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Satellite tagging of Swordfish (*Xiphias gladius*) caught by the recreational fishery in southeast Victoria

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Background

A targeted recreational fishery for swordfish (*Xiphias gladius*) has established in Australia over the last decade (Tracey and Pepperell, 2018). As the fishery is still relatively young, fundamental knowledge about the best capture techniques and the timing and location of the fishery, as well as the effects of capture methods, post-release survival and potential for localised depletion are poorly understood. This information is essential to the development of fact-based responsible fishing practices as well as effective and ethical management strategies. Given the international status of swordfish being the pinnacle of large game fishing, it is expected that the targeting of this species will increase in Australia, in turn, increasing the regional benefits from recreational game fishing. The extensive communication and extension of this new and exciting recreational fishing opportunity in conjunction with the contribution of this project on developing a robust knowledge base for responsible fishing practices is a great opportunity for this fishery to develop in a positive way.

This project will provide additional data into a previous study on post-release survival rates of Swordfish (Tracey and Pepperell, 2018). These combined results will be published in an international peer-reviewed journal. The results will also improve our understanding of the movement and behaviour of released fish to assess the potential for localised depletion and identify the seasonality of the fishery in the cooler temperate waters of Victoria and Tasmania. This information will complement existing research examining the movement and behaviour of swordfish tagged in sub-tropical waters in conjunction with the commercial longline fishery (Evans et al., 2014).

Here, we assess post-release mortality of Swordfish caught using recreational fishing practices and the movement and behaviour of surviving animals using electronic tagging technology. Data collected during this study will be combined with data from a study conducted in Tasmania. Movement and behaviour profiles are also presented for each fish where data was collected from the tag.

The information generated from this research will contribute to fact-based guidance on best techniques for improving the chance of post-release survival of swordfish if fishers choose to release their catch.

Study objectives:

• Contribute data for the quantification of post-release survival rates of swordfish caught by recreational fishers

• Identify aspects of capture and handling that can be improved to increase survival, improve animal welfare and inform decisions on whether to release a fish or not based on its physiological condition

• Determine migratory behaviour of swordfish in southeast Australia, contributing knowledge on connectivity, potential for localised depletion and regional seasonality of the recreational fishery in the area

Methods

Sampling of swordfish occurred on the continental shelf break adjacent to Lakes Entrance and Mallacoota in Victoria from May to June 2019 and June to July 2021.

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 one that has been "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 (i.e., the terminal section of fishing line). Once "landed", the fish can either 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 hereafter.

All fish recorded in this study were landed using the daytime deep-dropping method, with baits being set on the seafloor at between 350 and 650 m. Fishing tackle was not standardised as the study was conducted in collaboration with recreational fishers, so the equipment employed reflects the range of tackle configurations used within the fishery. Stand-up rod-and-reel gear were used (rather than the angler fishing from a game chair). The terminal tackle consisted of a length of monofilament leader between 5–20 m in length (200–400 kg breaking strain) with either a single J-hook or two J-hooks attached to the end with a dead bait (either a whole squid, fish, or strip of fish) affixed. Lines generally had between one and three waterproof lights affixed near the terminal tackle. A break-away weight system was used in all cases.

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 to assess if the fish's condition was suitable for release. The assessment scale has nine criteria (Table 1). In short, criteria A–E relate to signs of physical trauma caused by the capture, criterion F relate to whether the fish had been retrieved tail-first, and criteria G–I are indicators of moribundity. For each of the criteria, a value of 0, 1, or 2 was assigned. The maximum score is 18, indicating minimal damage. 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 criterion G, lack of response to having an eye shaded by hand (criterion I), deteriorated skin colour (criterion H) and whether the fish had significant peritoneal distension (criterion E) where the accumulated gases prevented the fish from descending.

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.

For each swordfish released, a pop-up satellite archival transmitter (MiniPAT; Wildlife Computers, Redmond, WA, USA) was attached. The tags were rigged with a Domeier 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 and crimped to the corrodible release pin of the PSAT tag.

