly reduced risk of deep hooking and subsequent mortality has been reported (Horodysky and Graves, 2005, Domeier et al., 2003, Prince et al., 2002).

In this study, seven fish were caught on a rig with a J-hook. Four of these died boat-side and were not released (57%). The cause of mortality was linked to either the deep-hooking and/or barotrauma in three cases (reported above) and the other was related solely to a deep hooking injury. The remaining two were satellite tagged and released with one fish identified as a mortality soon after release, this fish was deep hooked but had good physiological responses including body colour, general activity and eye response. It died, however, shortly after release. The remaining fish caught with a J-hook was identified as surviving.

Nine fish were caught using a circle hook. Three died boat-side and were not released (33%). The cause of mortality was linked to gill-arch hooking in one case and barotrauma in the other two cases. The remaining six fish were satellite tagged and released, with all but one identified as surviving. While the sample sizes are low, deep-hooking injury occurred in a greater percentage of fish when J-hooks were used and overall, hook damage was identified as a significant predictor of mortality. This concurs with the interviews with recreational fishers who had caught Swordfish from 2014-2016 with no deep-hooking reported by recreational fishers when using circle hooks, while 8% of fish caught with a J-hook configuration reported as deep-hooked. Fish caught using J-hooks were also reported to have a higher rate of hooking in the internal gill area (21%) compared to 14% for fish caught with circle hooks. Overall, 54% of Swordfish reported were hooked in the corner of the mouth, an area that is most likely to cause minimal damage. This is a relatively low percentage of mouth hooking compared to say southern bluefin tuna (94%) which are caught while trolling lures at a relatively fast speed (Tracey et al., 2016). Deep hooking rates vary among 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, and hook type. Passive fishing methods, such as drifting baits, which is the primary method used when deep dropping for Swordfish, often allow the fish to consume the bait more deeply prior to hook set, increasing the chances of deep hooking (Alós, 2009, Lennox et al., 2015, Grixti et al., 2007). Deep hooking rates have also been reported as relatively high for marlin (Graves and Horodysky, 2008, Horodysky and Graves, 2005) where baits are trolled slowly and in some cases the drag on the reel is released or the boat is stopped when a fish strikes in order to minimise the bait moving through the water to mimic an injured prey item.

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, external body injuries from foul hooking occurred in several cases but produced very little bleeding. Swordfish naturally endure external injuries, most commonly from cookie cutter sharks, with some fish observed to have many wounds on their body in various states of healing. One fish also had a significant predation injury near its tail from a larger shark, however this wound was in an advanced state of healing and did not affect the fish’s ability to prey on a bait.

Internal bleeding, however, did appear to be a significant factor indicating a high probability of mortality as it was correlated with all three fish that were identified as having a deep-hooking injury.

Horizontal movement

While Swordfish in the Pacific are currently managed at a broad spatial scale, with the fish adjacent to Australia managed under the auspices of the Western and Central Pacific Fisheries Commission as part of the ‘southwest’ Pacific stock (Davies et al., 2013) there is significant uncertainty as to the true stock structure of Swordfish in the region, with multiple stock structure definitions proposed based on molecular techniques (for review see Lu et al. (2016)). Lu et al. (2016) identified no evidence for panmixia for Pacific Swordfish using high resolution single nucleotide polymorphism (SNP) data and indicated that samples from temperate waters differed from most tropical samples (>24°C), and no difference detected among temperate samples. The PSAT data presented here contradicts this finding with most fish tagged migrating from temperate waters into tropical waters greater than 24°C, suggesting significant propensity for latitudinal mixing in the region of the Tasman/Coral Seas. The furthest north a fish was observed to migrate was to 11°S, approximately 3,800 km from the point where the fish was captured, into water temperatures approaching 28°C. This fish, however, returned to the continental shelf break of Australia at approximately 30°S, a total estimated journey of approximately 7,600 km in 196 days. Furthermore, there was little evidence of longitudinal migration throughout the Pacific with all fish remaining in the Tasman/Coral Sea basin for the duration the tags were attached (maximum 250 days). The fish mentioned above and one other were the only two that moved further east than 165°E, with the latter last detected at approximately 173°E. Genetic connectivity in the temperate Pacific, however, could possibly be facilitated by the limited longitudinal movements observed as only a small amount of gene flow is required to indicate a lack of differentiation between conspecific stocks (Lowe and Allendorf, 2010). Alternatively, larval dispersal is possibly a factor linking populations in the Pacific (Cowen and Sponaugle, 2009). Little is known of the pelagic larval duration of Swordfish but the spawning season is thought to be protracted and the region where spawning occurs is likely broad (Young et al., 2003).

The tag data presented here concurs with the theory that there is little migration of Swordfish out of the Tasman/Coral Sea region suggested by a previous study in which PSATs were deployed on Swordfish in the region (Evans et al., 2014). Evans et al. (2014) deployed 29 PSATs on Swordfish caught by the Australian commercial fleet adjacent to the southeast coast of Queensland, where the majority of commercial fishing occurs for Swordfish on the east coast of Australia. They reported all fish tagged within the Australian EEZ remained within the Coral/Tasman Sea for the duration the tags were attached (maximum 362 days), with only one individual observed to move east of 170°E. They did, however, report relatively limited latitudinal movement, with the majority of individuals estimated to move <10°, with only one fish reported migrating below 40°S.

The development of the recreational fishery in southeast Australia has provided an opportunity to further our knowledge of the movement and habitat preferences of the species in the region. In contrast to the commercial fishery that targets Swordfish in tropical and warm temperate clines between 15 and 35°S, the recreational fishery has developed in the cooler temperate waters from 35 to 43°S. Evans et al. (2014) postulate that the fish caught and tagged in warmer waters may not need to migrate great latitudinal distances as the warm water in the region the fish remained was suitable for spawning, which has been reported to occur in waters warmer than 24°C (Young et al., 2003) and the fact that the Tasman Sea contains the largest non-coastal chlorophyll-a concentration in the South Pacific Ocean (Tilburg et al., 2002) provides sufficient productivity for foraging, particularly around seamounts where Swordfish are known to aggregate for foraging in the region (Campbell and Hobday, 2003). In contrast, 71% of fish released in the temperate southeast of Australia that survived had migrations covering >10°, with most migrating over a distance greater than 20° and one greater than 30°. This infers that at least some Swordfish inhabiting the Tasman/Coral Sea undergo extended latitudinal migrations, with fish residing for periods of time in cooler clines, presumably to forage. These longer latitudinal migrations into cooler temperate waters have been reported for Swordfish from other regions around the world, including the northern Atlantic Ocean (Abascal et al., 2015), northwest Atlantic (Neilson et al., 2014, Neilson et al., 2009), northeast Pacific (Dewar et al., 2011) and northwest Pacific (Takahashi et al., 2003, Dewar et al., 2011). A broader review of a range of large pelagic species in the Pacific Ocean also described a general pattern in latitudinal movement of large marine predators (Block et al., 2011).

Swordfish were caught by the recreational fishery in southeast Australia from the months February to July, with peak catches in March and April. While the fishery is somewhat dependent on the seasonal availability of fish, it is likely that the niche nature of the fishery with a limited number of participants dictates the ‘fishing season’ to some degree. If there are periods of poor catches, fishers will reduce effort or redirect their efforts to other species, not necessarily reflecting whether the species is still available in the region. Based on PSAT data Swordfish were estimated to be in latitudes south of 40° from late February until mid-November, with peak cold area-restricted (CAR) behaviour occurring from March to September. The vast majority of CAR behaviour, where SST was <24°C, and a state-space model categorised the behaviour as area-restricted, occurred below 38°S. During this period however, several fish changed their behaviour to directed poleward transient behaviour. This occurred as early as May and as late as late October. All fish that engaged in this behaviour shifted back to an area-restricted behaviour state, in waters warmer than 24°C, referred to here as warm area-restricted (WAR) behaviour. WAR behaviour occurred as early as late May but peaked from late July through to December with evidence of persisting into January for the one individual that still retained a tag in this month.

In the southwest Pacific, Swordfish larvae are found primarily near northeast Australia from October to December with larvae most frequently encountered at temperatures above 24°C. Reproductively active females are also found in waters warmer than 24°C from September to March, with the greatest activity between December and February (Young et al., 2003). It is likely that the majority of fish tagged in this study were reproductively mature based on size at maturity estimates for Swordfish in the Pacific Ocean (DeMartini et al., 2007, Young et al., 2003). It is also likely that the majority of fish tagged, particularly the larger fish, were all females as mature males tend to concentrate in warmer latitudes whereas females, which grow larger than males are more common at temperate latitudes (DeMartini et al., 2007, Palko et al., 1981).

Given that the cold area-restricted (CAR) behaviour by definition was occurring in waters cooler than 24°C, it is likely this behaviour was related to foraging. The WAR behaviour however, is occurring in water warmer than 24°C and it is possible this is related to spawning behaviour. The timing of the WAR behaviour begins earlier than the spawning season proposed by Young et. al. (2003) but persists through the period when spawning would be expected to occur. In other regions, Swordfish larvae are found year-round, for example, in the central south Pacific near 10°S (Nishikawa et al., 1985). Based on the data presented here it is possible that Swordfish may have a broader temporal spawning window that previously thought.

In each case where WAR behaviour was identified the fish remained in a restricted area for approximately one to three months before a directed migration poleward, with the exception of one individual that moved east. There was no one area where fish displayed WAR behaviour, rather the individuals were spread throughout the Coral and northern Tasman Seas, including the Pacific archipelago. This may indicate that there is not one specific spawning ground for the species in the region, rather spawning may occur throughout a broad range. For three of the five fish that migrated north the WAR behavioural state was displayed outside or on the edge of the Australian EEZ. For the other two fish, this behaviour occurred within the EEZ. Furthermore, the fish that migrated equatorward earlier in the year tended to migrate further north than fish that migrated later in the year. This may be due to earlier migrating fish leaving in winter when water temperature in the southern region is lower, therefore having to migrate further north to find water temperatures preferred for spawning. On the other hand, fish leaving in spring did not need to travel as far north to find suitable water temperature before entering a WAR behavioural state. There was evidence of all fish but one (that went east) initiating a poleward migration after WAR behaviour, however, in most cases the tag detached before it could be determined how far south the fish was likely to travel. Although, in three of four cases where the return migration was observed the fish migrated southwest from outside Australia's EEZ back towards the coast of Australia. In one case the fish was observed to return to within 100 km of the release location following a journey of approximately 5,400 km after leaving in a northeasterly direction to the Lord Howe plateau, before returning to the Australian shelf break which it followed down the coast from approximately the New South Wales – Queensland border to Tasmania. Philopatry of large Swordfish has also been described from a PSAT study in the western North Atlantic, with fish undertaking seasonal migrations across a similar latitudinal gradient to this study from cooler waters north of 40° in Canadian waters to tropical latitudes adjacent to Florida and the Gulf of Mexico (Neilson et al., 2009). Neilson et al., (2009) also report strong fidelity with several fish homing to within close vicinity of their capture location on the Grand Banks. A study conducted in the same region using conventional tags also concluded that Swordfish return annually to the same general location for feeding (Beckett, 1972).

An objective of this study was to assess the movement of Swordfish caught in southeast Australia to determine the potential for localised depletion. The display of philopatry revealed above suggests that some fish may have a habitat preference for the cooler waters in the region where the recreational fishery has been focused to date and demonstrate seasonal resident behaviour, of which for periods of time the fish are inhabiting bathymetric features of the continental shelf break where they are targeted by recreational fishers using deep-dropping methods.

Sequential spatial depletion of Swordfish by the commercial fleet has been identified off the central east coast of Australia, with the fleet moving further offshore to maintain catch rates (Campbell and Hobday, 2003). The localised depletion was most evident in the inshore regions and around seamounts with a strong inverse relationship between catch rates, total annual effort in an area and the number of years any area has been fished (Campbell and Hobday, 2003). In the early period of the fishery there was a large difference in catch rates on and off seamounts, suggesting a preference for Swordfish to be more abundant around seamounts (Campbell and Hobday, 2003). This differentiation in catch rates however, only lasted for the first two years of the fishery. This indicates that unexploited Swordfish are likely to reside around features that attract productivity such as seamounts and bathymetric features on the continental shelf break. Furthermore, it indicates that there is little replenishment of stocks around these features over time if fishing effort persists. Localised depletion of Swordfish has been identified as a concern in the southwest Pacific in general (Davies et al., 2006).

