

Quantifying shark depredation and post-release survival in the Queensland East Coast Spanish mackerel *Scomberomorus commerson* fishery

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ABSTRACT

Context. Fishers report high levels of shark depredation and post-release mortality in the Queensland East Coast Spanish mackerel fishery, yet little empirical data exist for these sources of cryptic mortality, limiting the precision of stock assessments. **Aims.** This research aimed to quantify shark depredation and post-release mortality in this fishery. **Methods.** Depredation rates were recorded across 92 commercial and recreational fishing trips. To estimate post-release survival, 32 Spanish mackerel *Scomberomorus commerson* were tagged with survival pop-up archival tags. **Key results.** Shark depredation rates were 6% during commercial trips and 36% during recreational trips, with substantial daily variation. Highest depredation occurred in the Lucinda region and lowest in the Far North region. Statistical modelling indicated that sector and latitude had a significant effect on depredation rates, with higher depredation rates for recreational fishing and increasing depredation with more southerly latitude. Post-release survival of *S. commerson* was 53% and mortality was solely caused by predation shortly after release, likely by sharks. Post-release survival varied regionally, with the highest rates in Sunshine Coast (67%) and lowest in Lucinda (20%). **Conclusion.** Shark depredation and post-release predation lead to substantial extra mortality in the Queensland East Coast Spanish mackerel fishery, particularly in the recreational sector. **Implications.** Shark depredation and post-release survival rates were incorporated into the 2025 stock assessment, improving the precision of fishing mortality assessments and overall stakeholder confidence in the stock assessment outputs. These sources of mortality should continue to be monitored over time. Modifications to fishing practices and adoption of different fishing gears can mitigate depredation.

Keywords: catch-and-release, commercial fishing, cryptic mortality, fisheries management, fisheries observers, post-release predation, recreational fishing, satellite tagging, stock assessments.

Introduction

Quantifying the level of fishing mortality that a stock is subjected to is a key aspect of sustainable fisheries management, because of the significant impact it can have on a stock's population (Whipple *et al.* 2000; Walters and Martell 2002). Measuring fisheries landings and discards is the primary approach for quantifying fishing mortality, but can underestimate total fishing mortality if cryptic mortality is occurring and unaccounted for. Depredation can be a key source of cryptic mortality in some line fisheries, where predators such as sharks, cetaceans, large teleosts or pinnipeds consume hooked fish before they can be retrieved by the fisher (Mandelman *et al.* 2008; Mitchell *et al.* 2018a; Tixier *et al.* 2021). The depredation often occurs at depth, with the predator sometimes removing the entire fish or breaking off the fishing gear, leaving no trace of the depredation event. As a result, this form of mortality often goes unrecorded in fisheries logbooks, because it is not possible to verify what target species was lost to depredation (Gilman *et al.* 2008; Mitchell *et al.* 2018a). Shark depredation, in particular, occurs widely in Australian fisheries (Piddocke *et al.* 2022; Mitchell *et al.* 2023) and is affecting many line-caught species. Recent studies have shown that 5–15% of catch can be lost to this form of cryptic mortality (Mitchell *et al.* 2018b; Carmody *et al.* 2021).

Post-release mortality is another source of cryptic mortality which affects commercially and recreationally caught fish that are released, either because of being unsuitable size (smaller or larger than the permitted minimum or maximum sizes, or not marketable) or unwanted (wrong species, closed season or exceeding catch quota or bag or boat limits). Post-release mortality can be caused by a number of factors, including barotrauma (Stallings *et al.* 2023; Hughes *et al.* 2025), hook location (Maggs *et al.* 2024), exhaustion from long fight times (Holder *et al.* 2022), injuries to gills (Tracey *et al.* 2023) or predation (Muir *et al.* 2022). In the last case, predation is more likely to occur if the released fish's ability to escape the predator is compromised by the other aforementioned factors. Depending on the causal factor, post-release mortality can occur from minutes up to days after release. Post-release mortality is highly context specific, depending on the species, fishing gear used and environmental conditions (Musyl *et al.* 2009; Graves and Horodysky 2015). Post-release mortality has been quantified for tuna and billfish in Australia by using satellite tags, with reported mortality rates ranging from 13 to 56%, with predation being one of the key causes (Pepperell and Davis 1999; Tracey *et al.* 2016, 2023; Williams *et al.* 2017).

Spanish mackerel *Scomberomorus commerson* (Lacepède, 1800) is an important target species for fisheries across its range (Grandcourt *et al.* 2005; Lee and Mann 2017; Nguyen and Nguyena 2017; Chen *et al.* 2021). In Australia, three stocks of *S. commerson* occur in Western Australia–Northern Territory, Torres Strait and the East Coast (Buckworth *et al.* 2007; Williams *et al.* 2022). In the Queensland East Coast Spanish mackerel fishery, shark depredation and post-release mortality are believed to regularly occur and were identified as important sources of uncertainty in the 2021 stock assessment (Tanimoto *et al.* 2021). Anecdotal reports from fishers indicate that shark depredation has been increasing over the past 5–10 years, with depredation rates of >50% occurring on some trips in high depredation areas, particularly for recreational fishers. In addition to this, recent changes to the Queensland recreational bag limit for *S. commerson*, from three per person or six per boat to one per person or two per boat, are likely to result in more fish being released by recreational fishers. Therefore, there is a need to quantify cryptic post-release mortality to better understand whether management changes are benefitting the rebuilding of this stock. Also, the perceived rising impact of these two sources of cryptic mortality makes it vital to collect empirical data on their prevalence to address this data gap and improve the robustness of stock assessments. This will provide stakeholders with greater confidence in fisheries assessment and management.

This research sought to quantify shark depredation rates in the Queensland East Coast Spanish mackerel fishery through fisheries observer and citizen science-based data collection and to use satellite tags to determine post-release survival rates of recreationally caught *S. commerson*.

Materials and methods

Data collection

Shark depredation

Tagging was conducted under Animal Ethics approval from the Queensland Government Animal Ethics Committee (Permit number CA 2023/03/1697). Tagging in the Lucinda region was conducted under approval from the Great Barrier Reef Marine Park Authority (research permit number G49661.1).

Data on shark depredation for commercial *S. commerson* trips were collected by an onboard observer across five different vessels in Far North Queensland (Lockhart River region), central Queensland (Bundaberg, K'gari and Yeppoon) and south-eastern Queensland (Sunshine Coast) (Fig. 1). In total, 39 days of observer data collection was undertaken between 19 August 2022 and 21 June 2024 (Supplementary Table S1). Data metrics collected included the date and location of fishing, the length of time trolling was undertaken as a measure of fishing effort, the lure and bait type used, the number of fish hooked, landed undamaged and depredated. Fishing gear consisted of either rod and line, electric reels or handlines, depending on the region and vessel. Fishing vessels ranged in size from small 4-m dories in northern Queensland to larger 8-m vessels in south-eastern Queensland.

Shark depredation data were collected for 53 recreational fishing trips by a group of 17 experienced recreational fishers in the Capricorn Coast region of central Queensland and off Townsville in northern Queensland, between 25 November 2022 and 5 June 2024 (Table S1). These fishers used standard rod and reel fishing gear, with either hard body lures or live and dead bait consisting of either eastern sea garfish, *Hyporhamphus australis* (Steindachner, 1866), blue mackerel, *Scomber australasicus* Cuvier, 1832, southern ribbonfish, *Trachipterus arawatae* (Ramsay, 1881), Australian bonito, *Sarda australis* (Macleay, 1881), dorab wolf herring, *Chirocentrus dorab* (Forsskal, 1775) or yellowtail barracuda, *Sphyrna obtusata* Cuvier, 1829. Data collected included the same metrics as for commercial trips and were collected directly by the fishers rather than by observers. The same data were also collected by project staff during 10 specific tagging trips in northern, central and south-eastern Queensland, where standard recreational fishing practices were used.

Post-release survival

Thirty-two *S. commerson* individuals were tagged with Wildlife Computers survival pop-up archival tags (SPAT) to evaluate post-release survival, between 11 August 2023 and 15 January 2025 (Table S2). Of the 32 tags deployed, 11 were deployed at the Sunshine Coast, 10 at Mackay and 11 at Lucinda (Fig. 1). Fish for tagging were captured using standard recreational fishing practices and gear, including rod and reel and either hard plastic fishing lures with two treble hooks, live baits (yellowtail scad, *Trachurus novaezelandiae* Richardson, 1843 or *Scomber australasicus*) with one J

