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ESTIMATING POST-RELEASE MORTALITY OF LONG-LINE CAUGHT TROPICAL TUNAS IN THE PACIFIC OCEAN

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Estimating post-release mortality of long-line caught tropical tunas in the Pacific Ocean

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Abstract

Post-release mortality experiments were undertaken on bigeye (*Thunnus obesus)* and yellowfin (*T. albacares*) tuna to assess potential post-release survival probabilities of conventional tagging on such individuals during commercial longline operations. Survival was estimated from the release of 32 tuna tagged with pop-up, satellite survivorship tags (sPATs) during a commercial fishing trip aboard a Hawaii based tuna longline vessel. The tagged fish ranged in size from 103-145 cm fork length in size. Of the 32 sPATs released, 27 reported earlier than the pre-programmed 60 days, and five never reported. Of the 27 tags that reported data one tag appeared to shed early while the fish was still alive and swimming 32 days post-release while the remaining 26 tags deployed early due to mortality or other events, as observed through either sinking, ingestion by predators, or detached tags. Most mortalities occurred within four days post-release. The overall survival probability was estimated at around 10%, with some evidence that reduced time on the hook may increase this probability up to 50%. These results suggest that bigeye and yellowfin tuna caught during typical longline operations are unlikely to be suitable for electronic or conventional tagging experiments. Our study also suggests all discarded tuna should be treated as mortalities (including those discarded alive) for stock assessment purposes.

Key words: bigeye, yellowfin, sPAT, Hawaiian Islands, capture-mark-recapture

1. Introduction

Understanding post release mortality aids in the development of non-retention, catch and release policies and the design of monitoring programs for fisheries globally (Davis, 2002; Cooke and Shramm, 2007; Ellis et al., 2017; Reinhardt et al., 2017). Fishing mortality (F) (of recovered gear) can be split into two components, at vessel ($F_{capture}$) and, for animals released alive after capture, the mortality that may occur after release ($F_{release}$) (Campana et al., 2009; Carruthers et al., 2009; Gilman et al., 2013; Musyl et al., 2011; 2015). $F_{capture}$ can be considered in its general form as either an instantaneous or annual fishing mortality (Piet et al. 2007), typically estimated using the number of observed and recorded dead animals caught, whereas estimating $F_{release}$ is more challenging as individuals are no longer observed once they are released alive from the fishing gear. Estimated rates of $F_{release}$ vary considerably across taxa, gear types and environments (e.g. Eddy et al., 2016; Ellis et al., 2017; Musyl and Gilman, 2019; Nunes et al., 2019; Gil et al., 2020) and mortality due to the fishing interaction can be immediate or delayed for more than one-month (Swimmer et al., 2006; Musyl and Gilman, 2018; Schweitzer et al., 2020).

Non-retention of bycatch species often occurs in fisheries either for conservation purposes or the lack of a market for the product (Chan et al., 2014). 'High-grading' of target species can also occur for market purposes when the price for particular size classes are low in comparison to other sizes (Robertson, 1998; Huang and Liu, 2010). Estimates of non-retained catch and subsequent $F_{release}$ can be important for accurate stock and ecological risk assessments, particularly where non-retention rates are high (Cook, 2019) or in fisheries where quotas are derived from models that integrate total mortality information (Punt et al., 2006).

$F_{release}$ can also influence the design of Capture-Mark-Recapture (CMR) and biotelemetry studies (Brownie and Robson 1983). Such studies are widely used in fisheries science to estimate population parameters such as age/size specific mortalities (Polacheck et al., 2010), abundances (Schwarz and Seber, 1999; Bird et al., 2014), movement (Sibert and Hampton, 2003), and individual growth (Eveson et al., 2015). Increasingly CMR experiments are being applied in the research and management of tropical tuna fisheries (Fonteneau and Hallier, 2015; Leroy et al., 2015; Murua et al., 2015). The intent of CMR experiments is to mark a subset of the population and then monitor the population through recaptures of the marked fish. Population parameters can then be estimated for the size or age classes that the marked population aims to represent.