The number of fish extracted by the recreational sector in southeast Australia is much smaller than the volume extracted by the commercial sector on the mid-east coast of Australia. However, the recreational fishery is occurring in an area that could be considered the southern range edge for continental Australia and, as such, it is likely that the abundance of fish is going to be much less than the main population centre further north. The recreational fishery is also reliant on targeting fish directly on the bathymetric features of the continental shelf of Australia where the fish appear to be residing at times, whereas the commercial fishery sets longlines at night and catch fish not only near seamounts but also on the edges of thermal fronts often beyond the reach of recreational vessels. Hence, they are able to diversify their fishing region.

Therefore, while the number of fish currently being caught by the recreational fishery is low, and unlikely to have a significant impact on the overall stock of Swordfish, there is evidence of philopatry and resident behaviour in the region where the fishery is occurring. So, care should be taken to avoid serial depletion as the recreational fishery is limited in its ability to relocate their activities further offshore and fishing opportunity may become limited over time. This will be of greater concern if the number of fishers successfully engaging in the fishery was to expand dramatically. To date, however, in Tasmania at least, the growth of the fishery has been limited and only relatively few fishers regularly fish for the species.

Vertical movement

The consistent crepuscular diel vertical behaviour of Swordfish has been thoroughly reported, with the predominant behaviour involving fish moving to deeper water at dawn and then moving to shallower water at dusk (Carey and Robinson, 1981, Abascal et al., 2015, Abascal et al., 2010, Evans et al., 2014, Kerstetter and Fenton, 2012). The species spend the majority of time within a narrow range of low light level (Abecassis et al., 2012). It is likely that Swordfish follow the vertical movements of mesopelagic organism in the deep scattering layer during the day at depths of approximately 400 – 700 m and at night stay in the mixed layer, which would maximise the opportunity to feed on their major prey species over a 24-hour period (Dewar et al., 2011). This trend was consistent with the vertical behaviour observed for the Swordfish tagged in this study. Moon phase has been shown to influence the depth of Swordfish at night, this theory being first proposed by Carey and Robinson (1981), and has been identified as a factor in several studies (Abascal et al., 2010, Dewar et al., 2011, Loefer et al., 2007). While the GAMM used in this study did not identify a significant effect of lunar phase with depth at night, the individual contribution of lunar phase did indicate a relationship where depth at night increased closer to the full moon. This was a similar finding to that of Abascal et al., (2010) and is presumed to be a response to the vertical distribution of the feed in the mixed layer. It has also been proposed that when in surface waters at night Swordfish can also recover from thermal and oxygen debt acquired from spending time at depths with low oxygen and cold temperatures during the day (Carey and Robinson, 1981) and possibly facilitate an increased metabolic rate to aid digestion (Takahashi et al., 2003). The maximum depth of 1,100 m observed in this study was similar to that reported in other studies, for example >1,100 m (Abascal et al., 2010).

Swordfish are known to tolerate a broad range of temperatures which are often experienced with rapid and dramatic temperature changes as the fish ascend and descend most commonly at dusk and dawn (Dewar et al., 2011, Abascal et al., 2015, Abascal et al., 2010, Evans et al., 2014, Neilson et al., 2009, Abecassis et al., 2012). In this study, during the daytime, fish experienced minimum temperatures of 5.3°C at extreme depths around 1000 m. At 600 m, which was a more common depth for fish to inhabit during the day, temperatures ranged from 6 - 15°C (9°C Δ_t). At the surface Swordfish tagged in this study experienced temperatures ranging from 12 - 28°C (16°C Δ_t). The largest temperature range experienced for a fish on a dusk ascent to depth was 8 - 26°C (18°C Δ_t). These extreme temperatures and Δ_t are consistent with other studies on Swordfish from around the world (Abecassis et al., 2012, Dewar et al., 2011, Takahashi et al., 2003). Swordfish are one of several large pelagic predators that have evolved the physiological capabilities necessary to function at extreme conditions of pressure and temperature.

Swordfish have a suite of adaptations that augment the function of their visual, locomotor, circulatory and neural systems in the cold dark, and often oxygen limited waters at depth, providing them with a predatory advantage (Carey, 1982, Block, 1987, Fritsches et al., 2005, Kröger et al., 2009, Galli et al., 2009). Their large eyes (Kröger et al., 2009) and the specially adapted heating organ in the muscle next to their brain which can raise temperatures in the surrounding tissue to 10-15°C above water temperature (Fritsches et al., 2005, Block, 1987) are likely to enhance their predatory success in deeper cooler waters. Swordfish are also thought to be well adapted to lower oxygen concentrations at depth, with a larger gill surface area than striped marlin of equivalent size and unique branching of the distal gill filaments that increase the number of secondary lamellae (Wegner et al., 2010). It has also been proposed that the large mass of white muscle tissue in Swordfish might allow them to tolerate hypoxic conditions by accumulating an oxygen debt that can be compensated for when the fish spend time in warmer surface waters (Carey and Robinson, 1981).

While these adaptations have been well described in the context of physiological limitations in regard to diving and feeding behaviour in the studies referenced above it is interesting to consider oxygen and temperature constraints in regard to the behaviour of Swordfish during the capture event when hooked at depth, as occurs with the deep-dropping recreational fishing method. The accelerometer data presented in this study indicates that in all cases, the fish ascend to surface or near-surface depths of their own accord within minutes of being hooked. The Swordfish then constrain their maximum depth during the 'fight' to depths in the warmer and oxygen rich waters above the thermocline. One exception was a single fish that performed a single dive to almost 400 m after ascending to the surface before again moving above the thermocline. It is likely that Swordfish ascend above the thermocline to warm their muscle and re-oxygenate to maximise their physiological ability to 'escape'. Once the fish has spent time at or near the surface the angling durations are often protracted. It is possible that fishers can use this information to reduce angling durations. When angling large marlin, there is a thought that getting the fish boat-side early in the fight can provide an opportunity to apply a tag using a tag pole or gaff the fish. If this opportunity is missed the fish tend to be harder to get back to the boat. This same philosophy is likely to apply for Swordfish. Swordfish were observed in several cases to be sluggish or jump from the water and then spend a short period of time on the surface before descending to approximately 50 -150 m. An experienced crew could, in theory, apply a similar technique to those that target surface swimming marlin, by backing the boat down quickly on the fish to get an early opportunity to tag or gaff the fish while it is possibly still acclimating and re-oxygenating. It is likely however, that the fish will still be very 'green' and care should be taken as large Swordfish are known to be pugnacious and have damaged boats and injured fishers in the past (Smith, 1956). This opportunity did not present itself in all cases but could possibly significantly reduce angling duration.

Conclusions

In summary, the recreational Swordfish fishery that has developed in southeast Australia is likely to further expand as significant interest in the fishery exists although it is possible that the fishery will remain relatively niche compared to other game fish targets in the area, such as tuna. Swordfish have been identified as a relatively poor candidate as a catch and release only species. Some fish are suitable for release; however, fishers should easily be able to identify symptoms that will significantly reduce the probability of post-release survival, including deep-hooking and barotrauma. Fishers should be prepared to dispatch fish humanely and prepare their catch appropriately for consumption to minimise wastage, even if the intention of the fishing trip was to release fish.

The Swordfish caught off southeast Australia are part of the broader population inhabiting the Tasman/Coral Sea region. The tagged fish spent time foraging in the cooler waters south of 38° during the austral summer, autumn and winter months. Most fish embarked on an equatorward migration, presumably to spawn. Several fish then made return migrations, but it was uncertain if the fish were intending to move back below 38° south as in most cases the tags detached during these southward migrations. In one case however, philopatry was observed with an individual returning to within 100 km of the capture and tagging location. The resident behaviour and observed philopatry to cooler waters suggest that Swordfish could be susceptible to localised depletion, but it is unknown whether this phenomenon will have a significant effect on the accessibility of the recreational fishing sector to the resource.

Recommendations

The results indicate that post-release mortality is relatively high for Swordfish caught by the recreational sector using the day-time deep-dropping method. This will need to be considered in regard to current management strategies using catch limits. The practice of catch and release of fish once a regulatory catch limits has been reached should be discouraged as there is a high likelihood that a proportion of fish caught won't survive. However, to date, it has been rare for a boat to catch multiple Swordfish on one day's fishing.

The development of a Code of Practice for the recreational capture and handling of Swordfish based on the results of the study, and others, would be beneficial to inform the recreational sector on best practice to minimise wastage, improve the probability of post-release survival, improve animal welfare and ensure good stewardship to increase social license from the general community.

Furthermore, the ongoing engagement with recreational fishers, primarily through social media, popular recreational fishing magazines, television and information session is likely to facilitate 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.

Specific recommendations arising from the research are as follows:

- The deployment of additional PSATs will improve the statistical robustness of the post-release survival estimates.
- Increasing the program duration of the tags to remain with the fish for up to one year may assist to further resolve the evidence of philopatry to southeast Australia for Swordfish.
- The promotion of using circle hooks instead of J-hooks if the intention is to release a Swordfish is warranted as these hooks were shown to cause less damage to fish.
- Consideration should be given to whether further research into the use of release mechanisms that could aid fish to overcome barotrauma effects at release.

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Appendix 1: Accelerometer results

Fish that were caught with an accelerometer attached to the terminal tackle that were dropped from the hook during the angling event

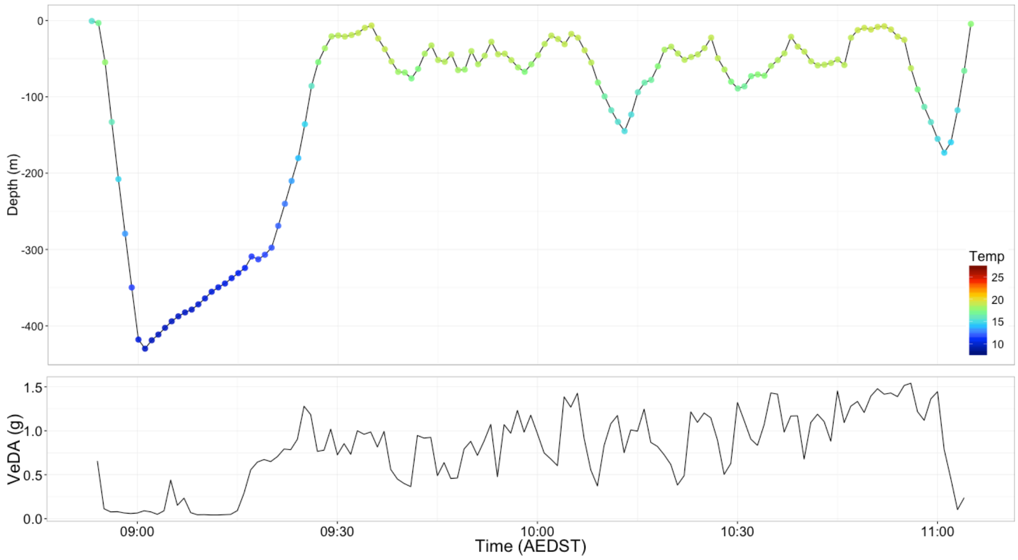

Figure 28. Depth and temperature profile (top figure) and vectorial sum of dynamic acceleration (VeDA) response (bottom figure) recorded on an accelerometer fitted to the terminal tackle during the deployment of bait, subsequent hooking and retrieval of a Swordfish that escaped the hook after 103 minutes. The fish was hooked on the 7th April 2016 adjacent to St. Helens. Each point on the top figure indicates a depth averaged one-minute time step and the colour of the point indicates the average recorded temperature throughout that minute as per the figure legend.