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 (i.e., depth seawater, m), temperature (°C), and light level (lumens). Tags were programmed to detach from the fish after 250 days with a sampling interval of 10 minutes, with one fish programmed to detach after 365 days. The tags were deployed with the on-board light attenuation coefficients set as constant (0.25). The tags released 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 sank to a depth greater than 1800 m (i.e., unlikely for a swordfish to reach normally), or the depth of the tag did not change by greater than ± 2.5 m over a 2-day period (whether at the surface or at a depth less than 1800 m), the tag would also detach from the tether. 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.

Mortality was determined from examination of the depth and temperature time series data just prior to the tag release. For example, a rapid increase in depth and then extended period of near-constant depth prior to reporting would be determined to reflect a mortality, because the positively buoyant PSAT should only sink while attached to the animal.

Each PSAT was affixed in the musculature just below the first dorsal fin using a purpose-made tagging pole, with the aim of inserting the anchor between two pterygiophores. Tags were attached immediately prior to an assessment of condition and suitability for release. Due to the large size and propensity for spontaneous movement of the landed fish, tagging was conducted at the first opportunity once the fish was boat-side, in case an early release was required to prevent injury to the fish or personnel. If this was the case, the line was cut as close to the hook as possible. Otherwise, after the tag was affixed the weight of the fish was estimated, the location of the hook (categorised as either: mouth, internal gill area, deep-hooked, or externally foul-hooked) and severity and source of bleeding were recorded (categorised internally and externally as either: nil, light, or extensive), and the hook removed where possible. If removing the hook was not possible, the line was cut as close to the hook as possible. During assessment, the fish were held alongside the vessel, which was moving forward at approximately 1–2 knots to provide gill perfusion until the fish freely kicked from the grip of the handler ("release"). The duration of time between landing to release was recorded as "resuscitation time", and release location GPS coordinates were recorded.

Data Analysis

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 was considered to be related to the capture event if the tag indicated the fish had died within 10-days of release (Tracey et al., 2016). Mortalities beyond this point were considered to be from natural causes. Statistical analyses were conducted in R 4.1.2 (R Core Team, 2021).

In addition to post-release mortality, some fish were identified as moribund at landing and were physiologically assessed as highly unlikely to survive and hence, not suitable for release (ACESS score $\leqslant$ 10). This assumed 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.

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, a speed parameter (standard deviation of modelled diffusion rate) of 3 m/s^{-1} was used based on previous information about sustained swordfish swimming speed (Carey and Robinson, 1981).

Results/Discussion

Post-release survival

Nine fish were caught as part of this study with angling durations ranged from 33 to 96 minutes and all fish were landed on single- or double-J hook rigs. The smallest fish was estimated at 50 kg and the largest at 280 kg, with an average size of 130 kg estimated.

Of the nine swordfish landed, three were assessed to have poor ACESS scores (< 10) and were moribund boatside. Two had substantial deep hooking damage, including to the gills with significant bleeding. The third had significant damage to the gills from the hook and also irremediable peritoneal distension. The remaining six were tagged with PSATs. The tagged fish were all assessed to be in good condition at the time of release (ACESS score > 14).

Of the six tagged swordfish, four released and successfully transmitted data from between 56 and 217 days after tagging (Table 2). One (SC0020) was an apparent predation or premature release the day of tagging, and the remaining tag (SC0021) failed to transmit data, so the fish's fate is unknown and hence the data was excluded from further analysis.

Combined with the data from Tracey and Pepperell (2018), the estimated survival rates of recreational deep-dropping caught swordfish overall was 44% and survival of those assessed to be in good condition for release was 15.4%. There were easily discernible contraindications for release with severe peritoneal distension and deep-hooking injury strong predictors of mortality (Tracey et al., In review).

Movement and behaviour

In total, the PSATs yielded approximately 62,000 depth-temperature-light data across 475 swordfish-days. Based on modelled geolocations at six-hour intervals, the four tagged swordfish covered 2159–8965 km, equivalent to an average speed of 1.4–1.73 km hr^{-1} across the tag deployments, similar or slightly faster than the maximum speed (1.5 m/s^{-1}) observed by Carey and Robinson (1981) while actively tracking Swordfish fitted with acoustic tags for up to five day periods.