In the Western and Central Pacific Ocean (WCPO) the most applied method for capturing large numbers of live tuna for CMR has been the use of pole and line fishing techniques (Leroy et al., 2015). To a lesser extent, dangling, handline and sportfishing on targeted CMR trips for bigeye (*Thunnus obesus)* and yellowfin (*T. albacares*) has yielded some individuals in the 70-130 cm fork length (FL) in size, but not enough have been captured using these methods to form a meaningful conclusion on $F_{release.}$ Pole and line is the most effective fishing technique for fish less than 70 cm FL in size as they can be rapidly brought on board a fishing vessel in large numbers and in a condition suitable for marking (Leroy et al., 2015). For tropical tuna species such as bigeye and yellowfin tuna which can grow to lengths in excess of 150 cm FL, obtaining a tagged population that is representative of all age/size classes has been dependent on the marking of sufficient numbers of <70 cm fish to permit a proportion of this marked cohort to survive until they reach larger size classes. Alternatively, these larger size classes can be caught, marked and released directly.

The largest commercial catches of bigeye and yellowfin tuna in the WCPO come from purse-seine and longline fisheries (Williams and Ruaia, 2020) with purse-seine vessels typically catching fish of <90 cm FL in length, and longline vessels catching those >90 cm in length. Thus far, CMR experiments for yellowfin and bigeye in the WCPO have resulted in few recaptures of individuals in larger size classes (SPC-OFP, 2020). Consequently, assessments of these stocks have little CMR data to integrate for estimating mortalities associated with the longline fisheries. It remains unclear if the reason for low recaptures is due to an insufficient number of marked individuals of larger size classes being present in the population or that tag recaptures are simply under reported in longline fisheries. To address the former, longline caught individuals that are alive and considered in a healthy condition can be marked and released to increase tagged individuals in these size classes directly (ICCAT 2019).

In the WCPO in 2019 the non-retained catch of bigeye and yellowfin in longline fisheries was 2.4% and 2.1% for each species respectively (Williams, 2020, *Suppl. Mat.* Figure S1). Although fisheries observers collect information on fish condition at release (alive healthy, alive injured and distressed, alive but dying, dead), all non-retained bigeye and yellowfin catches in the WCPO are assumed dead for stock assessment purposes (Williams, 2020).

Survivorship pop-up satellite tags have been used to estimate post-release mortality in tuna species caught within recreational fisheries (Kneebone et al. 2021). Here, we describe a similar study applied to longline caught and released bigeye and yellowfin tuna to investigate the $F_{release}$ of these species caught on longline fisheries operating in a commercial setting. We examine our results to inform (i) the design of future CMR experiments for bigeye and yellowfin tuna and (ii) total F estimates used in stock assessments for these species.

2. Methods

2.1 Marking

Thirty-two survival pop-up archival transmitting tags (sPATs, Wildlife Computers, Inc. Redmond, WA) were deployed on bigeye and yellowfin tuna by a specialist tagging technician in the Hawaiian Islands Exclusive Economic Zone and neighbouring high seas between 18 November -13 December 2020. The tags were deployed from the catch of a US-flagged fishing vessel during normal longline fishing activities.

The fishing vessel's longline consisted of 1000 lb test monofilament mainline, deployed and retrieved from a hydraulic spool (Lindgren Pitman (LP), Inc. Pompano Beach, FL), mounted on the aft portion of the house of vessel. The mainline was deployed on the port side of the vessel with a line shooter, also manufactured by LP. The speed of this line shooter can be adjusted so that gear can be targeted to different depths. The crew deployed plastic floats on 20 m float lines (per US regulations) and branch lines were 10 m long and composed of 2.1 mm diameter monofilament, to a 45-gram leaded swivel with a 30 cm braided wire trace and a baited 15/0 offset stainless steel ringed circle hook. Floats and branch lines were attached to the mainline at given time intervals, announced with a hook and float timer, and manufactured by LP. Additionally, five "radio" buoys were attached at the beginning and end of the line, and at each quarter. These buoys, manufactured by Marine Instruments, relay position, drift speed and direction, and water temperature every 10 minutes, and are displayed in a proprietary program on the vessel's bridge. This allowed the Captain to actively monitor the line's drift during and after the set and allow for gear recovery in the event of a parted mainline. Oceanographic factors, mainly sea-surface temperature, sea-surface height, and surface current were updated every second day on Orb-Image programming, and the captain identified favoured areas for setting considering these factors.