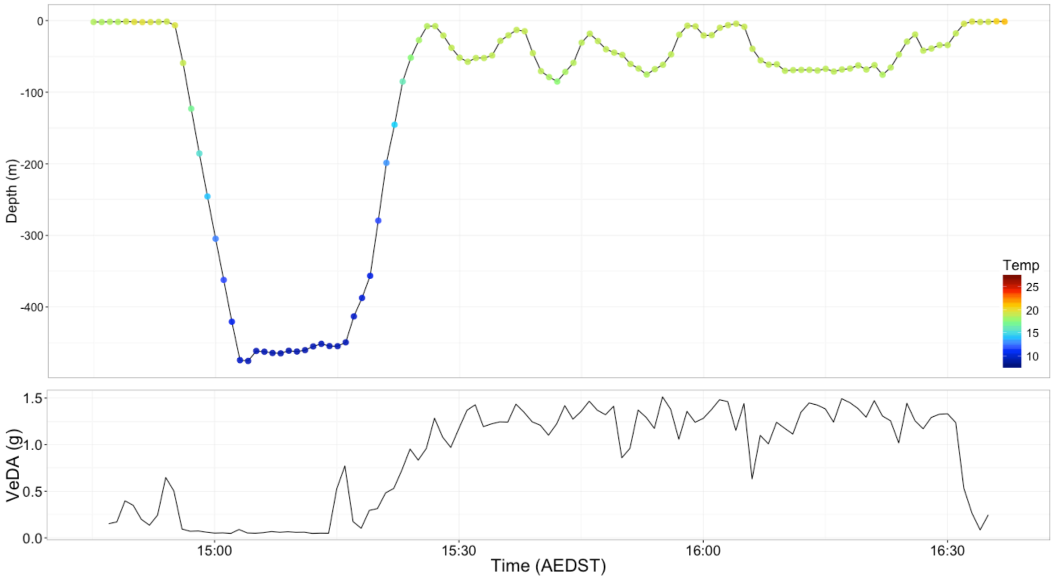

Figure 29. Depth and temperature profile (top figure) and vectorial sum of dynamic acceleration (VeDA) response (bottom figure) recorded on an accelerometer fitted to the terminal tackle during the deployment of bait, subsequent hooking and retrieval of a Swordfish that escaped the hook after 76 minutes. The fish was hooked on the 8th April 2016 adjacent to Bicheno. Each point on the top figure indicates a depth averaged one-minute time step and the colour of the point indicates the average recorded temperature throughout that minute as per the figure legend.

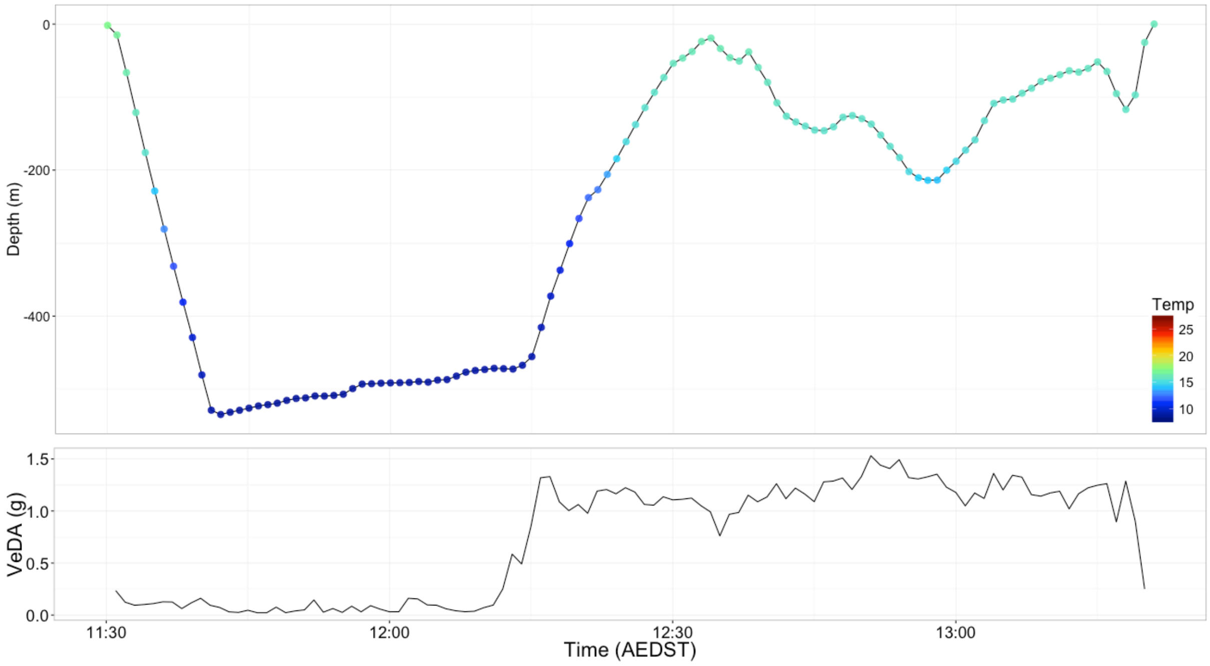

Figure 30. Depth and temperature profile (top figure) and vectorial sum of dynamic acceleration (VeDA) response (bottom figure) recorded on an accelerometer fitted to the terminal tackle during the deployment of bait, subsequent hooking and retrieval of a Swordfish that escaped the hook after 63 minutes. The fish was hooked on the 8th May 2016 adjacent to the Tasman Peninsula. Each point on the top figure indicates a depth averaged one-minute time step and the colour of the point indicates the average recorded temperature throughout that minute as per the figure legend.

Fish that were caught with an accelerometer attached to the terminal tackle that were assessed as moribund after landing

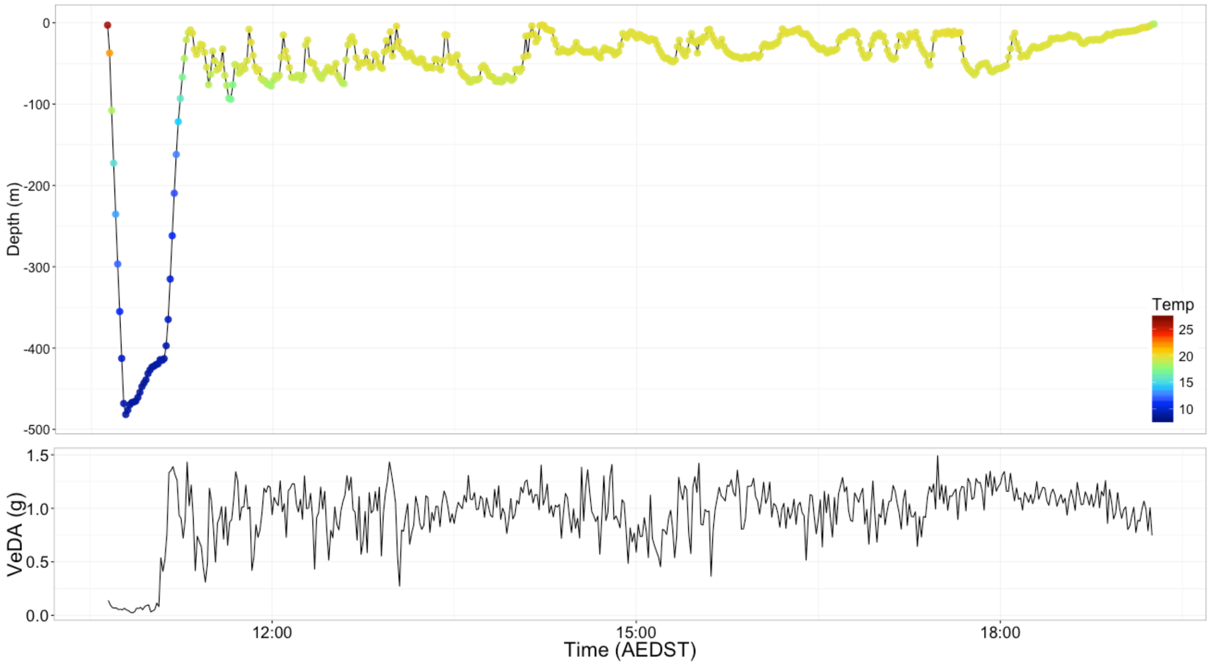

Figure 31. Depth and temperature profile (top figure) and vectorial sum of dynamic acceleration (VeDA) response (bottom figure) recorded on an accelerometer fitted to the terminal tackle during the deployment of bait, subsequent hooking and retrieval of Swordfish SC0005. Each point on the top figure indicates a depth averaged one-minute time step and the colour of the point indicates the average recorded temperature throughout that minute as per the figure legend. This fish was landed in a moribund state.

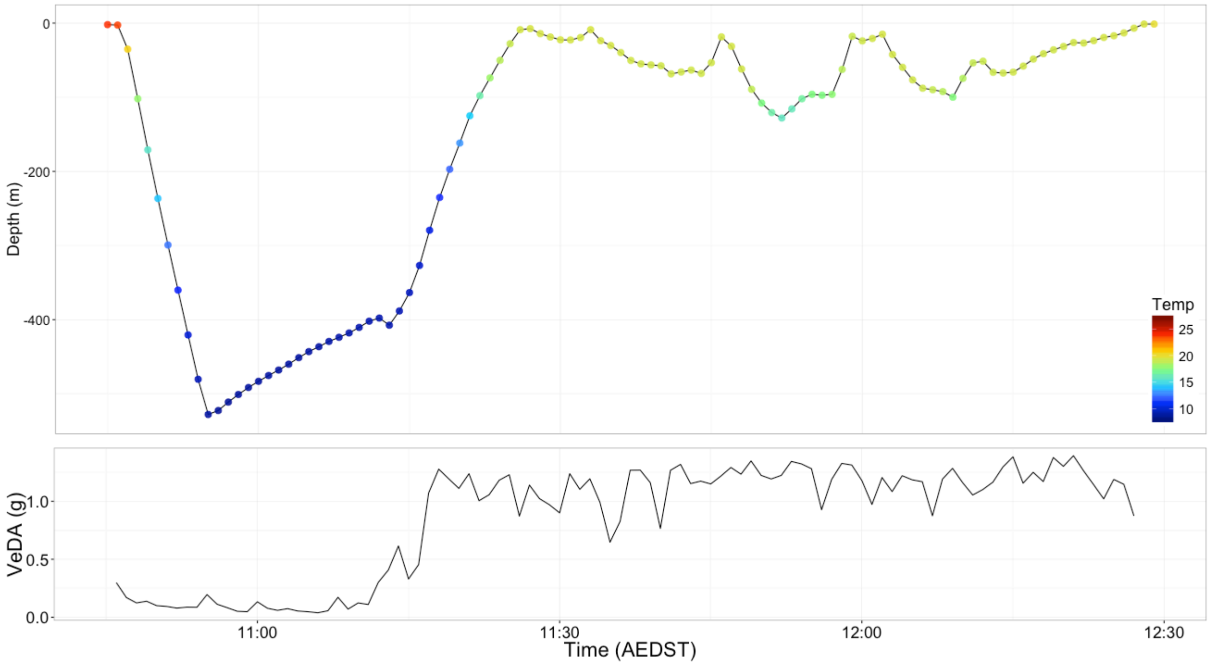

Figure 32. Depth and temperature profile (top figure) and vectorial sum of dynamic acceleration (VeDA) response (bottom figure) recorded on an accelerometer fitted to the terminal tackle during the deployment of bait, subsequent hooking and retrieval of Swordfish SC0006. Each point on the top figure indicates a depth averaged one-minute time step and the colour of the point indicates the average recorded temperature throughout that minute as per the figure legend. This fish was landed in a moribund state.

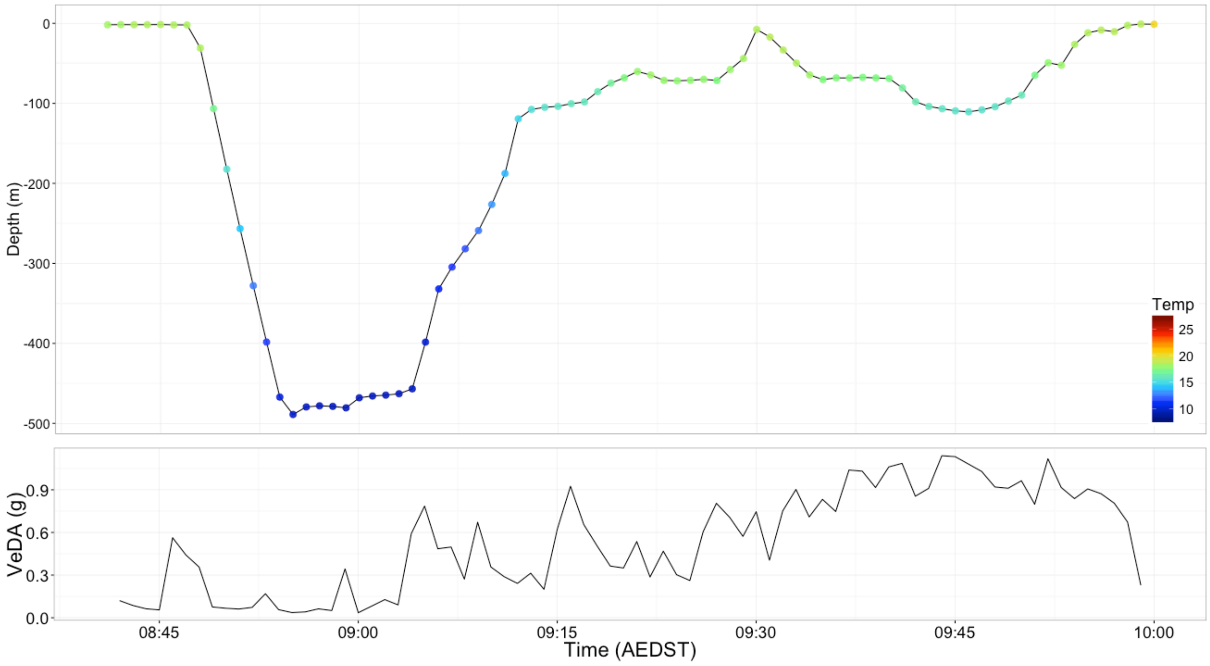

Figure 33. Depth and temperature profile (top figure) and vectorial sum of dynamic acceleration (VeDA) response (bottom figure) recorded on an accelerometer fitted to the terminal tackle during the deployment of bait, subsequent hooking and retrieval of Swordfish SC0009. Each point on the top figure indicates a depth averaged one-minute time step and the colour of the point indicates the average recorded temperature throughout that minute as per the figure legend. This fish was landed in a moribund state.