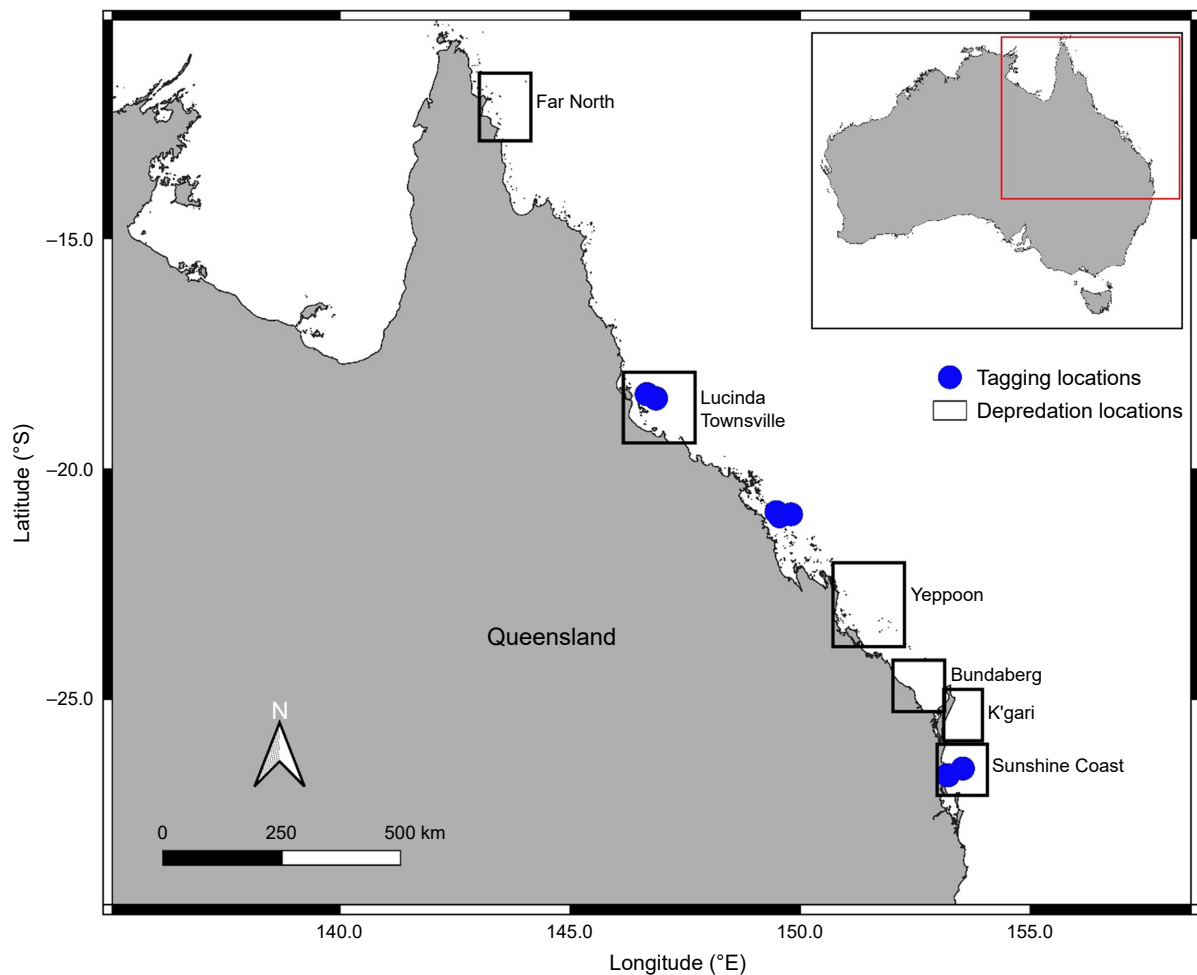


Fig. 1. Map of regions where shark depredation data were collected, as indicated by black boxes. Blue points show locations where satellite tagging was conducted. Red box on inset map shows the position of the study site in relation to Australia.

hook and two treble hooks or dead baits (*Sarda australis* or *Hyporhamphus australis*) with either two single hooks (ganged) or one single hook and one treble (Table S2). Data on the fight time and time out of the water were collected for each fish tagged.

The tagging process involved bringing a *S. commerson* onto either the deck, gunwhale or a cradle, depending on the boat setup, removing the hook(s) and then inserting a satellite tag into the dorsal musculature of the fish using a plastic (Domeier) dart head anchor ($n = 17$) or flat metal anchor ($n = 15$) (Fig. 2). A smaller dart tag was also inserted into the dorsal musculature, and a fork length measurement and fin clip tissue sample were taken for genetic analysis. Following this, the fish was released, with a score assigned on the basis of the release condition and any injuries present (Table S2). Injuries included damage to the mouth, gills or other body part from the hook, or other damage caused by the fishing line or from impacts of the fish against the boat. The satellite tags



Fig. 2. A *Scomberomorus commerson* with a satellite tag for assessing survival and a conventional dart tag in case of longer-term recapture.

were programmed to remain attached to the fish for 60 days, after which they released and floated to the surface, where they transmitted their data to ARGOS satellites.

Data analysis

Shark depredation

The depredation rate for commercial and recreational fishing trips was calculated as the proportion of total fish hooked (including both those that were depredated and those that were landed undamaged) that were depredated by sharks, following Mitchell *et al.* (2018b) and Carmody *et al.* (2021). Depredation rate was calculated for each region of Queensland and for commercial and recreational fishing trips. To further investigate the effect of key operational and environmental factors on shark depredation rates, a generalised linear model (GLM) was applied to combined data from both commercial and recreational fishing trips. The response variable used in the model was the number of fish depredated on each of the 92 fishing trips. Total number of fish hooked was used as an offset term in the model and was log + 1 transformed to achieve a more uniform distribution. This response variable and offset combination follows the method used in Mitchell *et al.* (2018b) and Carmody *et al.* (2021).

The negative binomial distribution, which is more appropriate for overdispersed data, was used for the GLM, because it produced the best model fit compared with other distributions tested, including Poisson, binomial and lognormal. Predictor variables included in the model were fishing sector (commercial or recreational), month, lunar illumination (using the *R* package *lunar*, ver. 0.2-01, see <https://CRAN.R-project.org/package=lunar>), latitude and distance to nearest urban centre (any urban centre with >1000 residents, on the basis of the Australian Bureau of Statistics (Australian Bureau of Statistics 2026). Correlation of continuous predictor variables was checked, to identify any variable combinations that had Pearson correlation values of >0.4. The combinations *month–latitude* and *month–distance to urban centre* were correlated at 0.5 and –0.88 respectively, so they were not included in the same GLM together. GLMs were run using the *stats* package (ver. 3.6.2, see <https://cran.r-project.org/doc/manuals/r-patched/packages/stats/refman/stats.html>) in *R* (ver. 4.3.2, R Foundation for Statistical Computing, Vienna, Austria, see <https://www.r-project.org/>). GLMs with different combinations of predictor variables were run using the ‘*dredge*’ function of the *MuMIn* package (ver. 1.46.0, see <https://CRAN.R-project.org/package=MumIn>), with the best fitting model having the lowest Akaike information criterion (AIC) (Akaike 1974) value. Model diagnostic checks included checking for zero-inflation, outliers and overdispersion using the *DHARMa* package (ver. 0.5.0, see <https://CRAN.R-project.org/package=DHARMa>) and multi-collinearity using the ‘*vif*’ function of the *car* package (ver. 3.1-5, see <https://CRAN.R-project.org/package=car>; Fox and Weisberg 2019). Significant predictor variables included in

the top model were plotted on the scale of the response variable using the ‘*visreg*’ function from the *visreg* package (ver. 3.0.0, see <https://cran.r-project.org/package=visreg>; Breheny and Burchett 2017).

Post-release survival

Light level and depth data from the sPAT tags, along with the deployment duration, allowed fate to be assigned to the tagged fish, on the basis of seven potential outcomes (Table 1). Five days was the minimum period chosen to indicate survival, to balance the need to account for delayed mortality from the effects of capture stress and predation, while not excluding too many tags due to short deployment durations resulting from premature tag shedding. Previous research has found that the majority of post-release mortality that occurs as a result of physiological impacts from capture happens within 1–4 days, for species including southern bluefin tuna, *Thunnus maccoyi* (Castelnau, 1872) (Tracey *et al.* 2016), Atlantic bluefin tuna, *Thunnus thynnus* (Linnaeus, 1758) (Marcek and Graves 2014), white marlin, *Kajikia albida* (Poey, 1860) (Horodysky and Graves 2005; Kerstetter and Graves 2008) and striped marlin, *Kajikia audax* (Philippi, 1887) (Domeier *et al.* 2003; Musyl *et al.* 2015). Previous studies have therefore used a minimum deployment duration of 5 days to confirm survival (Marcek 2013; Marcek and Graves 2014; Graves *et al.* 2016; Goldsmith *et al.* 2017). However, other research has emphasised that post-release mortality from predation can happen over a much longer timescales because of stress and injury, from 10 to 30 days post-release (Musyl and Gilman 2019; Benoît *et al.* 2020; Kneebone *et al.* 2021). Yet, using such a long timeframe to confirm survival would have been severely limiting in the current study, because only six tags had deployment durations >10 days.

The low number of fish tagged prevented detailed statistical analysis examining how factors such as fight time, air exposure time, hook type and fork length affected post-release survival. However, these parameters were visualised by generating boxplots. The probability of tag retention over the 60-day period was modelled on the basis of the date and time of tagging and tag pop-up, using a survival analysis with the ‘*survfit*’ function from the *R* package *survival* (ver. 3.8-6, see <https://CRAN.R-project.org/package=survival>). Fitted values were plotted as a survival curve by using the ‘*ggsurvplot*’ function from the *survminer* package (ver. 0.5.1, A. Kassambara, M. Kosinski and P. Biecek, see <https://CRAN.R-project.org/package=survminer>). Seven tags were omitted from this analysis because they did not record a pop-up date because of tag malfunction.