Table 2. Summary of the six swordfish tagged off Victoria with pop-up satellite archival transmitter tags. "Total distance" is as the crow flies' distance between modelled swordfish positions at six-hour intervals.

Deployment						Pop-up transmission				
Fish ID	Est. weight (kg)	Date	Latitude	Longitude	Program duration (d)	Date	Latitude	Longitude	Actual duration (d)	Total distance (km)
SC0019	90	18/05/19	38°50′S	148°28′E	250	13/07/19	38°15′S	149°22′E	56	2159
SC0020	270	22/05/19	38°10′S	149°26′E	250	27/05/19	38°11′S	154°14′E	6*	-
SC0021	125	08/06/19	38°54′S	148°31′E	250	-	-	-	DNR	-
SC0023	280	01/06/21	38°27′S	148°35′E	250	05/09/21	38°54′S	149°56′E	96	3432
SC0024	90	02/06/21	38°27′S	148°35′E	250	05/01/22	29°19′S	156°01′E	217	8965
SC0025	90	08/07/21	38°08′S	149°25′E	365	26/09/21	35°56′S	154°20′E	80	4235

* Likely predation/tag loss several hours after deployment, duration actually deployed on swordfish likely < 1d (see Figure 4).
DNR = did not report: the PSAT was either unable to resurface or otherwise failed to report to the Argos satellite system.

All four swordfish demonstrated the characteristic diel vertical migration pattern typical of swordfish (Figure 1). Sunlight hours were spent at 250–750 m depth (max = 893 m), with a shift to shallower in the water column after sunset (median night-time depth = 21–40 m), followed by a return to depth by dawn. SC0023 spent the daytime during the first few days post-release shallower, but had resumed normal diel behaviour by a week post-release (Figure 1). Minimum water temperatures experienced by each swordfish were 6–8.3 °C (at depth during the day; Figure 2). Mean temperatures experienced during the day were 11–13.8 °C, while mean temperatures experienced by individual swordfish at night were 15–16.7 °C. Figure 2 demonstrates the increasing proportion of time spent at depth from austral winter to summer, due to the increasing day length.

Similar horizontal movement behaviour was demonstrated by the four swordfish in the months following release (May–Sept; Figure 3). The fish remained in the Tasman Sea region between 34°S and 44°S, within relatively close proximity to the continental shelf. Modelling of the tagged swordfish movements suggests they also show restricted movements at a finer scale as well, either slowing or circling in areas on the scale of 10s of km. The one fish (SC0024) that retained its tag beyond September initiated a different movement pattern by late spring. It crossed the Tasman Sea, reaching the edge of the Lord Howe Rise after about one month, followed by a rapid movement northwest before the tag releasing from the fish (due to premature tag release-pin break) west of the Dampier Ridge.

PSAT data from SC0020 (excluded from the analysis) indicated this individual was most likely predated after release (Figure 4). While these data also demonstrate diel shift in depth, it was deeper at night than during the day, and perhaps more anomalously, the temperature was stable during rapid changes in depth, which could most plausibly indicate the tag had been swallowed on the day of release by a predator such as a mako shark (*Isurus oxyrinchus*), which maintain elevated visceral temperatures. As such, the individual was included as a post-release mortality.