Fish that were caught with an accelerometer attached to the terminal tackle that were landed and subsequently released with a satellite tag and determine to have survived post-release

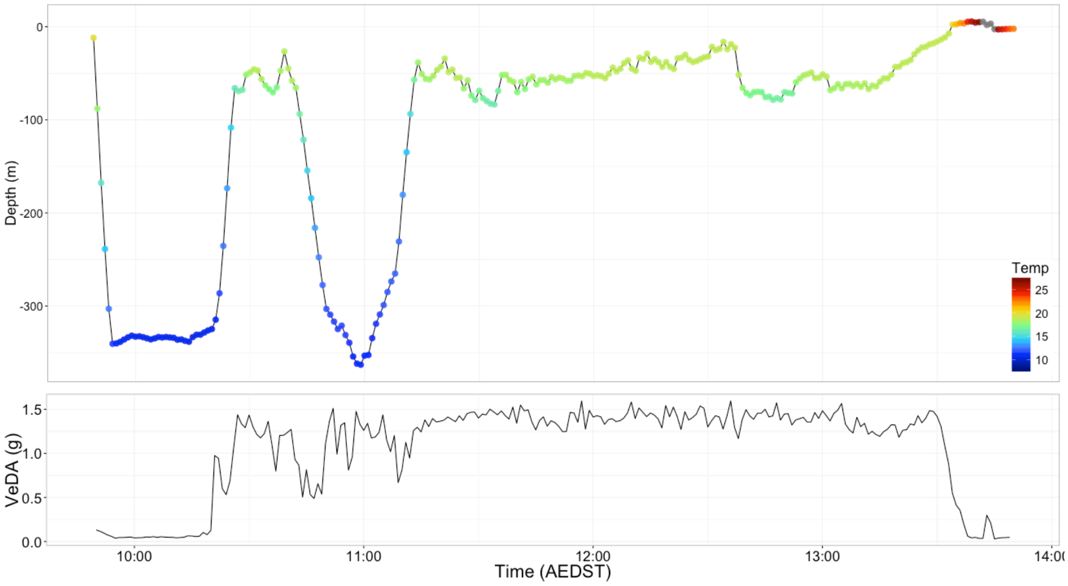

Figure 34. Depth and temperature profile (top figure) and vectorial sum of dynamic acceleration (VeDA) response (bottom figure) recorded on an accelerometer fitted to the terminal tackle during the deployment of bait, subsequent hooking and retrieval of Swordfish SC0007. Each point on the top figure indicates a depth averaged one-minute time step and the colour of the point indicates the average recorded temperature throughout that minute as per the figure legend. This fish was landed and released with a satellite tag. The tag indicated the fish survived post the catch and release process.

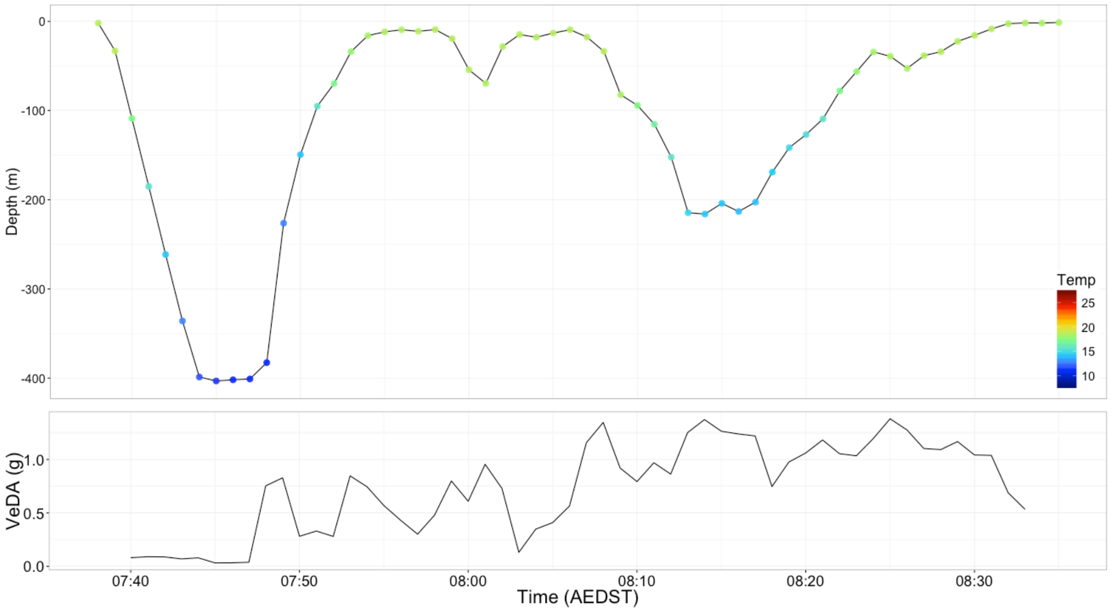

Figure 35. Depth and temperature profile (top figure) and vectorial sum of dynamic acceleration (VeDA) response (bottom figure) recorded on an accelerometer fitted to the terminal tackle during the deployment of bait, subsequent hooking and retrieval of Swordfish SC0008. Each point on the top figure indicates a depth averaged one-minute time step and the colour of the point indicates the average recorded temperature throughout that minute as per the figure legend. This fish was landed and released with a satellite tag. The tag indicated the fish survived post the catch and release process.

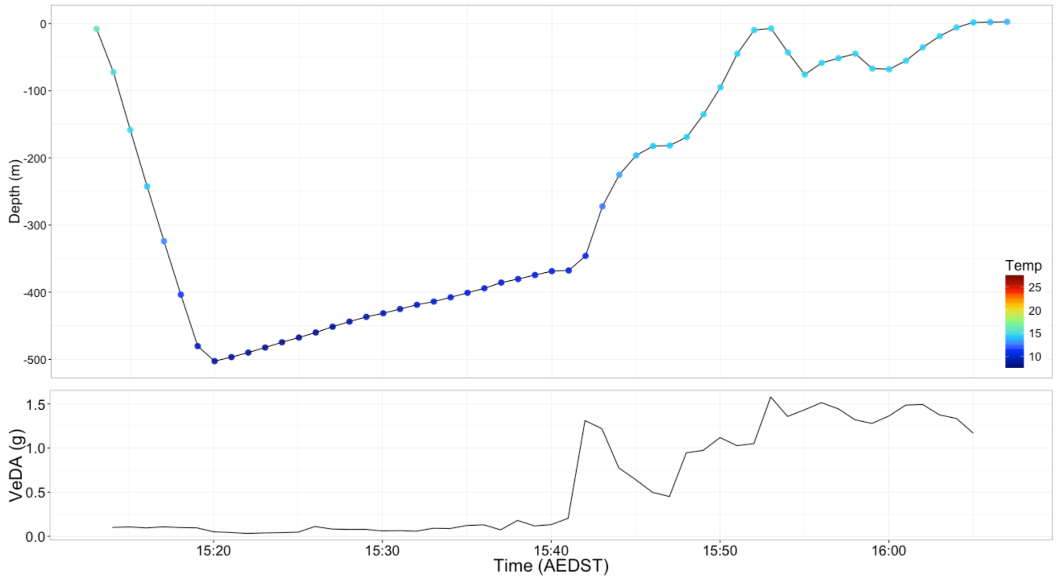

Figure 36. Depth and temperature profile (top figure) and vectorial sum of dynamic acceleration (VeDA) response (bottom figure) recorded on an accelerometer fitted to the terminal tackle during the deployment of bait, subsequent hooking and retrieval of Swordfish SC0013. Each point on the top figure indicates a depth averaged one-minute time step and the colour of the point indicates the average recorded temperature throughout that minute as per the figure legend. This fish was landed and released with a satellite tag. The tag indicated the fish survived post the catch and release process.

Fish that were caught with an accelerometer attached to the terminal tackle that were landed and subsequently released with a satellite tag and determine to have died post-release

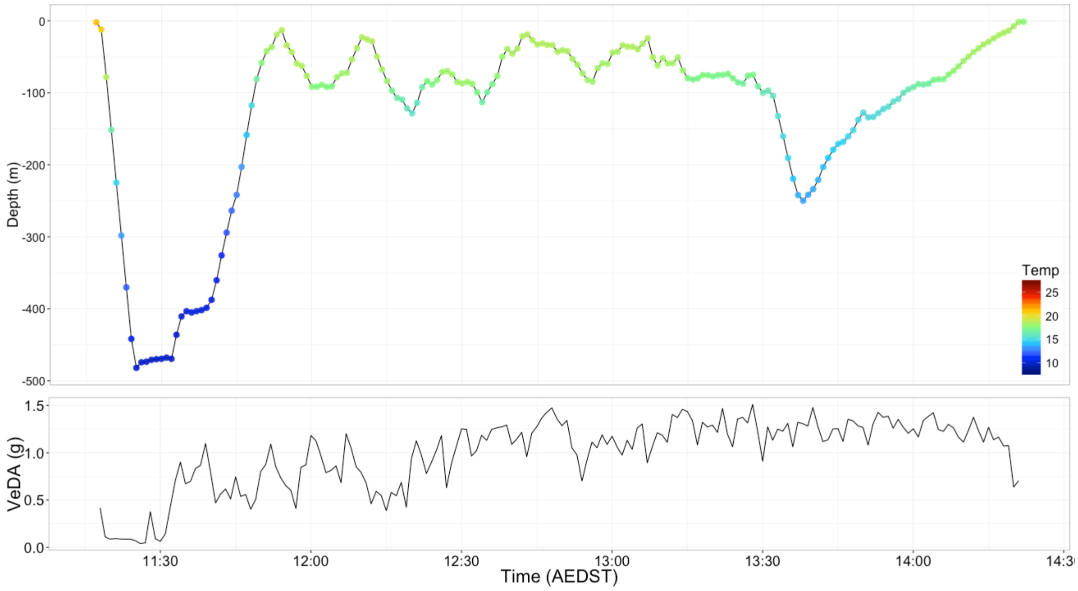

Figure 37. Depth and temperature profile (top figure) and vectorial sum of dynamic acceleration (VeDA) response (bottom figure) recorded on an accelerometer fitted to the terminal tackle during the deployment of bait, subsequent hooking and retrieval of Swordfish SC0010. Each point on the top figure indicates a depth averaged one-minute time step and the colour of the point indicates the average recorded temperature throughout that minute as per the figure legend. This fish was landed and released with a satellite tag. The tag indicated the fish survived post the catch and release process.