Setting occurred at or soon after daylight, depending on when the previous day's haul was completed. Haul completion was frequently late, causing the subsequent set to be delayed later in the day. Hauling on the starboard side of the vessel began at or around sunset and lasted 10-16 hrs. The vessel set 32-40 nm of horizontal distance (the actual distance of the mainline is much more due to the use of the line shooter) and 2500-3280 hooks which was typical of the Hawaii based longline fishery. Bait species used included pacific saury (*Cololabis saira*) and sardine (*Sardinops sagax)*. Depth of set was targeted at or below the thermocline, which in most cases was 130-165 m, with 24 hooks per float.

Only fish considered as appropriate for tagging by the tagging technician were selected and tagged. During the hauling operation, tagging candidates were identified, if the fish, at leader was swimming and pulling strongly and did not have visible "line rash", and abrasion on the skin caused from the fish being on the hook for an extended period of time and chafing against the line. Once the fish was identified as appropriate for tagging, a 120 cm half-moon shaped aluminium landing net with knotless webbing was used to bring the fish onboard (Figure 1). Because of the size of the tuna being landed (some in excess of 65 kg), at least 3 crewmen were required to lift the netted fish through the door and carefully place it on the matted deck for tagging. After another quick assessment for any other obvious damage to the fish (eye damage, excessive bleeding), the hook was removed, and the sPAT was placed in the pterigiophores of the second dorsal fin using a titanium pronged applicator. On the opposite side of the second dorsal fin, a 13 cm yellow conventional dart tag with recapture information was also placed. The fish was measured to the nearest centimetre using an aluminium calliper and then gently released overboard, with time and apparent condition at release noted. Species, float number, hook number and time and date of release were also recorded. The sPATs were programmed to "pop-off" 60 days after deployment. Each sPAT was rigged using a 10 cm monofilament tether and titanium anchor.

2.2 Survival PAT Data

The 32 sPATs were programmed to burn through their tether pin to "pop-up" on either the 60th day after deployment, once a critical depth limit of 1700 m was reached, or once the tag was floating at the surface for 24 hours. On reporting, sPATs provided daily minimum and maximum depths and external temperatures, alongside the relative change in ambient light level during the entire deployment. Higher resolution depth and temperature data from the final 5 days prior to reporting were also transmitted to aid in classification of fate and behaviour.

The data from each reporting sPAT was examined to determine the fate of the tagged fish. Fate was classified as death through either predation or stress/injury following the longline capture and tagging process, or survival through the sPAT either reporting at the programmed 60-days of liberty or with evidence of erroneous, early detachment. Predation was identified by ingestion of the tag, indicated by reduced changes in ambient light and temperature, followed by expulsion and floating of the tag to enable its reporting via satellite. When fate was classified as death, the number of days of survival was estimated to the nearest day by examination of the transmitted behavioural data.

2.3 Data Analyses

Cox regression models were fitted to the data in a survival analysis, using the number of days until apparent mortality as the response variable, and with tags that appeared to indicate survival to the end of the 60-day reporting period treated as right-censored. Species, length, and recorded fish condition were all considered as potential predictors of death rate. The effect of float position in the set at which the fish was landed, and hook number from float were also examined, as a potential proxy for time spent on the hook and depth, respectively.

3. Results

3.1 sPAT Reporting

During the 25-day cruise, 15 normal length sets and one short set (*Suppl. Mat.* Table S1) were made and nearly 6000 kgs of pelagic fish were landed. In addition to the primary target of bigeye tuna, 12 other marketable species of pelagic fish, three unmarketable, and five species of pelagic sharks were caught during the trip. sPATs were deployed on 26 bigeye and six yellowfin tuna (*Suppl. Mat.* Table S2).