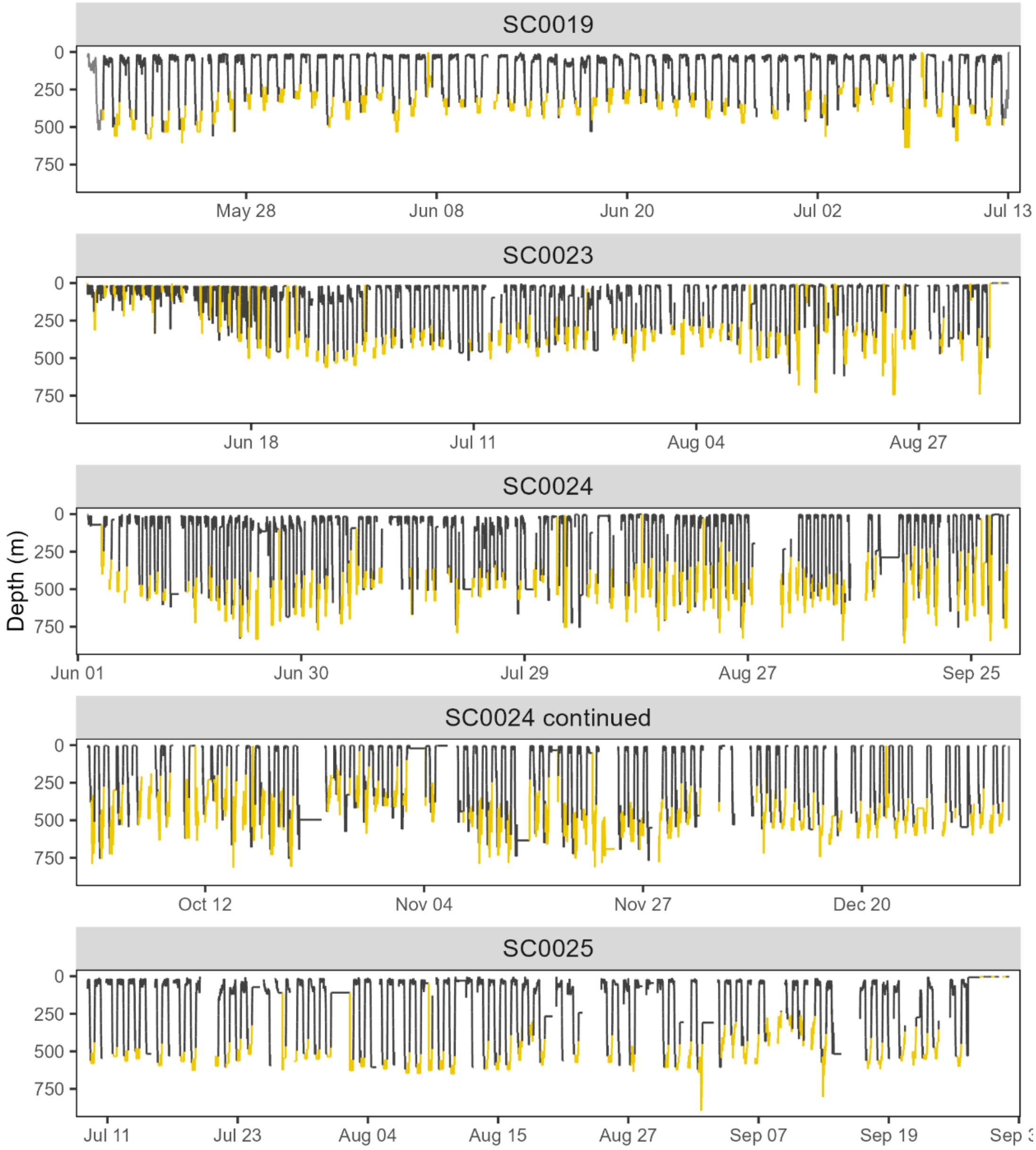

Figure 1: Swordfish depth data series inferred from PSAT depth sensor data, demonstrating the strong diel vertical migration pattern of swordfish in the region. Data recorded during the day (between local time of sunrise and sunset) are displayed in gold, data during night-time are shown in dark grey. Consecutive depth data are connected by horizontal lines, thus periods with an absence of depth data appear as having no change in depth.