Results

Shark depredation

Shark depredation occurred on 29% of commercial fishing trips, resulting in a mean catch loss of 6%. However, there

Table 1. Fate categories assigned to tagged fish based on deployment duration, light level and depth data generated.

Fate assigned	Criteria used to assess
Survival	The tagged fish survives for the whole deployment duration (60 days) or until the tag is shed (>5 days), as indicated by normal depth and light level patterns.
Natural mortality	Tagged fish dies of natural causes >5 days after tagging event. Natural mortality is detected by the fish sinking to the bottom and remaining at the same depth for >24 h, which triggers the tag to release and float to the surface.
Natural mortality (predation)	Natural predation occurs >5 days after the tagging event and is indicated by a drop in light levels to zero for >24 h when the tag is ingested by a predator, after which the depth goes to zero and the light level returns to a normal diel pattern once the tag has been expelled by the predator and floated to the surface.
Capture induced mortality (stress from capture)	Tagged fish dies <5 days after tagging event because of the stress of capture. Mortality is detected by the fish sinking to the bottom and remaining at the same depth for >24 h, which triggers the tag to release and float to the surface.
Capture induced mortality (predation)	Tagged fish dies <5 days after tagging event because of predation. This is identified using light-level data, because light levels drop to zero when the tag is ingested by a predator and then returns to normal after a few days when the predator excretes the tag.
Not assessable (data limitation)	Tag fails to report the data necessary to determine the fate of the fish.
Not assessable (premature deployment)	The tag stays on the fish <5 days, so the fate cannot be clearly determined because of lack of data.

was a high degree of variability in depredation rates among commercial trips, ranging from 0 to 57% per trip (Table S1). The number of fish hooked per day on commercial trips ranged from 0 to 73, with 0–20 fish depredated per day (Table S1). For recreational trips, depredation occurred on 54% of trips, with a mean catch loss of 36% per trip. It must be noted that, although *S. commerson* were the target species, it is possible that some of the fish depredated were other co-occurring pelagic species, such as spotted mackerel, *Scomberomorus munroi* Collette & Russo, 1980, great barracuda, *Sphyrna barracuda* (Edwards, 1771), or wahoo, *Acanthocybium solandri* (Cuvier, 1832), because in most cases the shark depredated the hooked fish and snapped off the line, preventing identification of the fish depredated. Although depredation was assumed to be caused by sharks due to either seeing them around the boat or catching them, it is possible that other predators such as dolphins or large teleosts (e.g. *S. barracuda* or Queensland grouper, *Epinephelus lanceolatus* (Bloch, 1790)), were responsible.

The depredation rate was variable across different latitudes of Queensland, with highest median depredation of 33% for the Lucinda region, which were all recreational fishing trips (Fig. 3). Median depredation rates were all $\leq 20\%$ for the other regions where fishing trips took place, although the range of values was notably high for Yeppoon (all recreational trips), from 0 to 100%, with a median of 20%. Median depredation rates were very low (<5%) for the Far North (commercial trips), Townsville (recreational trips), Bundaberg (commercial trips) and K'gari (commercial trips) regions, whereas Sunshine Coast (mix of recreational and commercial trips) had intermediate levels of shark depredation (median of 13%) (Fig. 3).

The top-ranked model produced by the 'dredge' function included the predictor variables sector and latitude, which explained 28 and 11% of the deviance in the response variable respectively (Tables 2, S3).

For the predictor variable sector, the model fitted value was 0.33 fish depredated per trip for commercial fishing compared with 2.34 for recreational fishing (Fig. 4a). There was a positive linear relationship between number of fish depredated and latitude, rising from 0.42 at 12°S to 4.36 at 27°S (Fig. 4b).

Post-release survival

On the basis of the assessments of depth, temperature and light level data from tags, eight tagged fish were deemed to have survived, including one that was deemed to have experienced natural mortality from predation (245430), with seven classified as suffering captured induced mortality from predation (Table S2). This predation was likely caused by sharks because they were often observed around the boat, although it is possible that other predators such as dolphins or large teleosts were responsible. Zero tagged fish were classified as having suffered capture-induced mortality from effects other than predation or from natural mortality. Therefore, overall, the survival rate of tagged fish was 53%. Twelve tags were not assessable due to the deployments being too short (i.e. <5 days, due to tag shedding, for example) and five were not assessable due to data limitations (e.g. the tag failing to report adequate data). These tags were not included in the calculation of post-release survival rates.

The post-release survival rate varied by region, with the highest value of 67% for Sunshine Coast, followed by 50% for Mackay and 20% for Lucinda (Fig. 5). Lucinda had six tags that were unassessable due to deployments being too short (<5 days), whereas Mackay had five and Sunshine Coast had only one. Sunshine Coast had four tags that were not assessable due to data limitations and Mackay had one (Fig. 5). Owing to the small sample sizes, no formal statistical analysis was conducted on this variation by region.

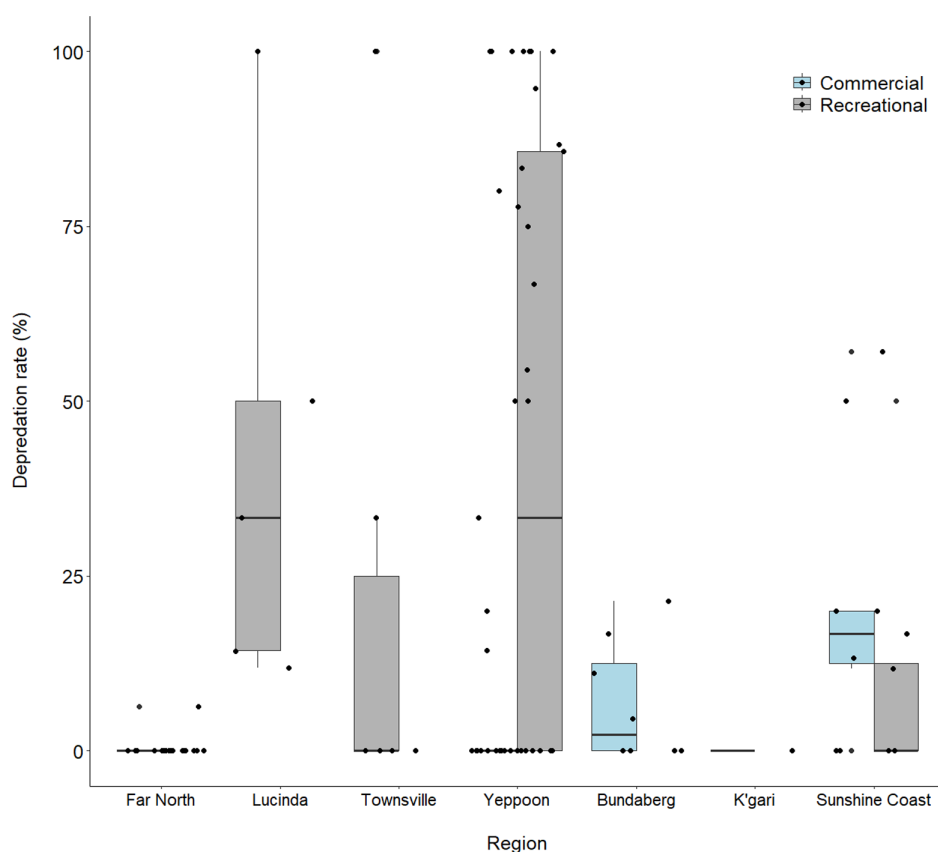


Fig. 3. Shark depredation rates by region in Queensland, during commercial (light blue bars) and recreational (grey bars) *Scomberomorus commerson* fishing trips. Black points indicate depredation rates for individual fishing trips, solid black lines inside boxes represent the median depredation rate.

Table 2. Summary metrics for the generalised linear model run to assess the impact of operational and environmental factors on the occurrence of shark depredation.

Predictor variable	Chi-Square value	Degrees of freedom	P-value
Sector	37.931	1	<0.001
Latitude	14.044	1	<0.001

Two examples of how satellite tag data were used to assign fate are provided in Fig. 6 and 7. Depth and light level data for tag 245430 confirmed initial survival, with a consistent pattern of rapidly oscillating depth from 0 to 42 m (with a mean of 15.4 ± 9.6 m) and cyclical diel light level pattern (Fig. 6). However, a drop in light level to zero then occurred for >24 h from 27 April to 29 April 2024 (Fig. 6b), which likely indicated that this fish was predated on and the tag was ingested by the predator, before being expelled and floating to the surface on 29 April 2024. Due to this predation happening 17 days after release, this tag was therefore classed as a natural mortality (predation). Temperature recorded during this deployment ranged from 23.4 to 26.4°C, with a mean temperature of 25.2 ± 0.6 °C (Fig. 6a).

Tag 245410 showed clear signs of a capture-induced predation event occurring 17 min after release (likely by a shark because sharks were sighted around the boat), indicated by the rapid drop in light level to zero when the tag was ingested by the predator and then remaining at zero for >24 h (Fig. 7b, d). Additionally, the depth pattern was markedly different from other tagged *S. commerson*, with the majority of time spent between 40 and 50 m (Fig. 7a), as opposed to the frequently oscillating depth pattern with a greater range of depth and regular forays near the surface, as seen in other tagged *S. commerson* (Fig. 6a). The temperature range detected by this tag was from 21.3°C to 22.3°C, with a mean of 22.1 ± 0.1 °C (Fig. 7a, c).