Of the 32 sPAT tags released, 27 reported earlier than the pre-programmed 60 days, and five never reported. The five non-reporting tags may have been failures, although on examination of the depth profiles for those fish that died and sank following longline capture and tagging, the sinking speed was fast, often in excess of 0.3 m/s. The sPAT tags used in this study are tested to survive pressures of 2000-2500m but, given the observed sinking speed and pin burn times in reporting tags, it is possible that the sPATs that did not report were crushed at depth before they were able to release and float to the surface. In our subsequent analyses, these five non-reporting tags can be treated as censored survivors at time zero, effectively removing them from the analysis as they contribute no information on post-release mortality rates.

Of the sPAT tags that reported, all but one indicated detachment through either sinking or predation, the majority of which occurred within four days (Figure 2). The remaining sPAT that reported appeared to indicate a pre-mature release where the tag was shed 32 days after tagging (fish 208712, *Suppl. Mat.* Figure S2). The longest survival time was 49 days from release, for a bigeye tuna that was exhibiting typical, and diurnal behaviour (Scutt Phillips et al. 2017) immediately prior to apparently dying at depth and sinking to the ocean floor (fish 208733, *Suppl. Mat.* Figure S3). A summary of release covariates and survival times is given in Table 1.

Detailed examination of the vertical behaviour provided by reporting sPATs revealed three main mortality patterns (Figure 3). The most common was an extended surface-association up to three- or four-days post release before apparent mortality and sinking to the ocean floor (12 fish). There were also several clear predation events within the few days post-release, indicated by tags reporting a lack of changing light levels, some tags reporting consistent temperatures with depth, and extended, non-tuna like vertical movement behaviour (six fish). These included very shallow vertical behaviour with short, bounce dives (similar to that reported for billfish, e.g. Sippel et al., 2011, Luo et al., 2006, Hoolihan et al., 2011, or possible beaked whales e.g. Baird et al. 2006), and high frequency vertical movement with a diel pattern similar to that reported for silky shark (*Carcharhinus falciformis*) behaviour, (Filmalter et al., 2011; 2015), and shortfin mako (*Isurus oxyrinchus)* shark (Abascal et al., 2011). Finally, there were four instances of atypical behaviour in the days immediately following release, ending with sudden floating of the tag at surface and one or more spike dives to depth before the tag began to report. While it is possible that these are shedding events, without considerable necrosis around the tagging area, we suggest that shedding of titanium anchors from behind the pterygiophores was less likely, given that the tagging technician did not report poor placement for these tags. Instead, we have assumed for the purposes of our analyses, that these are either predation events in which the tag is not ingested, or that the tag itself is predated upon and torn from the fish, before subsequently floating to the surface and then pulled down to depth or swallowed and immediately regurgitated by subsequent scavengers.

3.2 Post-release Mortality Estimates

As a supplement to Cox-regression modelling, the Kaplan-Meier estimator (reference) was used to provide a simple description of post-release mortality using data from 27 of the sPAT deployments. For this analysis the five non-reporting tags were excluded from the analysis. Given the uncertainty in assigning fates to four of the prematurely floating tags described above, two datasets were considered for analysis. A conservative dataset, assuming 26 observed mortality events, including these premature floating tags, and one censored event at day 32 corresponding to the apparent shedding event. An alternative survival analysis was also run on a less-conservative dataset, where the four prematurely floating tags were assumed to be shedding, and therefor censored, events and not predation mortalities.

Figure 4 shows the Kaplan-Meier survival curve for days since release for the conservative dataset. The observed survival status at the end of the 60-day study period was zero for all fish. Given the low sample number in our analysis, identifying an accurate estimate of survival probability was not possible, but the data indicate an asymptote at 0.1-0.15. The median survival time, the point at which survival probability fell below 0.5, occurred at two days, occurring between one and three days within 95% confidence limits.