Appendix 2: PSAT results – vertical behaviour and most probable geo-location tracks

Fish that were caught and released with a PSAT attached that were determined to have not survived post-release

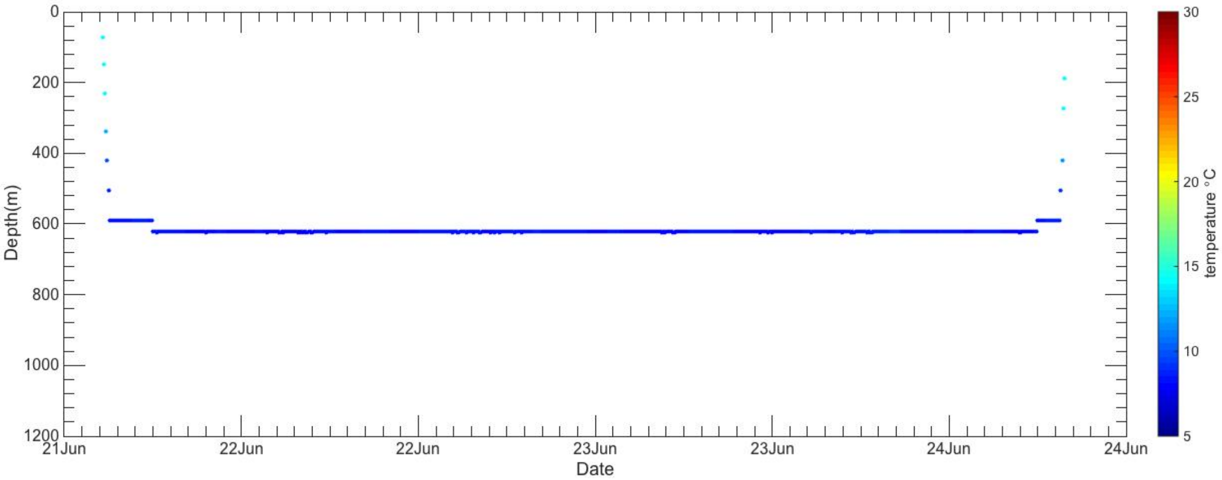

Figure 38. The depth/temperature time series of the satellite tag attached to fish SC0001, the tag stayed attached for three days. The colour of the points indicates the temperature reported by the tag as per the figure legend.

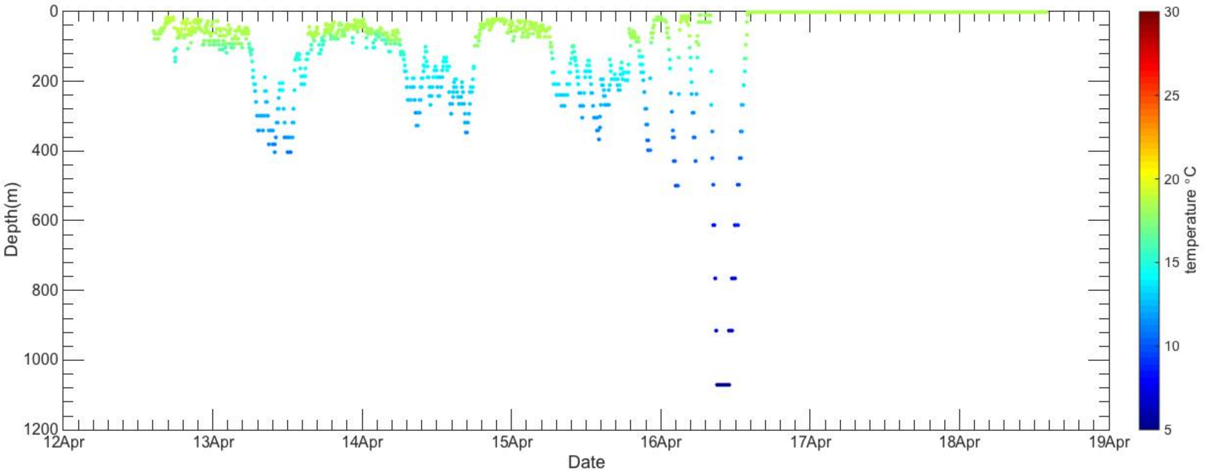

Figure 39. The depth/temperature time series of the satellite tag attached to fish SC0010, the fish was at liberty for 6 days. The colour of the points indicates the temperature reported by the tag as per the figure legend.

Fish that were caught and released with a PSAT attached that were determined to have survived post-release

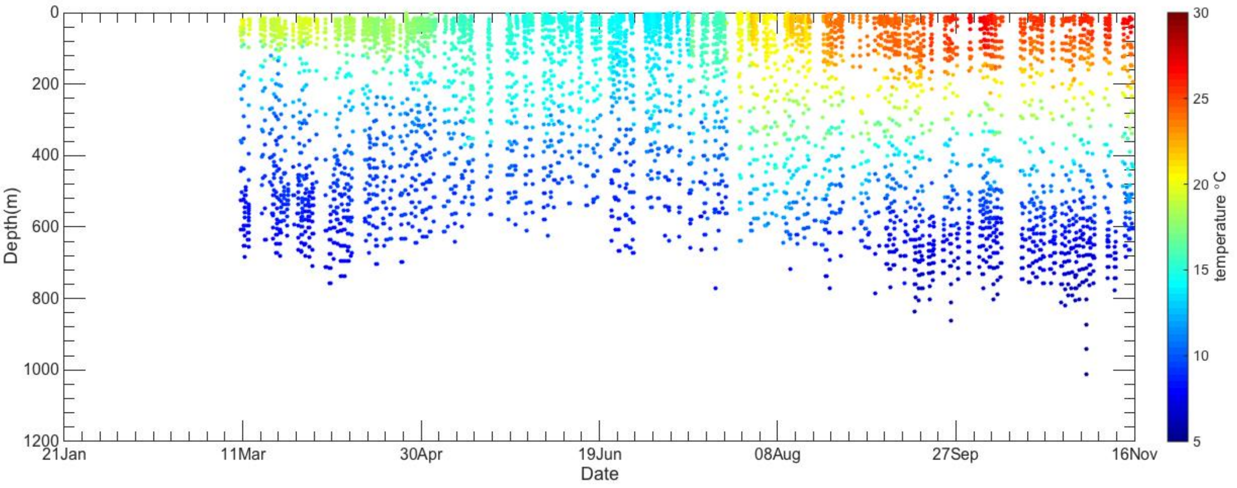

Figure 40. The depth/temperature time series of the satellite tag attached to fish SC0004, the fish was at liberty for 250 days. The colour of the points indicates the temperature reported by the tag as per the figure legend.

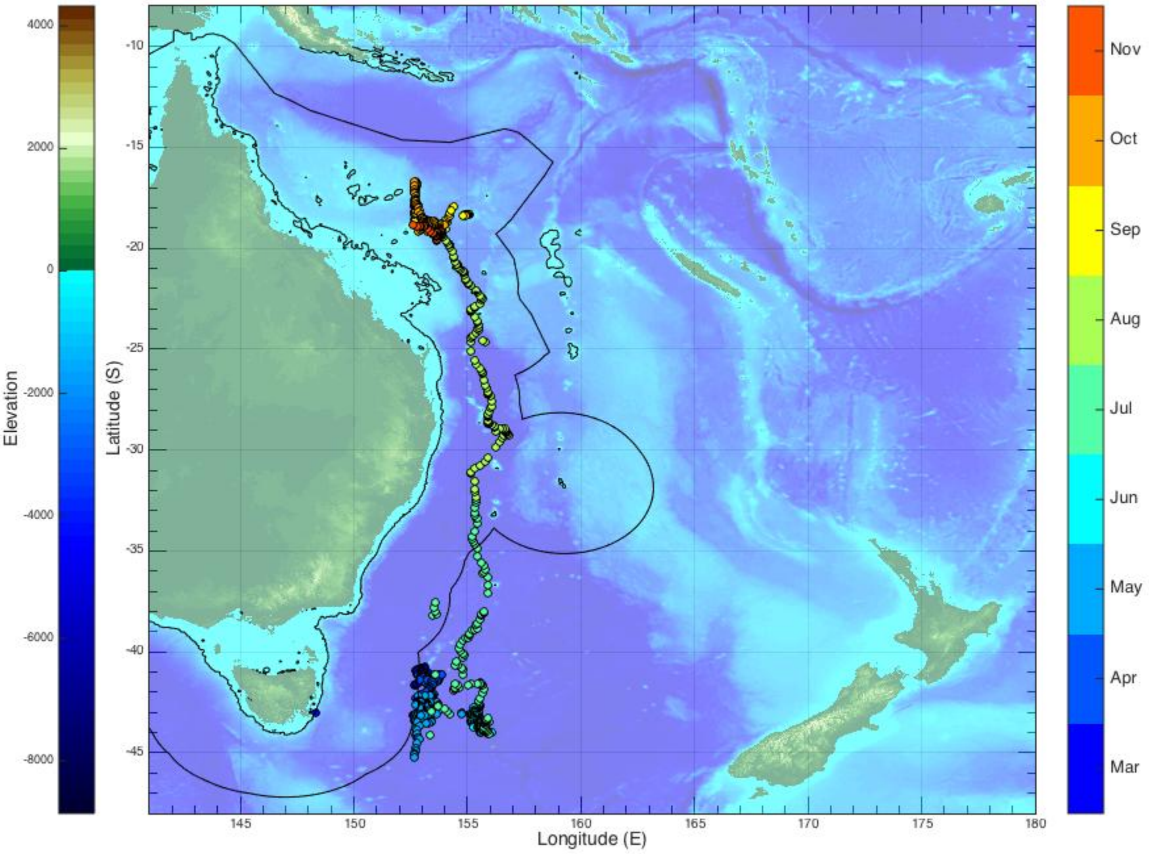

Figure 41. Most probable track of Swordfish SC0004 tagged adjacent to Tasmania. The fish was at liberty for 250 days. The colour of the points indicate the month as per the figure legend on the right-hand side of the figure.

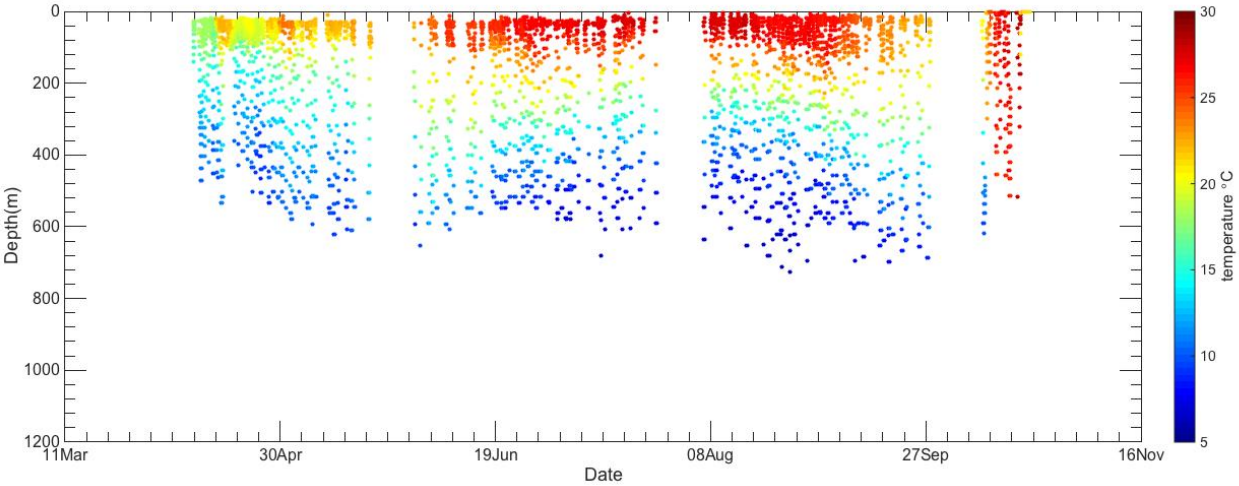

Figure 42. The depth/temperature time series of the satellite tag attached to fish SC0007, the fish was at liberty for 196 days. The colour of the points indicates the temperature reported by the tag as per the figure legend.