The probability of tag retention declined rapidly over time across the 60-day period, with only one tag remaining attached to a *S. commerson* for the whole period. Within 0.53 days, the retention probability dropped from 1 to 0.68 ± 0.09 (mean $\pm$ standard error), then plateaued until 3 days (Table S2, Fig. 8). The retention probability then continued to decline consistently, reaching 0.4 ± 0.1 after 6.07 days and 0.2 ± 0.08 after 13.21 days (Fig. 8).

The fork length range of fish tagged was 79–128 cm, with a mean of 104 ± 13 cm. Notably, 100% of fish <95 cm died and

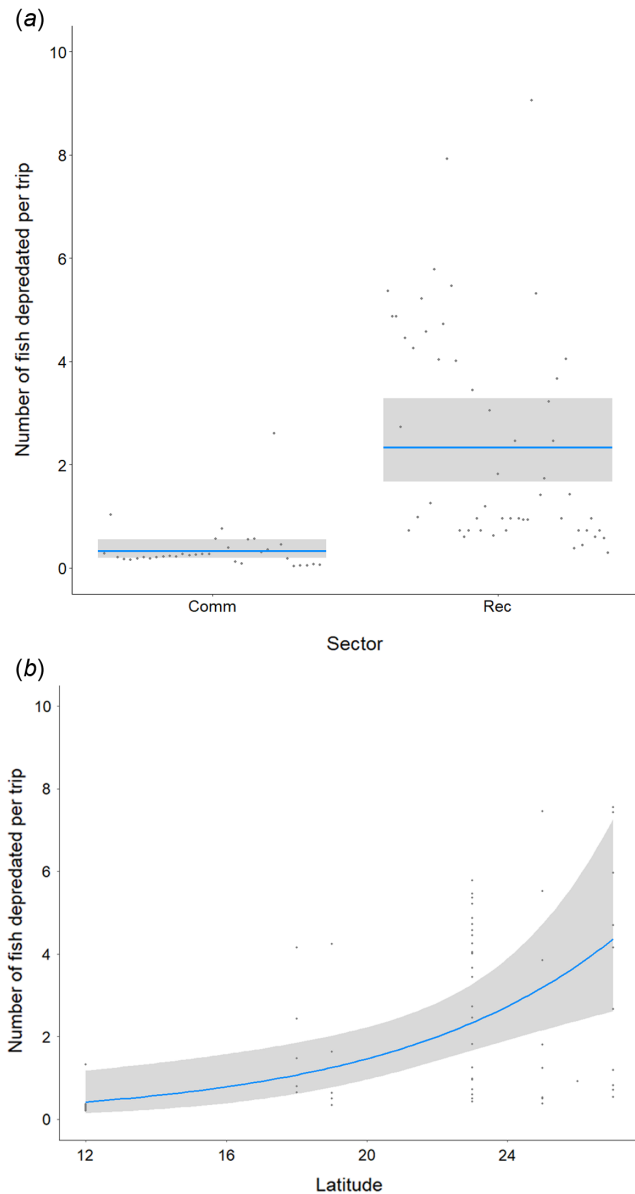


Fig. 4. Generalised linear model plot showing the modelled number of fish depredated per trip by (a) sector and (b) latitude. Blue lines indicate model fitted values and grey shaded bars represent 95% confidence intervals. Grey points indicate model partial residuals. Comm, commercial fishing; rec, recreational fishing.

the median fork length of those fish which survived (108 cm) was higher than of those which did not survive (93 cm) (Fig. 9).

Movements of tagged fish were quite variable, with some fish only moving short distances in a localised area, and others travelling much further. This included an individual that travelled at least 127 km in 4 days (Fig. 10b) and another which swam from the Sunshine Coast to offshore from Stanage in 36 days, a minimum distance of 630 km (Fig. 10d). Fish tagged in the same area generally travelled in different directions, rather than showing a clear directed migration pattern.

Fish tagged during spawning aggregations at reefs offshore from Lucinda showed a range of movements, with none appearing to remain on the same reef for the whole tag deployment duration (Fig. 10a).

Discussion

Shark depredation

The current study was the first to quantify shark depredation rates in the Queensland East Coast Spanish mackerel fishery, providing important data on the extent of additional fishing mortality occurring as a result of shark depredation. The shark depredation rate recorded in the current study for the commercial fishing trips (6%) was very similar to that recorded on fishing grounds off Townsville in 1980, where 17 of 293 fish hooked were depredated (5.8%) (McPherson 1981). However, in other regions of Queensland where fishing was conducted, depredation rates were negligible (McPherson 1981). In the Western Australia Mackerel Managed Fishery, reported depredation rates ranged from 1.7 to 5.7% across the different fishery regions, with a marginally increasing trend over time (Carmody *et al.* 2021). The depredation rate in the current study also falls within the lower end of the 0.9–26% range of depredation rate values previously recorded in studies across many commercial fisheries worldwide (Mitchell *et al.* 2018a).

However, the recreational depredation rate recorded in the current study was much higher (36%). This rate is corroborated by data from an ongoing boat ramp survey program that has been collecting shark depredation data for a range of species at >45 boat ramps across Queensland, since 6 July 2023 (Fisheries Queensland, unpubl. data). The boat ramp survey data show that on trips where depredation occurred, 30–47% of the catch was lost to shark depredation, with highest depredation occurring in the Wide Bay and Burnett region and lowest in the Far North region (Fisheries Queensland, unpubl. data). The overall percentage of recreational trips where depredation occurred was higher in the current study (54%), v. in the boat ramp survey data (36% across 704 trips) (Fisheries Queensland, unpubl. data). Depredation rates across 68 recreational trolling trips targeting pelagics in north-western Western Australia were lower, at 11.8% (Mitchell *et al.* 2018b), although this included species other than *S. commerson*. A study in Florida recorded a depredation rate of 20% in the commercial trolling fishery for king mackerel, *Scomberomorus cavalla* (Cuvier, 1829), although bottlenose dolphins, *Tursiops truncatus* (Montagu, 1821), were responsible for depredation in this case (Zollett and Read 2006).

Sector had a significant effect on number of fish depredated per trip in the GLM, explaining 28% of deviance in the response. The large differences in depredation rates between commercial and recreational trips likely occurred for a variety of reasons. First, mean depredation rates are expected to be inherently lower in commercial fishing because recreational fishers' catches were limited due to the low recreational bag

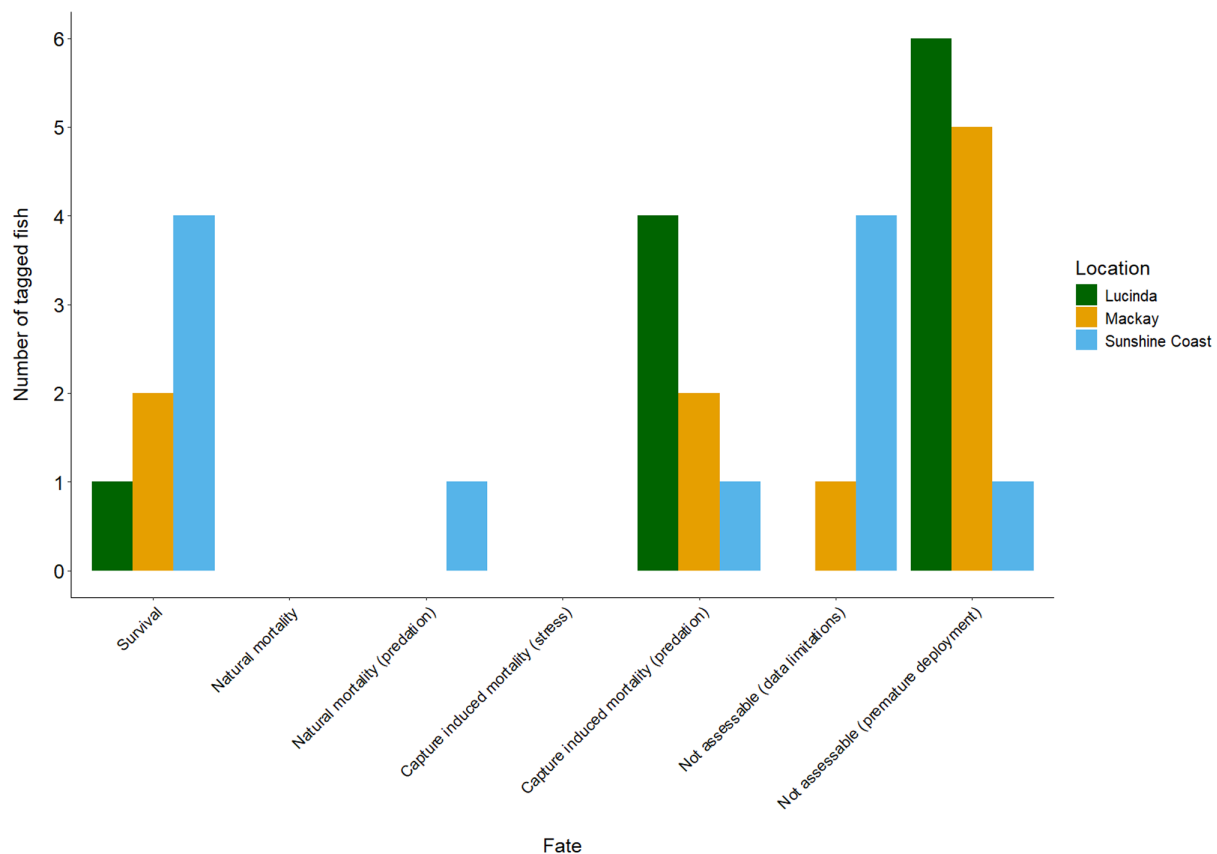


Fig. 5. Fate classification of tags by region. Green bars indicate *Scomberomorus commerson* tagged in Lucinda, with yellow for Mackay and blue for the Sunshine Coast.