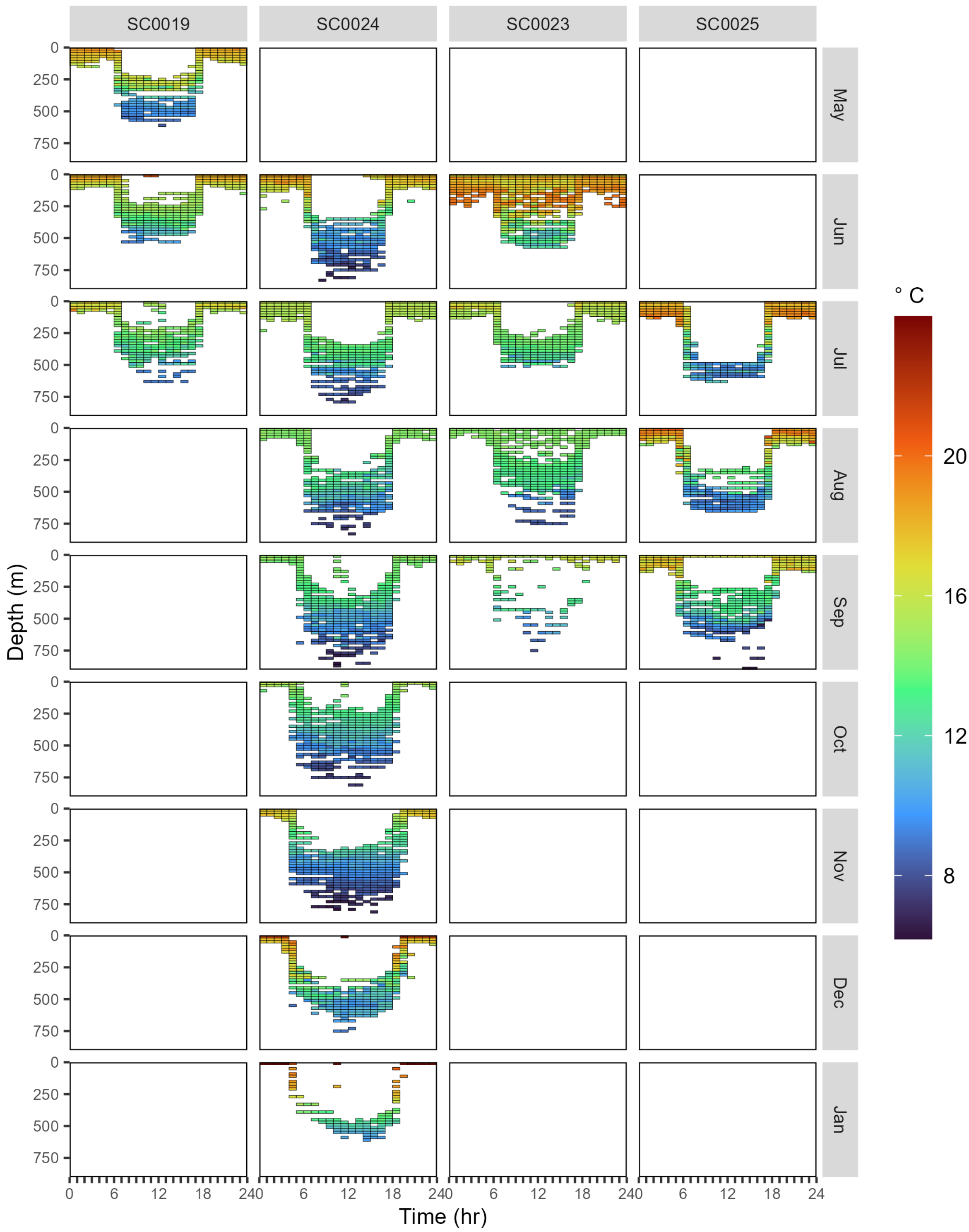

Figure 2. Mean water temperature-at-depth by hour of the day (AEST) of swordfish, by month.