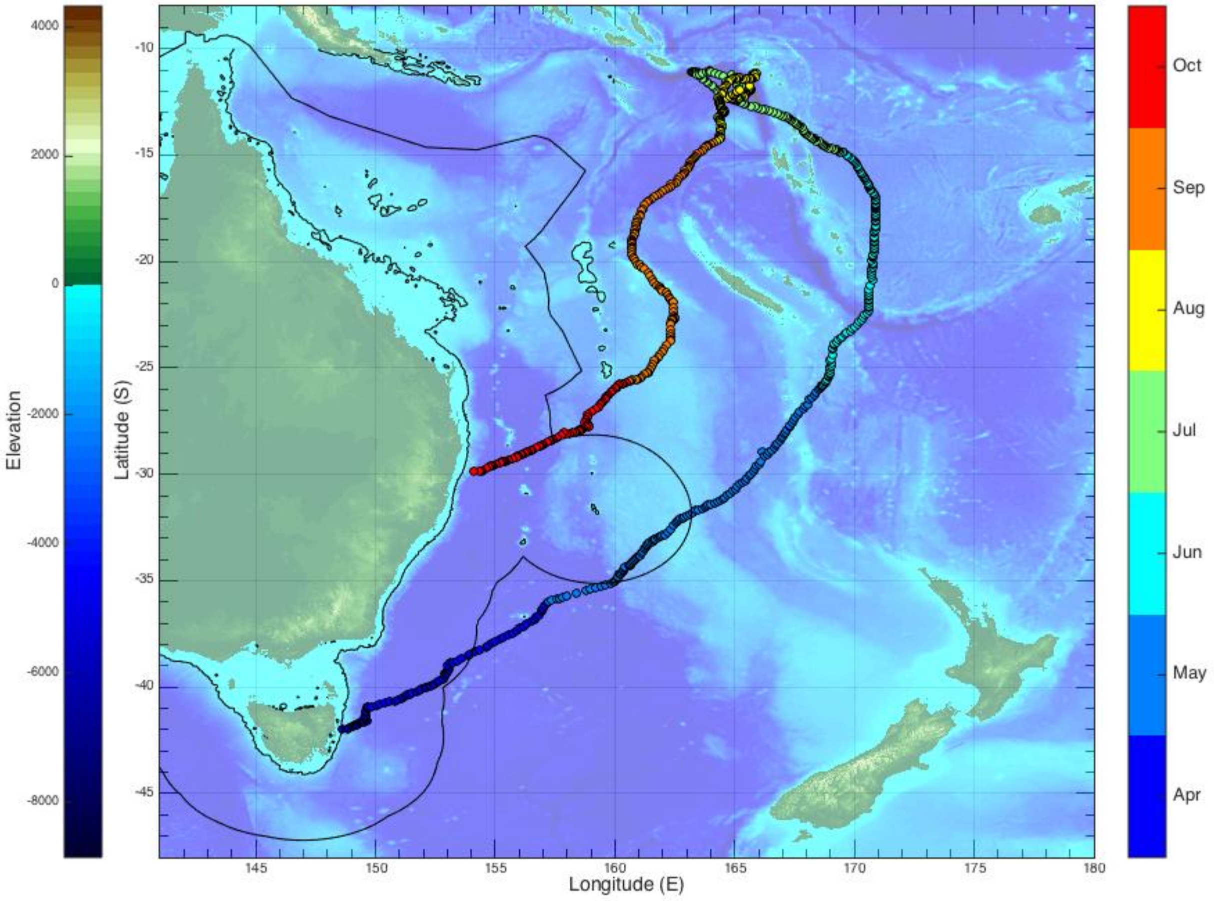

Figure 43. Most probable track of Swordfish SC0007 tagged adjacent to Tasmania. The fish was at liberty for 196 days. The colour of the points indicate the month as per the figure legend on the right-hand side of the figure.

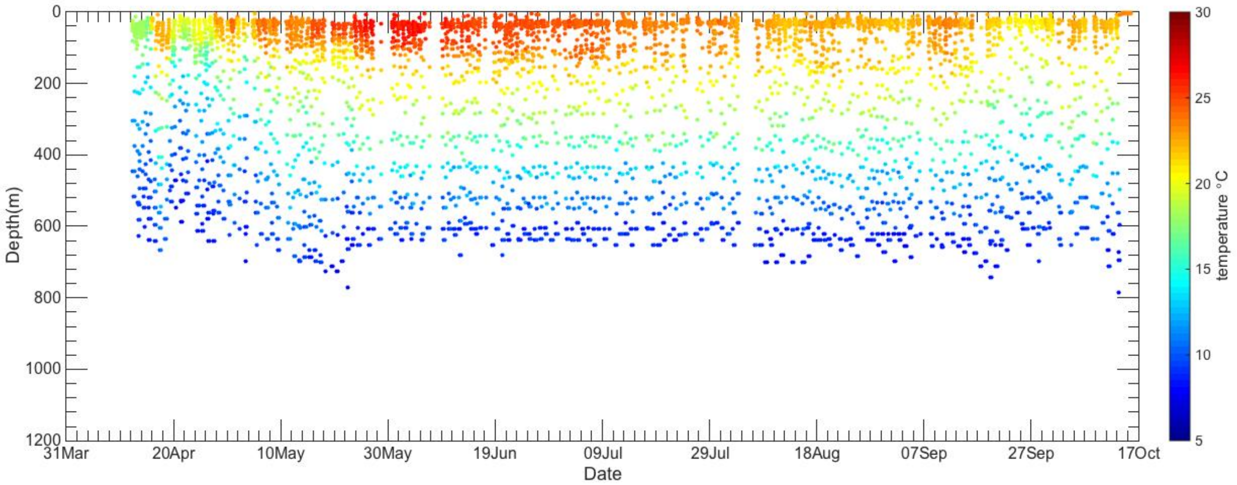

Figure 44. The depth/temperature time series of the satellite tag attached to fish SC0008, the fish was at liberty for 186 days. The colour of the points indicates the temperature reported by the tag as per the figure legend.

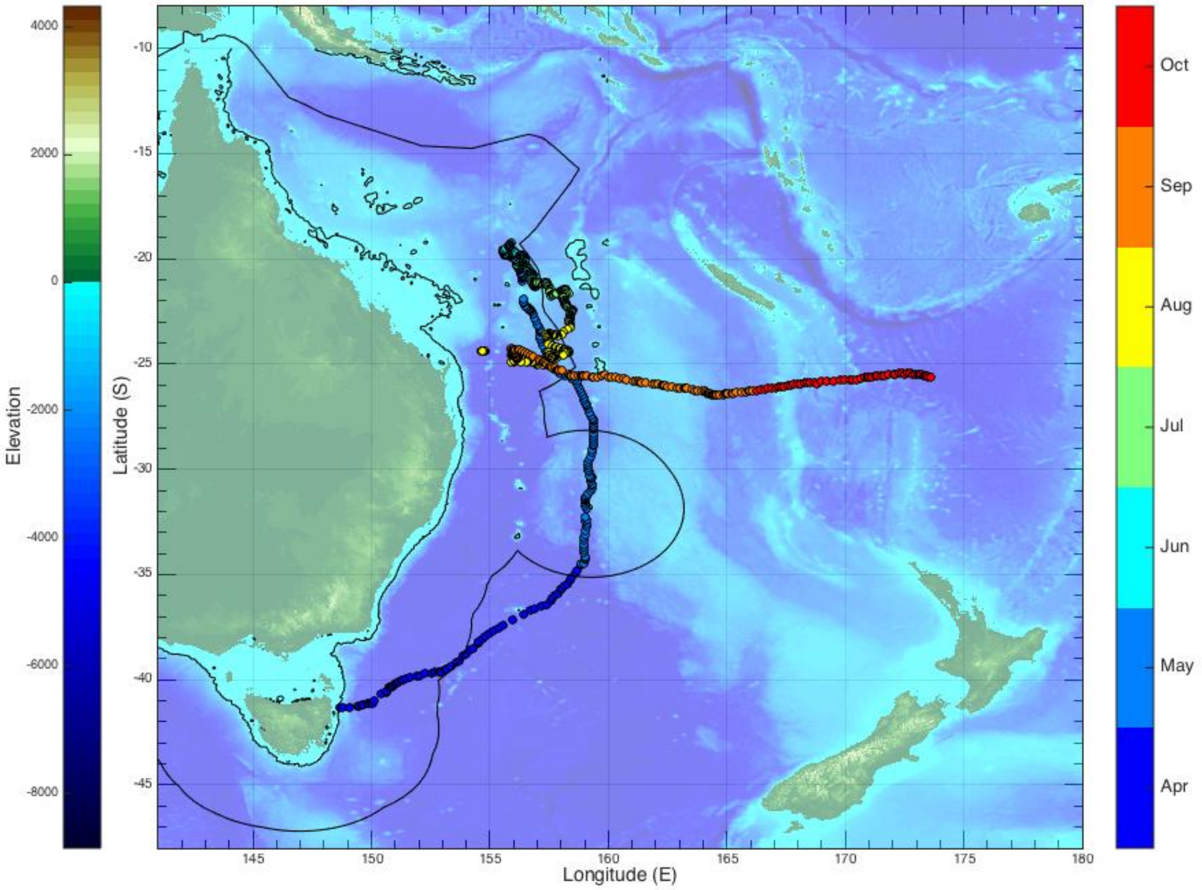

Figure 45. Most probable track of Swordfish SC0008 tagged adjacent to Tasmania. The fish was at liberty for 186 days. The colour of the points indicate the month as per the figure legend on the right-hand side of the figure.

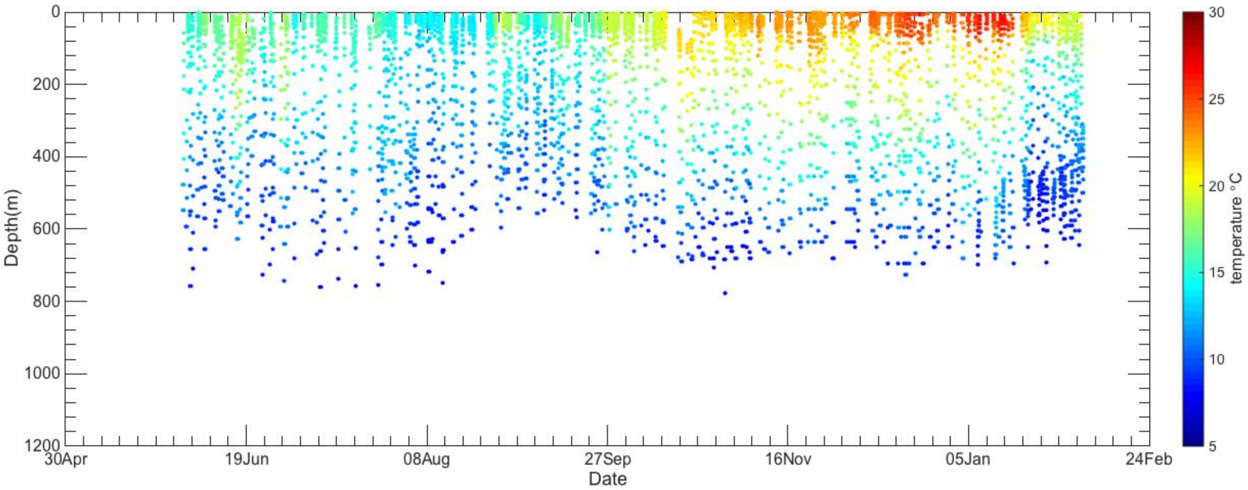

Figure 46. The depth/temperature time series of the satellite tag attached to fish SC0012, the fish was at liberty for 250 days. The colour of the points indicates the temperature reported by the tag as per the figure legend.