limit. Therefore, a recreational fisher could land one fish and lose one fish to shark depredation and the resulting depredation rate would be 50%. Conversely, commercial fishers sometimes caught over 20 fish in 1 day, so the proportional loss of fish to depredation would be expected to be lower. Differences in depredation rate between commercial and recreational fishers may have also been driven by differences in the fishing gear used. Commercial fishers mainly use electric reels and winches, which are faster to retrieve hooked *S. commerson* than the rods and reels typically used by recreational fishers. Additionally, commercial fishers generally spend a greater amount of days on the water, resulting in increased experience and knowledge of the spatial patterns in shark depredation, so they know which areas to avoid because depredation may be high. Commercial fishers also often target less frequently visited fishing sites, which tend to have lower shark depredation rates because less behavioural conditioning of sharks occurs in these areas (Mitchell *et al.* 2018b). This was evident for the commercial fishing trips in the Far North region, which had very low depredation rates. Last, the fact that depredation rates were self-reported by the recreational fishers compared with collected by observers for the commercial trips, may have led to differences in the way data were recorded and their representativeness.

Latitude also had a significant effect on number of fish depredated in the GLM, with a linear increase in depredation with increasing latitude. This result potentially reflected the influence of increased concentration of commercial and recreational fishing activity in the southern part of Queensland, where a higher proportion of the population is located. Indeed, there was a very low incidence of depredation (1 fish depredated of 153 hooked) in the 21 fishing trips which occurred at ~12°S, which is a remote part of Far North Queensland where little fishing activity occurs. Higher concentration of fishing vessels has been found to lead to higher depredation in a previous study of recreational fishing in Western Australia (Mitchell *et al.* 2018b). Carmody *et al.* (2021) reported that depredation rates in the Western Australia commercial mackerel fishery were positively correlated with distance to town centre; however this metric did not have an important influence in the current study, perhaps because there is a more consistent and frequent occurrence of towns along the Queensland coast than across north-western Western Australia.

Recent research in Queensland has identified the shark species responsible for depredation, by collecting genetic swab samples from partially depredated fish and broken off fishing line (Vardon 2025). *Scomberomorus commerson* was

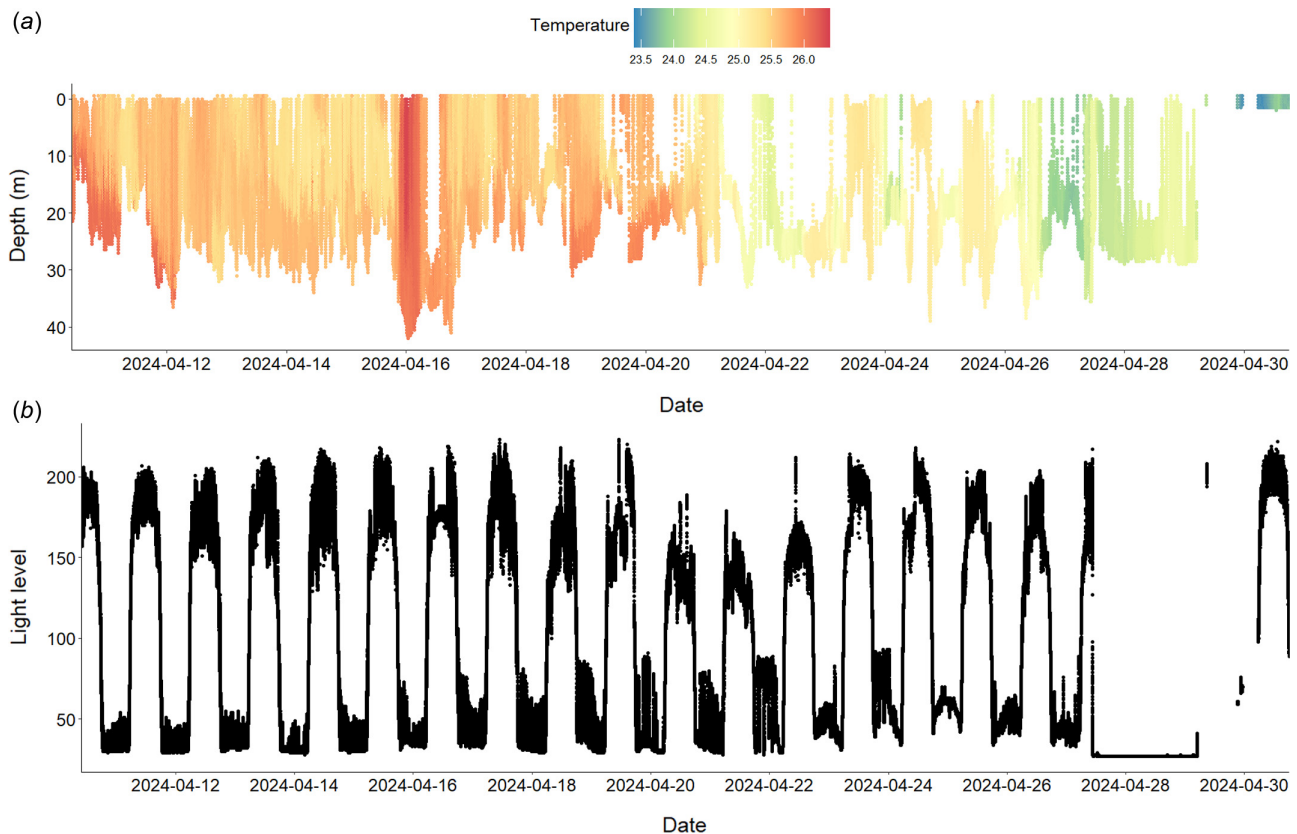


Fig. 6. Combined (a) depth-temperature and (b) light level timeseries for *Scomberomorus commerson* tag 245430.

the third-most depredated species in this study and depredation was identified to be caused primarily by bull sharks, *Carcharhinus leucas* (Müller & Henle, 1839), grey reef sharks, *Carcharhinus amblyrhynchos* (Bleeker, 1856), pigeye sharks, *Carcharhinus amboinensis* (Müller & Henle, 1839) and sandbar sharks, *Carcharhinus plumbeus* (Nardo, 1827), as well as other whaler (Carcharhinid) shark species (Vardon 2025). It is important to consider that the shark species responsible for depredation are likely to vary substantially throughout different regions, depths and seasons due to the movement dynamics and behaviour of the shark species.

The depredation data collected from the current study were directly incorporated into the 2025 stock assessment for Queensland East Coast Spanish mackerel (Sumpter *et al.* 2025), on the basis of recommendations from the previous stock assessment in 2021, which used an estimated depredation rate not informed by empirical data (Tanimoto *et al.* 2021). The 2025 stock assessment included separate rates for commercial and recreational fishing depredation. For commercial fishing, the depredation rate was fixed at 6% across the timeseries used in the stock assessment model, because of the consistent rates being recorded in both the current study and in McPherson (1981). Conversely, for the recreational fishery, depredation rates in the model were increased from 12% (a nominal value representing double the commercial rate) in 2009 to 36% in 2024 (Sumpter *et al.* 2025). This increasing index was used

to account for changes over time reported by experienced fishers, which are theorised to have been driven by changes in shark behaviour, reduction in trawl fishing discards for sharks to feed on and recovering shark populations due to increased management restrictions on commercial shark fishing in 2009 (Sumpter *et al.* 2025). The combination of commercial and recreational fishing depredation rates were included in the stock assessment model by making adjustments to the catch estimates for each year to account for depredation (Sumpter *et al.* 2025). This stock assessment was one of the first globally to incorporate shark depredation directly into a stock assessment model, so it will act as an important guide for other fisheries also looking to account for the effect of cryptic mortality from shark depredation on stock biomass.

This study showed that shark depredation is having a substantial effect on the Queensland East Coast Spanish mackerel fishery, particularly for recreational fishers. Modifications to fishing methods can provide some benefit for mitigating shark depredation, including switching from standard rod and reel setups to electric reels or winches, motoring forwards to retrieve a fish once it is hooked, using lures instead of bait (especially live bait) to reduce the odour cues likely to attract sharks, moving fishing location regularly, not revisiting the same sites multiple days in a row, not dumping fish waste or burley near fishing sites, and leaving a location if a shark is sighted on the echosounder (Coulson *et al.* 2022; Mitchell *et al.* 2024).