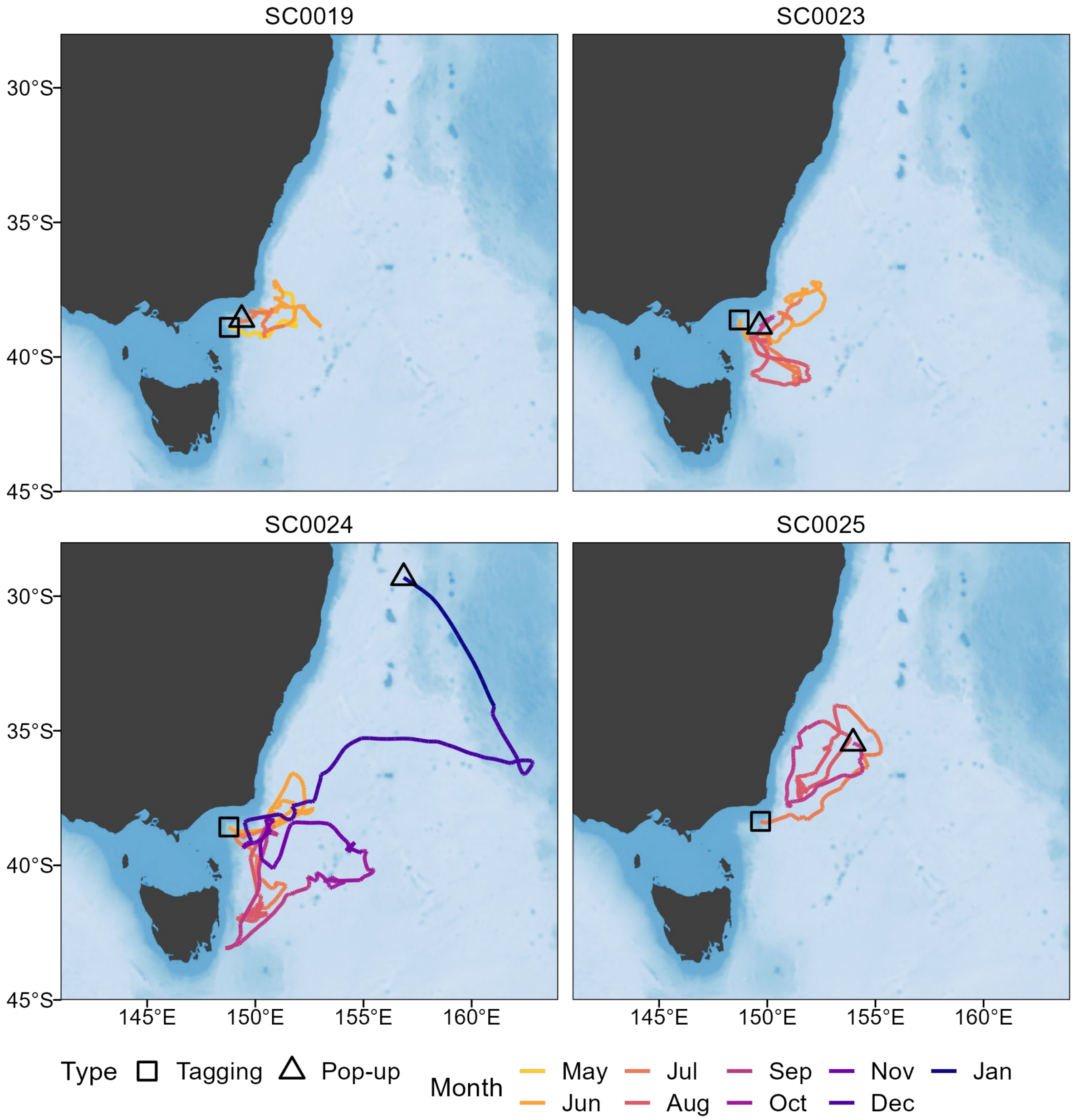

Figure 3: Modelled most likely paths of the four swordfish tagged off of Victoria that yielded multi-day data. Paths were interpolated at six-hour intervals. Start and end of the tracks are indicated with square and circle markers, respectively.