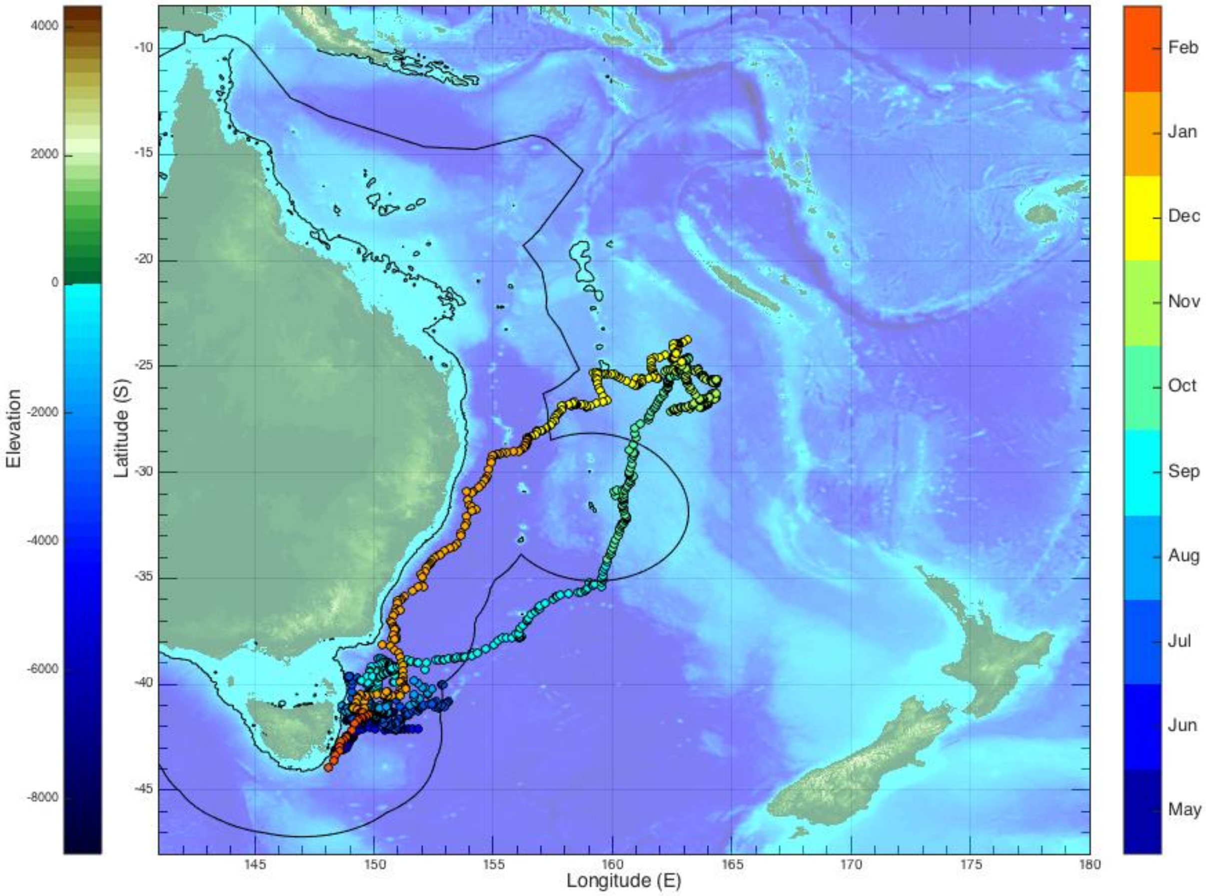

Figure 47. Most probable track of Swordfish SC0012 tagged adjacent to Tasmania. The fish was at liberty for 250 days. The colour of the points indicate the month as per the figure legend on the right-hand side of the figure.

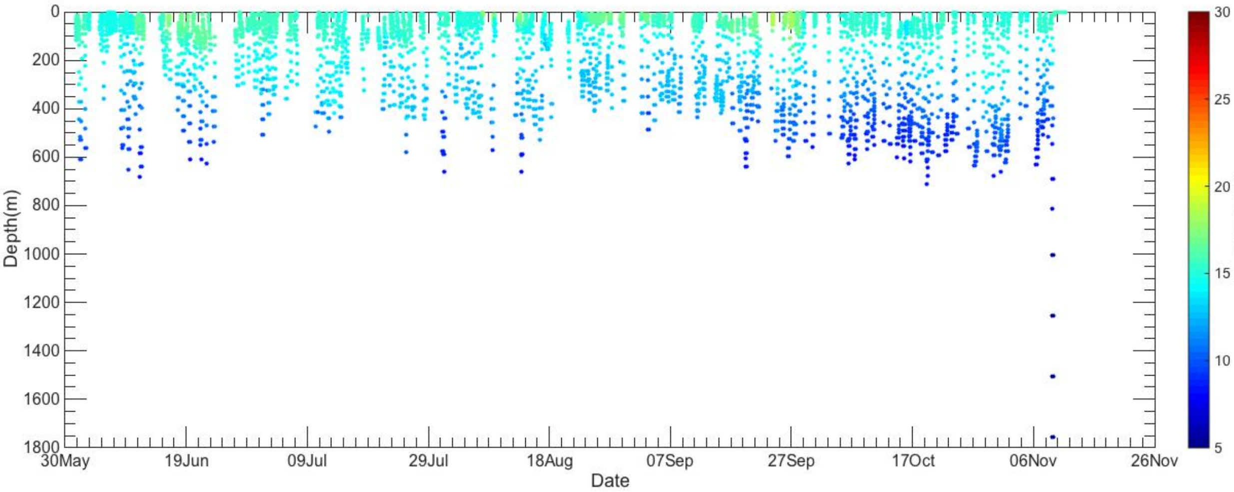

Figure 48. The depth/temperature time series of the satellite tag attached to fish SC0013, the fish was at liberty for 164 days. The colour of the points indicates the temperature reported by the tag as per the figure legend.

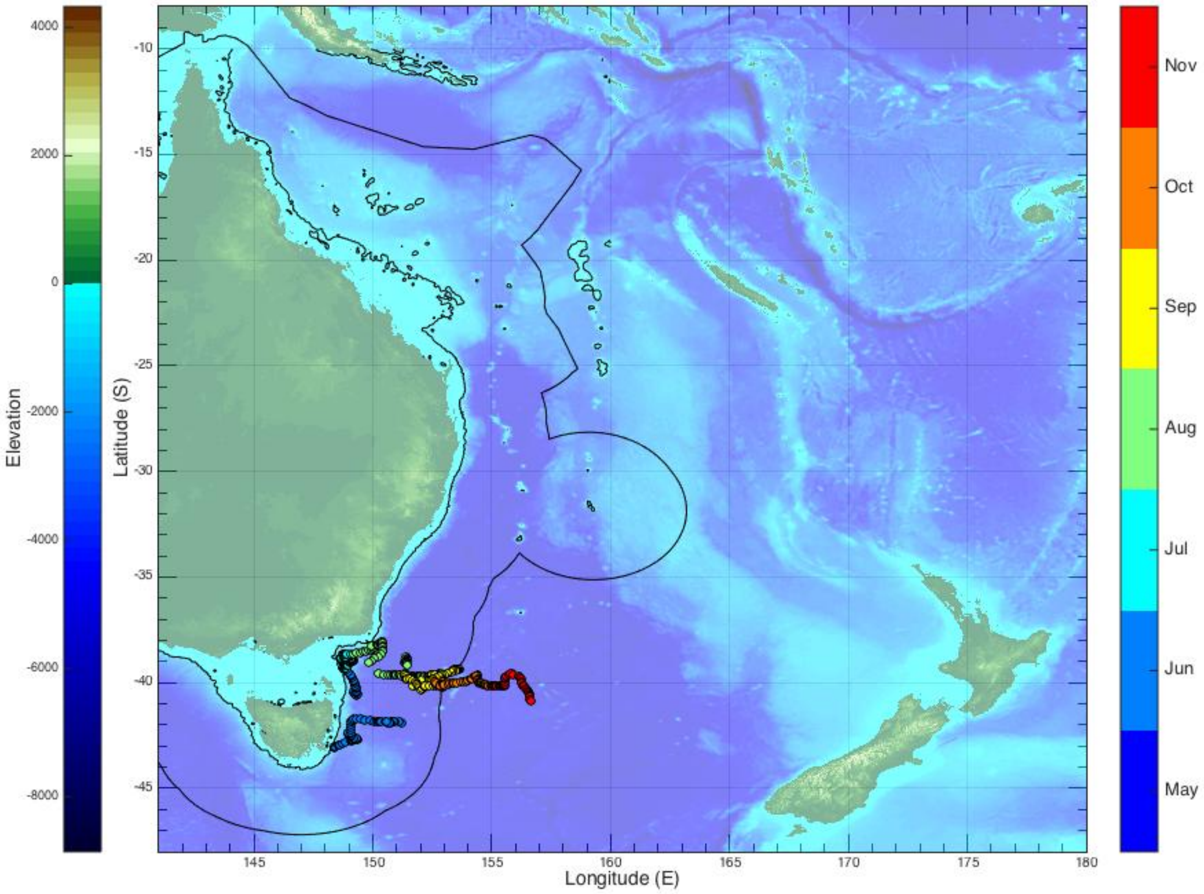

Figure 49. Most probable track of Swordfish SC0013 tagged adjacent to Tasmania. The fish was at liberty for 164 days. The colour of the points indicate the month as per the figure legend on the right-hand side of the figure.

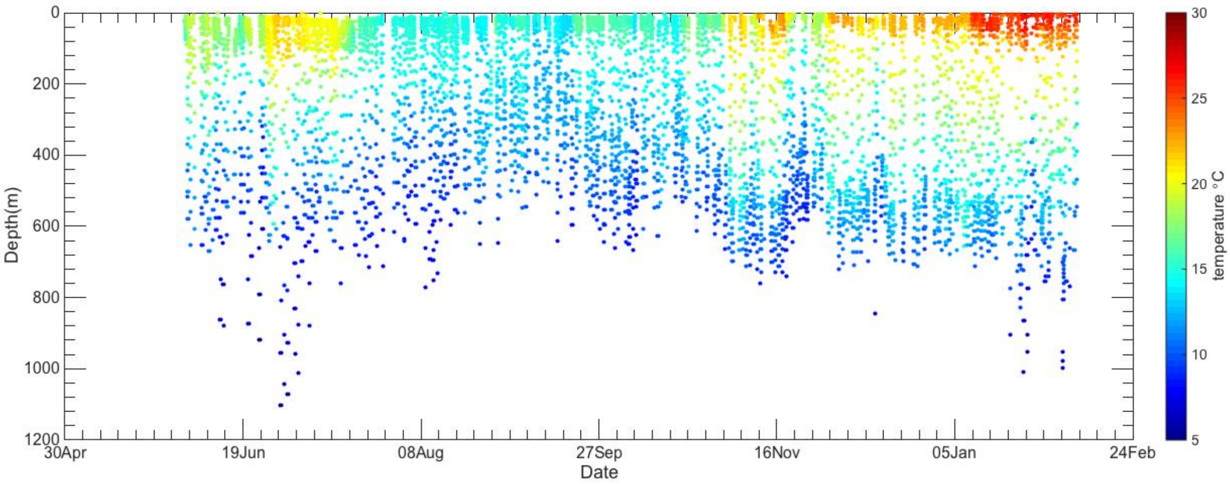

Figure 50. The depth/temperature time series of the satellite tag attached to fish SC0014, the fish was at liberty for 250 days. The colour of the points indicates the temperature reported by the tag as per the figure legend.

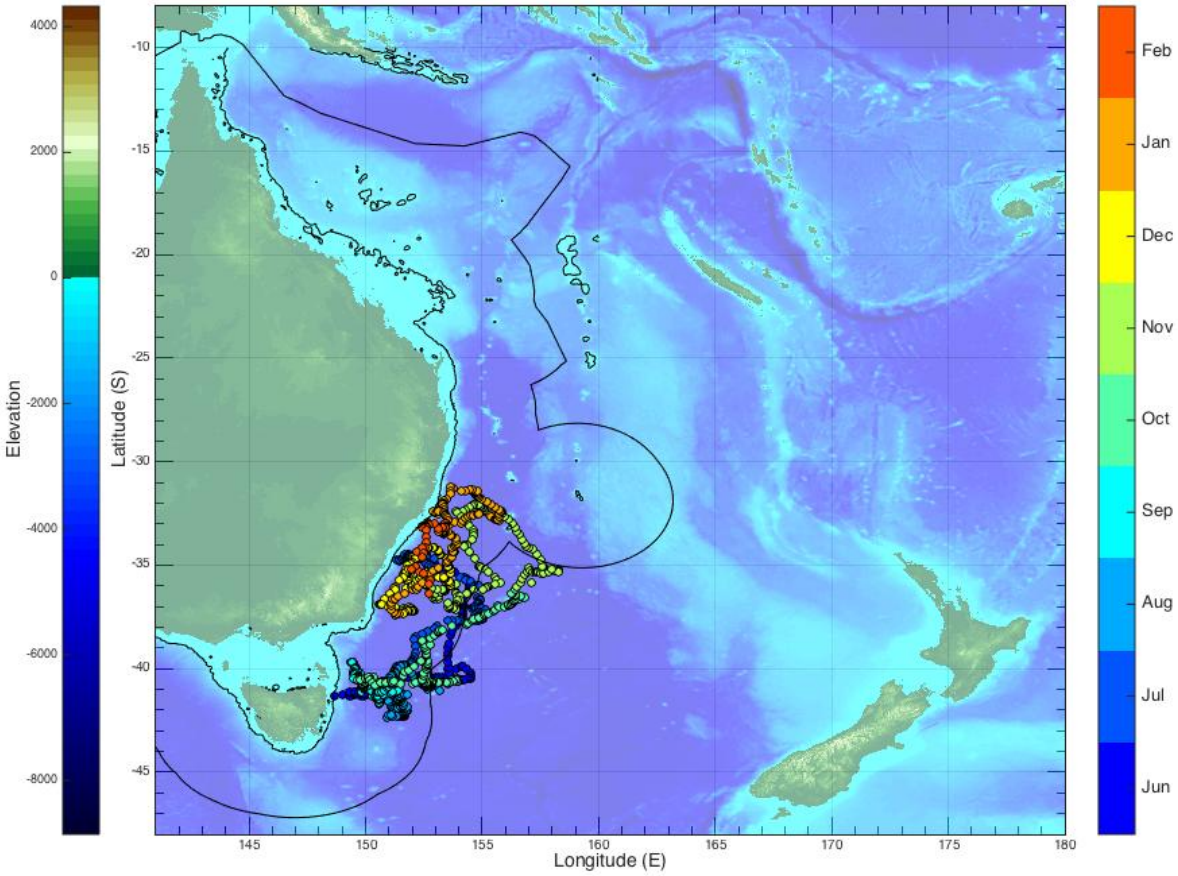

Figure 51. Most probable track of Swordfish SC0014 tagged adjacent to Tasmania. The fish was at liberty for 250 days. The colour of the points indicate the month as per the figure legend on the right-hand side of the figure.