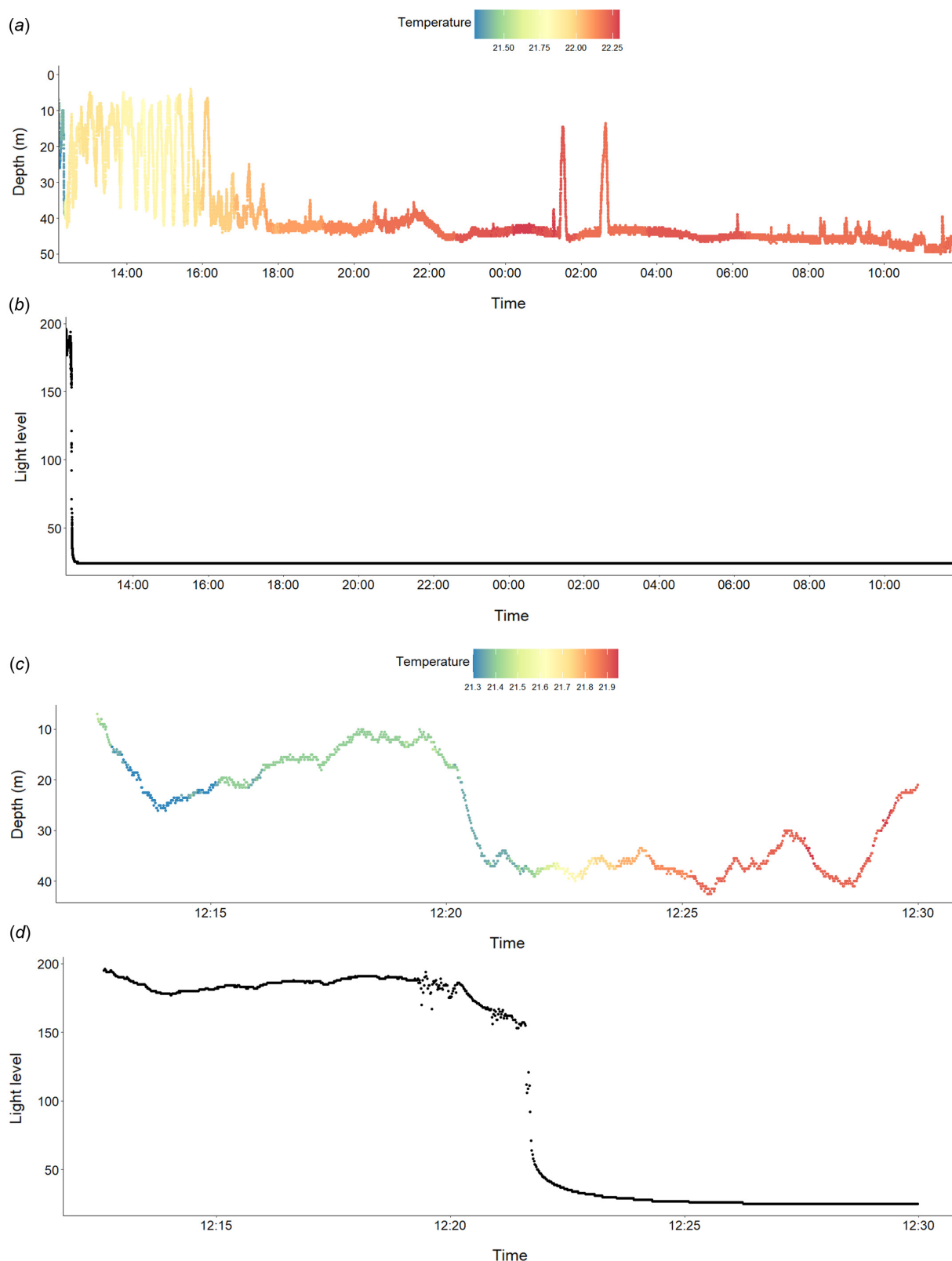


Fig. 7. Combined depth-temperature and light level time series for *Scomberomorus commerson* tag 245410. (a) Depth-temperature for first 24 h of deployment; (b) light level for first 24 h of deployment, with rapid drop in light levels shortly after release indicating predation; (c) depth-temperature for first 30 min after release; (d) light level for first 30 min after release, further indicating the rapid drop in light level.

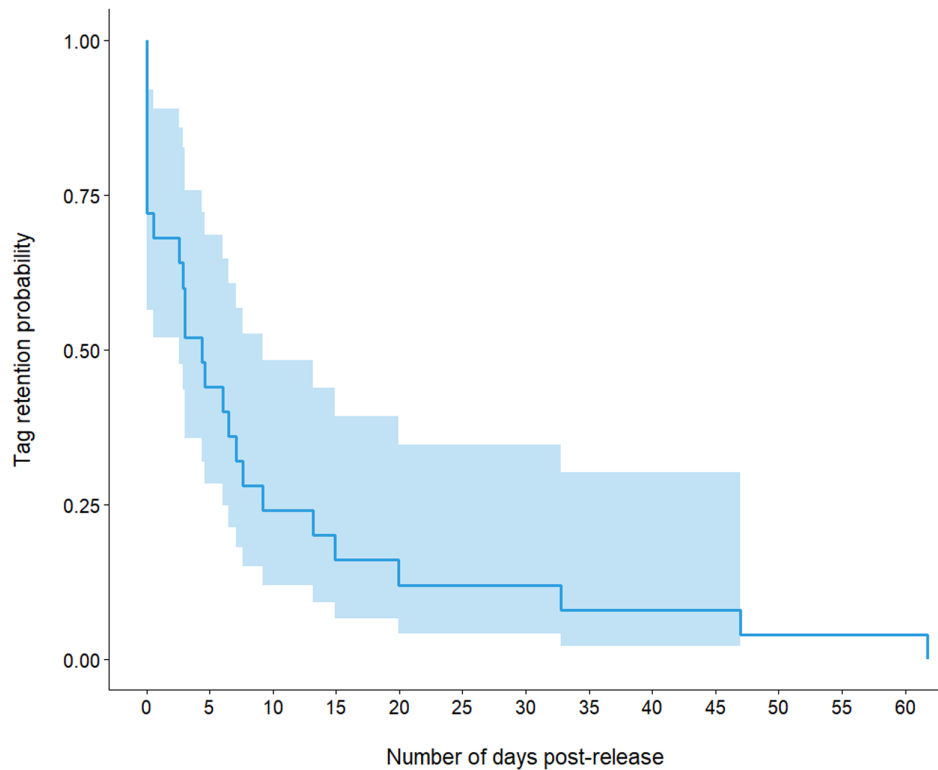


Fig. 8. Tag retention probability over time (days post-release). Model fitted values are indicated by the solid blue line, with 95% confidence intervals denoted by blue shading. Seven tags were excluded from this analysis due to not having a pop-up date.

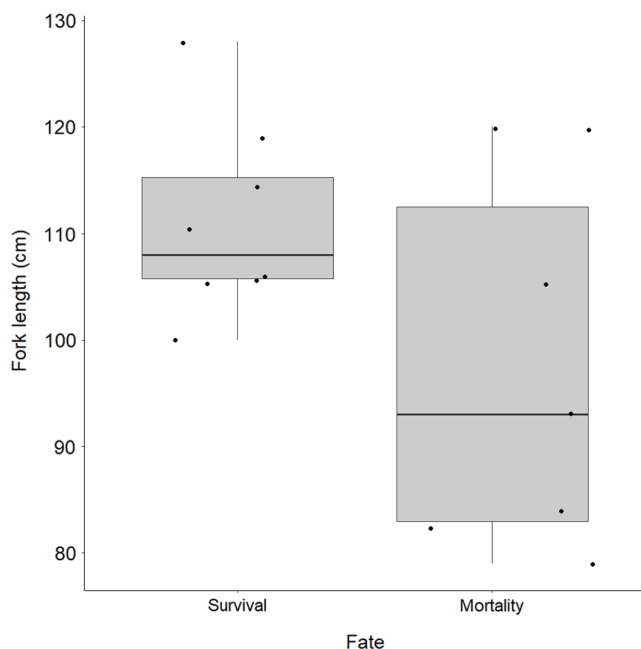


Fig. 9. Fate of satellite tagged *Scomberomorus commerson* compared with fork length in centimetres.

However, these methods can be limited in their effectiveness (Coulson *et al.* 2022); so, further research is needed to investigate other methods of mitigation. An ongoing national-scale project is exploring suitable methods for mitigating shark depredation in Australian line fisheries, by combining a global literature review, a series of stakeholder workshops, and an online survey to identify and rank promising methods for future testing on a large scale (J. D. Mitchell, unubl. data). Ultimately, managing and reducing the impacts of shark depredation will be critical for the sustainable management of this fishery into the future.