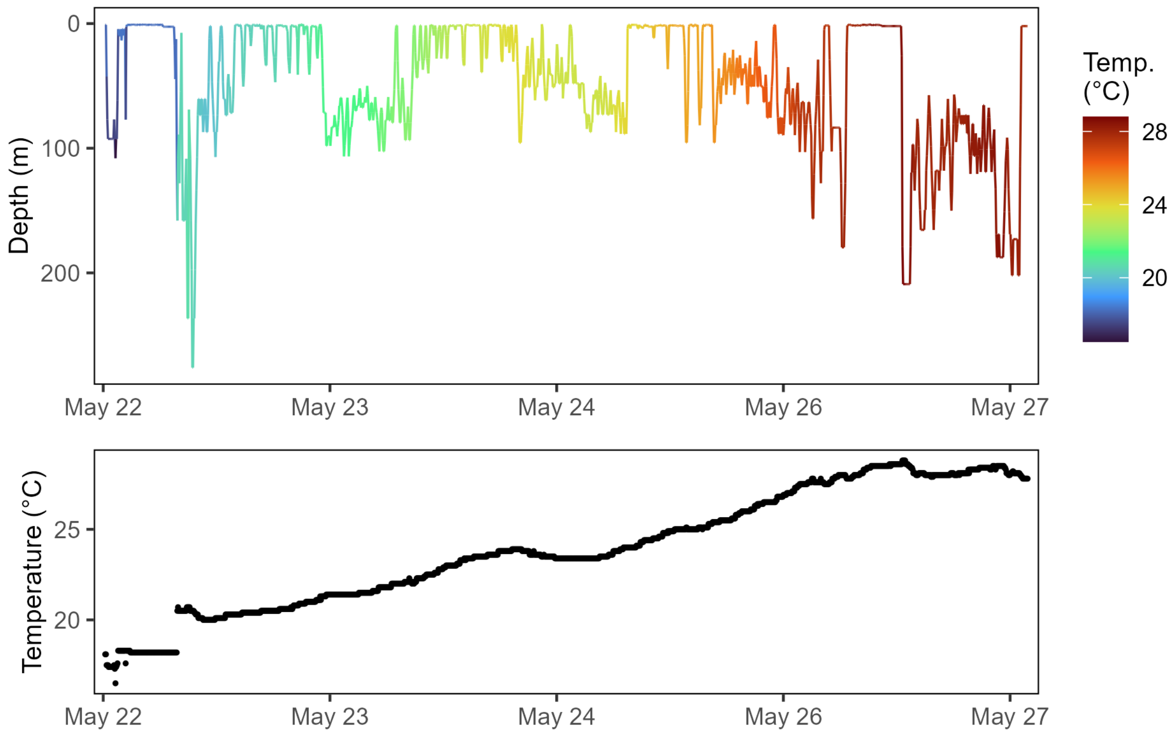

Figure 4: PSAT depth and temperature sensor data from presumed mortality/tag loss SC0020, demonstrating an anomalous pattern of a sudden increase in temperature during a dive on the first day, and stable temperature at depth after the first day. These data are consistent with the PSAT ending up in an endothermic predator's stomach (e.g., a mako shark).

Conclusions

Overall, the combined survival rate for landed swordfish caught during this study and Tracey and Pepperell (2018) was 44%. Severe peritoneal distension, and deep/gill-hooking injury were strong predictors of reduced survival, while angling duration and fish weight did not have a discernible effect on mortality. Among swordfish assessed to be in suitable condition for release, affixed pop-up satellite archival tags indicated 85.6% (57.8 – 95.7%; *n* = 13) survived after release (Tracey et al., In review). While the swordfish fishery is superficially similar to more common istiophorid (e.g., marlin) billfish game fishing, the unique physiology and behaviour of swordfish and depths at which they are targeted present a unique challenge for stewardship as the typical catch-and-release billfish game fishing ethos may not be appropriate; these results suggest swordfish caught deep-dropping are a poor candidate for purely catch-and-release angling. Predictors of post-release mortality are readily observable, so fishers should be prepared to humanely dispatch fish exhibiting internal hooking injuries or severe peritoneal distension.

In regard to fish movement, three of the four tagged fish that produced movement data indicated that they remained resident in southeast Australian near shelf break waters until at least August. Beyond this point, two tags detached and did not produce any further data, while one indicated the fish had moved into waters off Southern New South Wales during August and September, and the last fish began a rapid migration north, presumably to spawn (Young et al., 2003), in late November. Interesting this fish also remained in the cooler near shelf-break waters off southeast Australia, including Tasmania until September. These results suggest that it is possible that the recreational Swordfish season could run as late as September, but the data suggests that fish will begin to migrate away from cooler southern waters in August.

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