When a dataset assuming floating tags as censored events rather than mortalities was used, the survival asymptote increased to around 0.2. Median survival time remained at two days, although the 95% confidence limits extended from one to six days.

3.3 Factors influencing mortality

Using Cox proportional hazards methods, four covariates were examined for their potential influence on survival in the most conservative dataset: species, fork length, condition at release, and float position on the line during hauling. However, given the number of observed mortalities in this experiment, there was little signal for a Cox regression survival analysis to identify significant effects.

Testing of the proportional hazards assumptions and other model diagnostics were also extremely limited for the same reasons. While many of the fish in this study were tagged during the same haul event, and then released into potentially similar environments of predation, we assume here that all survival times are independent. Schoenfield residuals (Grambsch & Therneau 1994) were calculated for each covariate to examine the hazard response over time (see *Supplementary materials* figure S4). Fish condition was the only covariate that indicated breaking of the proportional hazards assumptions ($p < 0.01$), although this appeared driven by the very low numbers of events occurring after the initial four days.

Regardless, none of the covariates were found to be significant in estimated survival probability when using the conservative dataset. However, when considering early-release floating tags as censored events, float number was found to be significant (hazard ratio = 1.012, 1.001 to 1.024 95% CI, $P = 0.04$), with decreased survival predicted when tagged fish were hauled later in the set. Examining model predicted survival curves across the quantile values of the observed float number in our study, survival probability ranged from around 0.5 for fish tagged at the beginning of line hauling, to 0.05 for fish hauled later in the set (figure 5).

4. Discussion

Our study indicates that post release mortality of tropical tuna caught by commercial longline gear and operations is likely to be very high. The survival analyses indicate a 20-30% survival rate within four days of release, potentially reaching an asymptote of just 10%. Survival rates of large tunas satellite tagged using rod and reel gears have been estimated as much higher than those found in longline captured tuna here (92%, Kneebone et al. 2021). Other studies of tagged tuna captured by rod and reel also indicate that tagging itself does not result in high levels of mortality (e.g. Lam et al. 2020 Tolotti et al. 2020), and lab studies also showed no survival or behavioural impacts of satellite tagged, captive mahimahi (*Coryphaena hippurus*) compared to untagged conspecifics (McGuigan et al. 2021). It appears that the commercial longline hauling is more responsible for the high mortality we have observed, rather than the satellite tagging procedure itself. These results suggest that targeting bigeye and yellowfin tuna for mark recapture through standard commercial longlining operations is not a viable method of obtaining growth or other life history information of these size classes, regardless of the type of tag deployed. Despite individuals being selected by scientific crew as in the best possible condition for tagging, examination of the vertical behaviour reported by sPATs post-release suggest that the probability of post-release survival was extremely low. Either the time on the hook, hauling and capture simply left fish too exhausted or stressed to survive release back into their environment (Pankhurst & Dedual 1994), or there was a high incidence of serious injuries that were not apparent from an external examination. Individuals either struggled with depth-control before sinking or were quickly predated by what appears to be sharks or marine mammals, which may have been present in high densities around the hauling operation of the fishing vessel. For either case, this happened within four days for 80% of fish. After that we observed three instances of potential, 'delayed' mortality ranging from 6 to 26 days, and one clear instance of predation just prior to day five. Natural mortality for bigeye and yellowfin tuna at these size classes is estimated to be around 3.5-4% and 6-10%, respectively, per month (Decharme-Barth et al., 2020; Vincent et al., 2020), and it is worth noting that one of the two fish tagged in this study assumed not to have experienced longline-tagging mortality still appeared to die of unassigned causes nearly two months after release. It is plausible that this represented a natural mortality event.