Post-release survival

The results of satellite tagging 32 *S. commerson* in different regions of Queensland showed a post-release survival rate of 53%. Although no other satellite tagging studies have been conducted on this species to compare mortality rates with, work by Tobin *et al.* (2014) tagged *S. commerson* with external acoustic transmitters to investigate movement patterns at spawning reefs in northern Queensland. Tobin *et al.* (2014) found that 50% of the 44 fish tagged in the first year and 27% of the 62 fish tagged in the second year were never detected, providing an approximate assessment of survival rates. Yet,

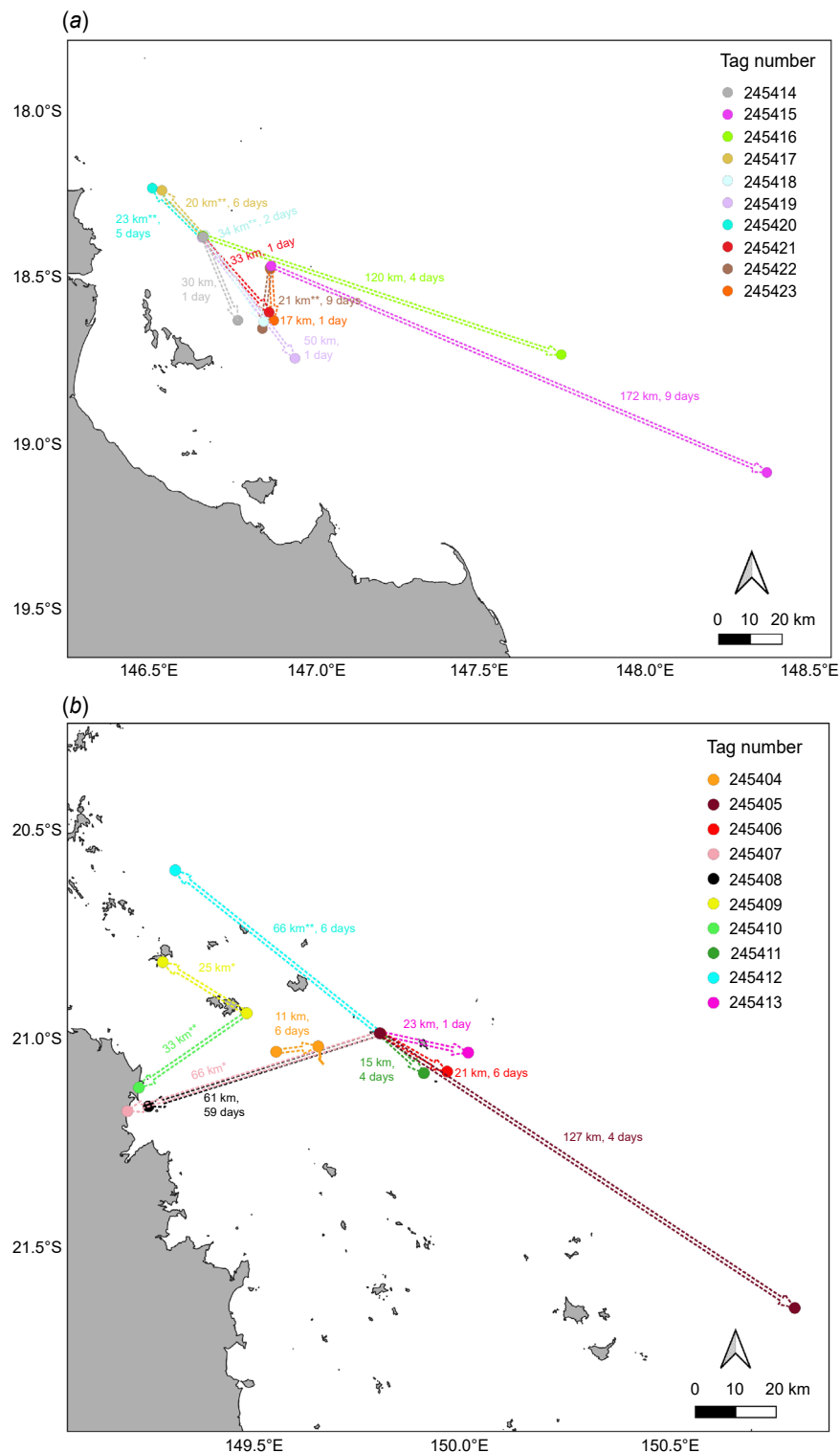


Fig. 10. Maps of *Scomberomorus commerson* minimum straight-line movements, calculated from the tagging and tag pop-up locations. (a) Fish tagged near Lucinda, (b) Mackay, (c) Sunshine Coast, and (d) a long-distance movement for a fish tagged at the Sunshine Coast. Approximate distances based on where tags were found, instead of the pop-up locations, are indicated by an asterisk (*). Where part of the movement was that of a predator that ingested the tag after preying on the tagged *S. commerson*, it is indicated by a double asterisk (**).

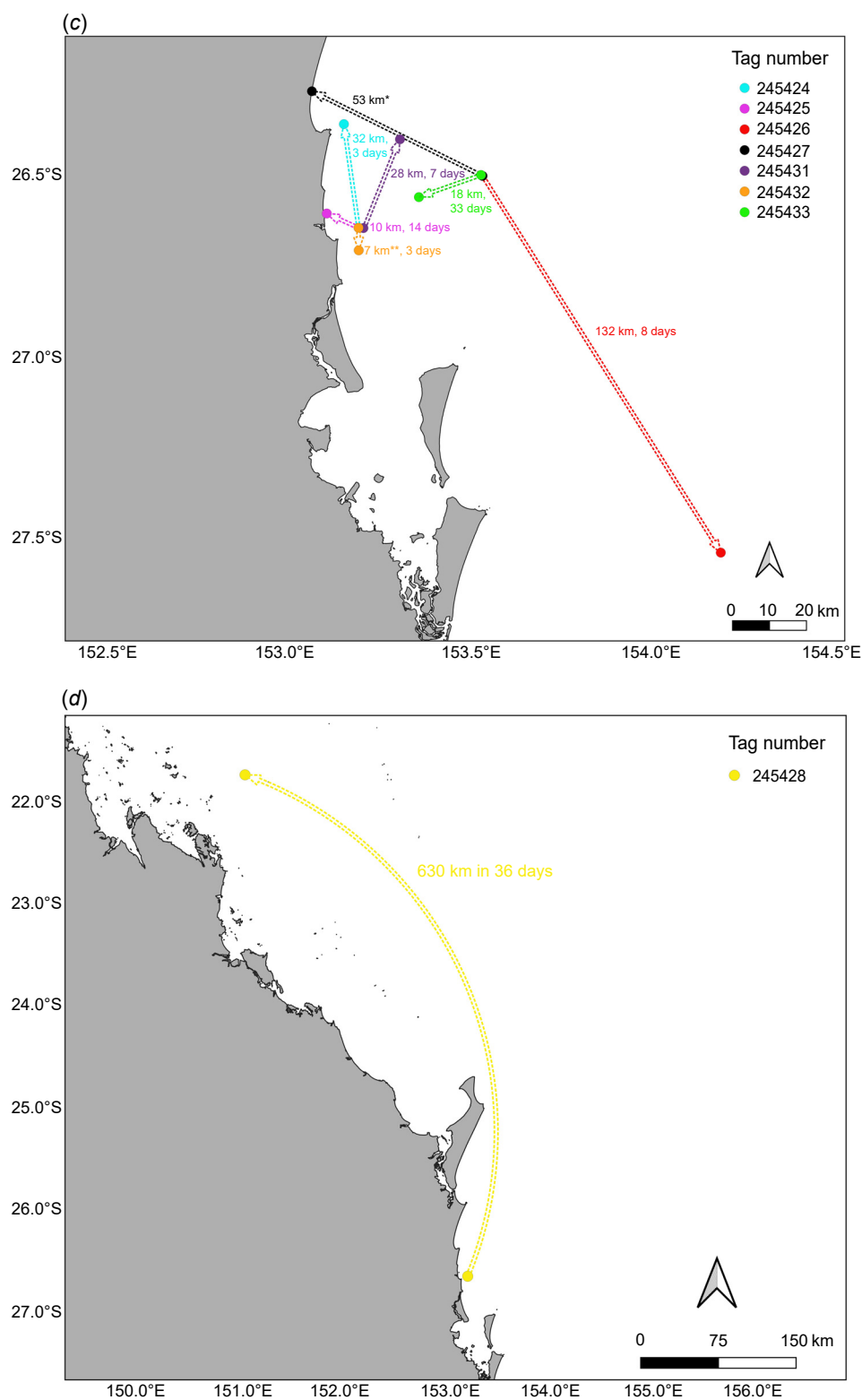


Fig. 10. (Continued).

this result likely underestimated survival rates because some fish may have survived but not been detected by the acoustic receivers due to leaving the area or shedding the tags. Similarly, the current study used a cut-off of 5 days to indicate survival of tagged *S. commerson*; however, this may have underestimated post-release mortality, because some studies suggest that impairment from the capture process can result in mortality 10–30 days after release, including from post-release predation (Musyl and Gilman 2019; Benoît *et al.* 2020; Kneebone *et al.* 2021). Yet, in the current study, using a longer cut-off time would not have been viable due to the higher rate of tag shedding.

The survival rate in the current study was similar to the 50% used as an estimate in the 2021 Queensland East Coast Spanish mackerel stock assessment (Tanimoto *et al.* 2021). The new empirical data for survival generated in the current study were used in the 2025 stock assessment to improve the accuracy of the fishing mortality metric used in the stock assessment model (Sumpter *et al.* 2025). The survival rate was variable across the three regions where fish were tagged, likely due to the presence and behaviour of sharks, similar to the depredation results. Specifically, post-release predation was highest for fish tagged at Lucinda, which may have occurred because these fish were tagged during spawning season, where large numbers of *S. commerson* aggregate on reefs near Lucinda (Tobin *et al.* 2014). These aggregations would likely attract higher numbers of sharks into the area, which is supported by the result that Lucinda had the highest median level of shark depredation in the current study. The presence of *S. commerson* and other reef fish spawning aggregations were theorised to be a factor influencing seasonal movements of bull sharks into the central Great Barrier Reef region (Espinoza *et al.* 2016) and higher shark abundance and residency has been reported at other fish spawning aggregations around the world (Mourier *et al.* 2016; Rhodes *et al.* 2019). However, the low overall number of datapoints in this study should be noted when interpreting these results, and other environmental and operational factors could have also influenced the variation in post-release survival by region.