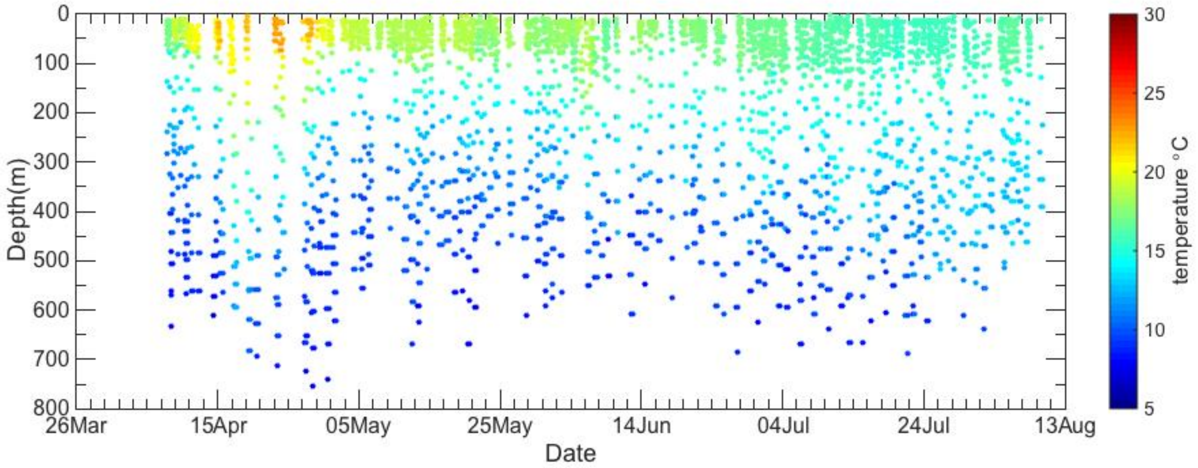

Figure 52. The depth/temperature time series of the satellite tag attached to fish SC0016, the fish was at liberty for 127 days. The colour of the points indicates the temperature reported by the tag as per the figure legend.

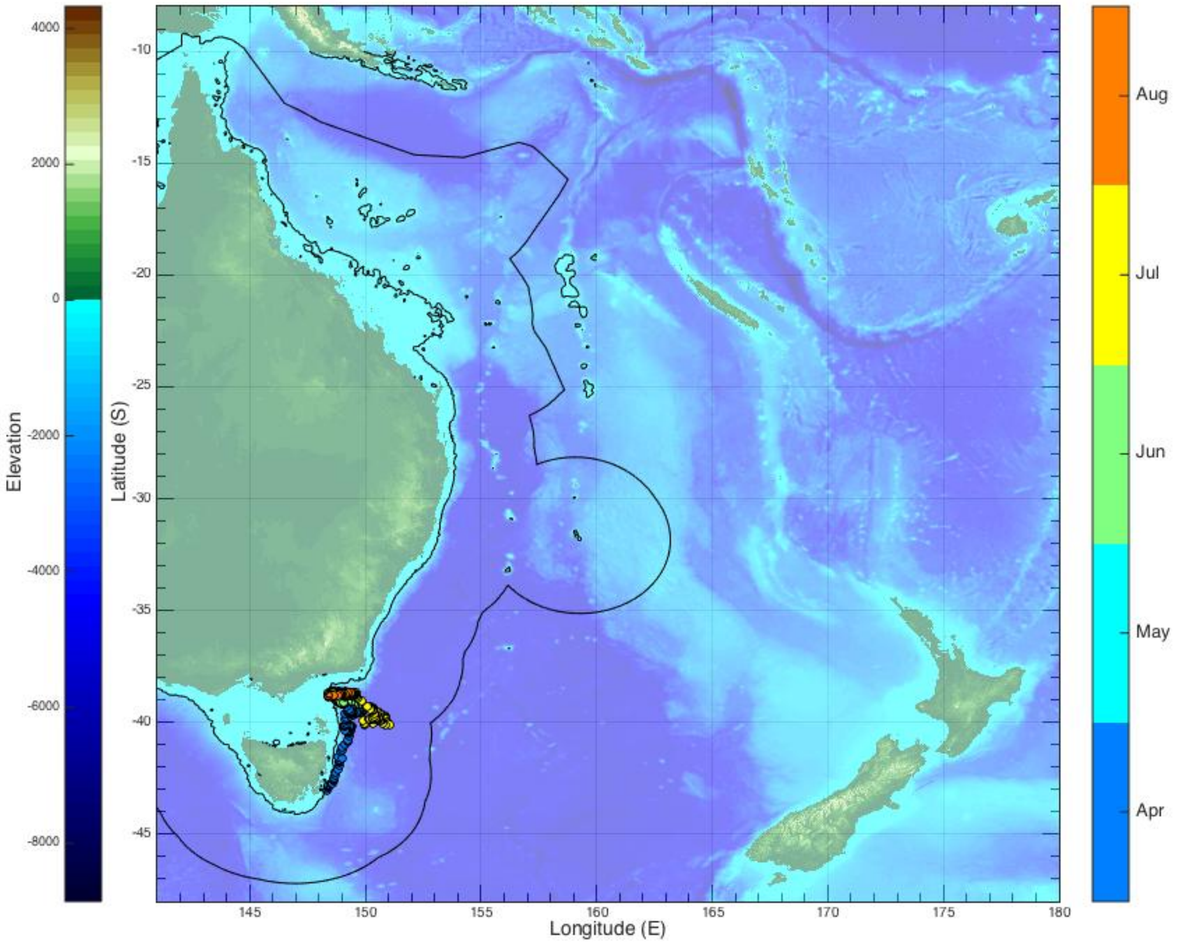

Figure 53. Most probable track of Swordfish SC0016 tagged adjacent to Tasmania. The fish was at liberty for 127 days. The colour of the points indicate the month as per the figure legend on the right-hand side of the figure.

Appendix 3: List of researchers and project staff

Dr Sean Tracey -IMAS

Dr Julian Pepperell – Pepperell Research & Consulting Pty. Ltd.

Mr Andrew Pender – IMAS

Mr Jaime McAllister – IMAS

Appendix 4: 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 5: 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. The reporting of one particular fishing trip with Paul Worsteling had over 5-million interactions on the ifish social media platforms.

Print media

Tracey, S.R. (2014) Australian Swordfish released with satellite tag. *Bluewater Boats & Sportsfishing.* Issue, 105, p 14.

Al McGlashan (2015) Sorting out the Swordfish. *Daily Telegraph -Sydney*. Published 3/1/15

Anon (2015) Fishers hooked on Swordfish. *Mercury newspaper – Tasmania*. Published 14/2/15

Lutrell, A. (2016) Swordfish lure anglers to state. *Mercury newspaper – Tasmania*. Published 15/4/16

Lutrell, A. (2016) Positive signals for broadbill Swordfish fishery. *Mercury newspaper – Tasmania*. Published 29/10/16.

O'Connor, T. (2016) Swordfish study providing insights into recreational tag and release sustainability. *ABC News*. Published 30/5/16

Pepperell, J. (2016) New Swordfish revelations. *Bluewater Boats & Sportsfishing.* Issue, 118, 46-53.

Australian Fisheries Management Authority (2016) Distribution and movement of Australian Swordfish. *Bluewater Boats & Sportsfishing.* Issue, 120, p 46-50.

Yick, J. (2016) Tassie anglers' record-breaking tagging efforts. *Bluewater Boats & Sportsfishing.* Issue, 120, p 10.

Lutrell, A. (2017) Swordfish at home in Tassie. *Mercury newspaper – Tasmania*. Published 23/10/17

Tracey, S.R. (2017) Recreational fishing for Swordfish in Australia – Opportunities and knowledge gaps. *Lateral Lines – Australian Society of Fish Biology newsletter.*

Tracey, S.R. (2017) Recreational fishing for Swordfish in Australia – Opportunities and knowledge gaps. *Invited feature article for the Game Fishing Association of Australia's Annual journal.*

Tracey, S.R. (2017) Huge sword satellite tagged off Tasmania. *Bluewater Boats & Sportsfishing.* Issue, 124, p 13.

Yick, J. (2017) Deep-dropping dominates Tassie gamefishing season. *Bluewater Boats & Sportsfishing.* Issue, 125, p 25.

Simpson, T. (2017) Big Swordfish and a can of worms – To release or not to release: that is the question. *Bluewater Boats & Sportsfishing.* Issue, 125, p 34-43.

Tracey, S.R. (2017) Swordfish satellite tag gets futuristic. *Bluewater Boats & Sportsfishing.* Issue, 126, p 25.

Pepperell, J. (2017) Australia's age of Swordfish. *Bluewater Boats & Sportsfishing.* Issue, 126, p 25.

Tracey, S.R. (2017) Satellite track from 350 kg- plus Swordfish. *Bluewater Boats & Sportsfishing.* Issue, 127, p 12-13.

Presentations

Tracey, S.R. (2014) Swordfish presentation night. *Audience – Tasmanian community.* Bellerive Yacht Club.

Tracey, S.R. (2014) Swordfish presentation night. *Audience – Tasmanian community.* Devonport Yacht Club.

Tracey, S.R. (2016) Understanding the movement, behaviour and post-release survival rates of Swordfish to sustainably develop a new large pelagic game fishery off the coast of Tasmania. *Invited presentation to an audience at Tackleworld Cranbourne*. Cranbourne, Australia.

Tracey, S.R. (2016) Understanding the movement, behaviour and post-release survival rates of Swordfish to sustainably develop a new large pelagic game fishery off the coast of Tasmania. *Invited presentation to an audience at Fishing Fever*. Mordialloc, Australia.

Tracey, S.R. (2016) Understanding the movement, behaviour and post-release survival rates of Swordfish to sustainably develop a new large pelagic game fishery off the coast of Tasmania. *Invited presentation to an audience at Hooked on Bait and tackle*. Hoppers crossing, Australia.

Tracey, S.R. (2016) Understanding the movement, behaviour and post-release survival rates of Swordfish to sustainably develop a new large pelagic game fishery off the coast of Tasmania. *Invited feature presentation for the Game Fishing Association of Australia's Annual General Meeting presentation dinner.* Cairns, Australia.

Tracey, S.R. (2016) Understanding the movement, behaviour and post-release survival rates of Swordfish to sustainably develop a new large pelagic game fishery off the coast of Tasmania. *Presentation to the board of TARFish*. Hobart, Australia.

Tracey, S.R. (2017) Understanding the movement, behaviour and post-release survival rates of Swordfish to sustainably develop a new large pelagic game fishery off the coast of Tasmania. *Invited presentation to the Latrobe Valley Game Fishing Club*. Lakes Entrance, Australia.

Tracey, S.R., Pepperell, J.G., Williams, S.M., Hartmann, K. (2017) Movement, habitat preferences and behaviour of Swordfish satellite tagged at the southern extent of their known range in Australia. *Indo-Pacific Fish Conference*. Tahiti, French Polynesia.

Television

IFISH – Season 11, episode 5. Dedicated one-hour show on Swordfish tagging trip. 2016

IFISH – Season 11, episode 11. Dedicated 30-minute show on Swordfish tagging trip. 2016

IFISH – Season 11, episode 16. Dedicated 30-minute show on Swordfish tagging trip. 2016

IFISH – Season 12, episode unknown. Dedicated one-hour show on Swordfish tagging trip. 2017