The survival rates of *S. commerson* in the current study were lower than the <80% reported for large pelagic fish, such as black marlin, *Makaira indica* (Cuvier, 1832), sailfish, *Istiophorus platypterus* (Shaw & Nodder, 1792) (Musyl *et al.* 2015), *T. maccoyi* (Tracey *et al.* 2016), and swordfish, *Xiphias gladius* Linnaeus, 1758 (Tracey *et al.* 2023). However, in the current study, mortality appeared solely due to the influence of post-release predation of *S. commerson* by sharks; there was no evidence of capture-induced mortality due to reasons other than predation (although some fish may have died as a result of injuries or the stress of capture had they not been predated on). The high rate of post-release predation recorded here was contrary to most other studies looking at post-release survival of large pelagic fish, where predation accounts only for a minor portion of mortality. Evaluation of *M. indica* by Pepperell and Davis (1999) and observations from Williams

et al. (2017) reported post-release predation levels of 12.5 and 5% predation of tagged fish in northern Queensland respectively, and Sepulveda *et al.* (2020) reported that only one individual of 40 tagged northern bluefin tuna, *Thunnus orientalis* (Temminck & Schlegel, 1844), was predated. *Scomberomorus commerson* is generally smaller and therefore potentially more vulnerable to predation than are the larger species such as marlin, which have been the focus of most previous pelagic post-release survival studies (Musyl *et al.* 2015; Graves *et al.* 2016). Indeed, there was also evidence of a potential natural predation event on tag 245430 ~17 days after release, further highlighting the natural vulnerability to predation of this species. Yet, it is possible that this mortality resulted, in part, from longer-term impacts to fitness from catch and release. In general, post-release predation is an understudied component of mortality across all studies on fish, with Raby *et al.* (2014) finding that <2% of studies on bycatch and catch-and-release investigated post-release predation. The current study therefore makes an important contribution to better understand its impact on overall fishing mortality.

Smaller fish had a lower survival rate than larger fish in the current study, possibly due to increased stress from capture; for example, higher blood lactate levels have been reported for smaller *T. maccoyi* (Tracey *et al.* 2016) and they have a reduced ability to evade predators after release (Raby *et al.* 2014). The minimum landing size for *S. commerson* in Queensland is 75-cm total length, which is below the minimum length at maturity of 79-cm fork length (McPherson 1993). Therefore, on the basis of the results of the current study, which showed 100% mortality for fish of <95 cm, it is likely that undersize immature fish released by recreational fishers will have a high mortality rate. The hydrodynamic drag caused by the tag itself could have also contributed to reduced ability to evade predators in the smaller fish tagged in this study.

The sPAT tags deployed on *S. commerson* in the current study provided useful information on movement patterns. The majority of tagged fish exhibited localised movements of less than 50 km after release, although five fish did move greater than 50 km in a short time (<10 days). These longer distance movements away from the area of tagging may have potentially represented a flight response to the stress of capture. Higher tailbeat frequencies and activity levels after release have been documented in *T. thynnus* for 5–10 h after release (Gleiss *et al.* 2019; Dolton *et al.* 2022). Conversely, the movements away from the tagging locations in the current study could have been part of the normal migratory movements of the species, where some individuals migrate from northern Queensland down to mid-New South Wales in austral summer months, followed by a return migration in austral autumn and winter (Buckworth *et al.* 2007). Indeed, the longest movement detected in the current study was a northward movement of over 630 km in 36 days in April–May 2024, which supports this seasonal migration pattern. However, an acoustic tagging study of *S. commerson* in the

Great Barrier Reef Marine Park found that most tagged fish spent more time on the same reef where they were tagged, as opposed to moving to other reefs, with tagged fish remaining within the array for up to 152 days (Tobin *et al.* 2014). Tag and recapture data from the New South Wales Gamefish Tagging Program (NSW GFTP) has also recorded a similar pattern of mostly short-distance displacements, with a mean distance travelled of 107 km and a mean time at liberty of 389 days for 104 fish tagged and recaptured (NSW DPIRD, unpubl. data). A small number of longer-distance movements were also recorded; for example, a fish travelled 888 km from Ulladulla in New South Wales to Mackay in northern Queensland in 29 days and another from Nambucca Heads in New South Wales to the Ribbon Reefs in northern Queensland in 566 days (NSW DPIRD, unpubl. data). Overall, recapture rates in the NSW GFTP were low at 1% (109 fish recaptured of 10,569 tagged), highlighting the importance of using more active tagging methods to assess movement patterns and post-release survival. The satellite tagging conducted in the current study provided high-resolution data on survival, depth, temperature and movement patterns of *S. commerson*, which are valuable for better understanding their ecology.

Early tag shedding affected many of the satellite tags deployed on *S. commerson*, with 50% of the tags shed within ~4 days. This study was the first to satellite tag *S. commerson*, therefore, no prior information about the best form of tag anchors was available. Both plastic Domeier dart heads ($n = 17$) and flat metal tag heads ($n = 15$) were used (Table S2), with the former having greater success (average tag deployment duration of 346 h and 11 min for Domeier v. 73:35 for metal), due to their greater ability to lock into the flesh and pterygiophores of the fish. Ensuring that the tag head was inserted at a 45° angle into the muscle underneath the dorsal fin until it locked in between the pterygiophores, as identified by practising on dead Spanish mackerel, was paramount for ensuring improved tag retention. Tag placement technique improved throughout the study on the basis of experience, as more fish were tagged. Tag shedding is a common occurrence that has affected other studies working on large pelagic fish using this form of tag and can occur due to the soft flesh of the fish and the difficulty in getting correct tag placement (Pepperell and Davis 1999; Rohner *et al.* 2021). To improve tag retention, other methods could be utilised for future research, such as double dart, cinch up or threaded rod attachments (Runde *et al.* 2022). In addition to the tags which had premature deployments, five tags failed to report the necessary data to determine fate of the fish. Failure in data reporting is a common issue for sPAT and miniPAT tags (Sepulveda *et al.* 2020) and can occur for a range of reasons, for example physical damage to the tag during an attempted predation event or due to water ingress (Lam *et al.* 2022).

Conclusions

The empirical data on shark depredation produced by the current study were recently incorporated in the Queensland East Coast Spanish mackerel stock assessment conducted by the Queensland Government in 2025 (Sumpter *et al.* 2025). In this assessment, the depredation rate for the commercial sector was kept constant at 6.02%, whereas the recreational depredation rate was increased from 12.04% in 2009 to 36.58% in 2025 (Sumpter *et al.* 2025). This increase was incorporated to reflect anecdotal reports of rising depredation, which may have been driven by recovery in shark populations because of reduced commercial harvest, and reduced trawl discards for sharks to feed on, which could have led to them depredating catch from other fishing vessels instead (Sumpter *et al.* 2025). The incorporation of these empirical data addressed a key recommendation made in the previous stock assessment in 2021 (Tanimoto *et al.* 2021), which was also emphasised by fishers. Importantly, the empirical data provided a more accurate representation of depredation rates than did the estimated approach used in the 2021 assessment, which assumed a depredation rate of 0% in 2009, increasing by 1.8% per year, up to 20% in 2020 (Tanimoto *et al.* 2021). Similarly, the post-release survival estimate produced by the current study was incorporated into the 2025 assessment (Sumpter *et al.* 2025), improving on the arbitrary value used in the 2021 assessment (Tanimoto *et al.* 2021). Future research should aim to continue collecting data on shark depredation rates in the commercial and recreational *S. commerson* fishery, to track trends over time and thus accurately account for this source of cryptic mortality. Further satellite tagging should also be pursued, to increase the data availability and enable more detailed statistical analysis of the range of factors that may be influencing survival rate, such as gear type used, handling practices and air exposure time. Blood sampling to measure levels of key stress indicators, such as lactate, glucose and pH (Skomal 2007), could also be incorporated into this work, to provide a physiological assessment of the impact of catch and release on *S. commerson*. This integrated approach will enable the designing and dissemination of best-practice guidelines for fishers, to further improve post-release survival rates in this fishery. The approach used in this study to quantify shark depredation and post-release survival rates and incorporate them into the stock assessment provides a useful guide for other fisheries looking to improve management and assessment of *S. commerson* across other parts of its range. More broadly, the methodology and results of this study are also informative to a growing number of other fisheries around the world where depredation is occurring but remains unassessed and unmanaged.

Supplementary material

Supplementary material can be accessed from the article page online.

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Ethical statement. Tagging was conducted under Animal Ethics approval from the Queensland Government Animal Ethics Committee (permit number CA 2023/03/1697). Tagging in the Lucinda region was conducted under approval from the Great Barrier Reef Marine Park Authority (research permit number G49661.1).

Data availability. All data relating to this research are presented in Table S1 and S2 in the Supplementary material and are available on request.

Conflicts of interests. The authors declare that they have no conflicts of interest.

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