High rates of post release mortality have not been observed in other species caught by pelagic longline fisheries. Pelagic sharks are reported to experience post release rates ranging from 11% to 57% out to 30 days depending on species, animal condition, handling, and fishery (Musyl and Gilman, 2019; Hutchinson et al., 2021) with slightly lower rates reported for billfishes (11%-18%) (Musyl and Gilman, 2019). These rates are approximately equivalent to those reported in recreational fisheries for tuna and billfishes (Sepulveda et al. 2020; Tracey et al., 2016; Marcek and Graves, 2014; Stokesbury et al., 2011; Horodysky and Graves 2005; Musyl et al., 2015; Domeier et al., 2003). Hook types can significantly affect the mortality rates of species caught by longline fisheries (Reinhardt et al., 2018). For example, lower rates of $F_{capture}$ have been observed for yellowfin and bluefin tuna when circle-hooks in comparison to J-hooks are deployed (Reinhardt et al., 2018) indicating that these hook types may have lower impact on these species. In the same meta-analyses however, Reinhardt et al., (2018) were not able to detect an effect of hook type on bigeye tuna. The technique used to lift fish from the water to the deck can also influence rates of post release mortality (Sakai and Itoh, 2013), and it is very possible the hauling and de-hooking procedure specific to our tagging study also influenced post-release mortality. Mortalities were higher for southern bluefin tuna when lifted using the branch line in comparison to the lift occurring via a spoon-net or basket (Sakai and Itoh, 2013), and the half-moon shaped landing net used in our study may have similarly aided in reducing the stress associated with lifting on to the deck for tagging. However, while other potential covariates were collected in our study, including those that may be proxy for time spent on the hook by individual fish, our results did not show strong evidence for an effect on mortality when compared to the null model of survival and many more replicates would be required to quantify this further. Such an experiment appears to be of little worth, given the very low survival rates we have presented here.

Our analysis supports the current approach of assuming that all longline captures of tuna (i.e. including live discards) as mortalities for the purposes of constructing catch data for stock assessments of tunas in the WCPO (Williams, 2020). Increasing access to tuna has been identified as a potential solution to improve the food security within the Pacific Islands and nutrition of its communities (Bell et al., 2015). While discarding of tuna in the WCPO more commonly occurs on catches of small-sized tuna (Chan et al., 2014) some discarding of large sized fish occurs in the longline fisheries (Williams, 2020, *Suppl. Mat.* Figure S1). Given the high mortalities likely experienced, a full retention (Chan et al., 2014) or other policy that incentivizes their use in supplementing Pacific Island food security needs may be a better use of this resource.

Conventional tagging of tropical tunas caught on longline gears is a technique employed by some tagging programmes (e.g. the Atlantic Ocean Tuna Tagging Programme), although at a small scale (< 500 releases, AOTTP data https://www.iccat.int/aottp/en/aottp-data-release.html). Short lines or short surface longlines, less than 500 hooks (Itano, 2004) has also successfully been used to capture, tag and release tunas where post release mortalities have been low (Allain et al., 2005; Williams et al., 2014), but these trips have been dedicated tagging expeditions using modified techniques rather than commercial operations. While the longline gear settings varied between the different platforms used in these expeditions, the operations were specifically adapted to optimize tagged fish survival. A low number of hooks (175 to 270) per set, and caution taken in the hauling speed to minimize fish baro-trauma was conducted (Allain et al., 2005). The significance of float number in our analysis of the less conservative dataset presented here suggests that such short sets and less hauling stress may indeed decrease post-release mortality.

While modified fishing operations may approach results in lower rates of $F_{capture}$ and $F_{release}$ in comparison to standard commercial operations, the small number of fish captured with these modifications is likely insufficient for broad scale application of conventional tagging. Our results highlight the importance of large-scale CMR of small individuals to ensure significant numbers of fish surviving to adult life stages, coupled with active engagement in the recovery of tags in longline fisheries.

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JSP conceived the project, JSP, SN, BML, JM designed the project, JM implemented the project, RB advised on analyses, MH facilitated access to observer data and provided equipment. All authors contributed to writing and editing the manuscript.

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Figure 1. Half moon aluminium landing net used to bring yellowfin and bigeye tuna deemed suitable for tagging aboard.

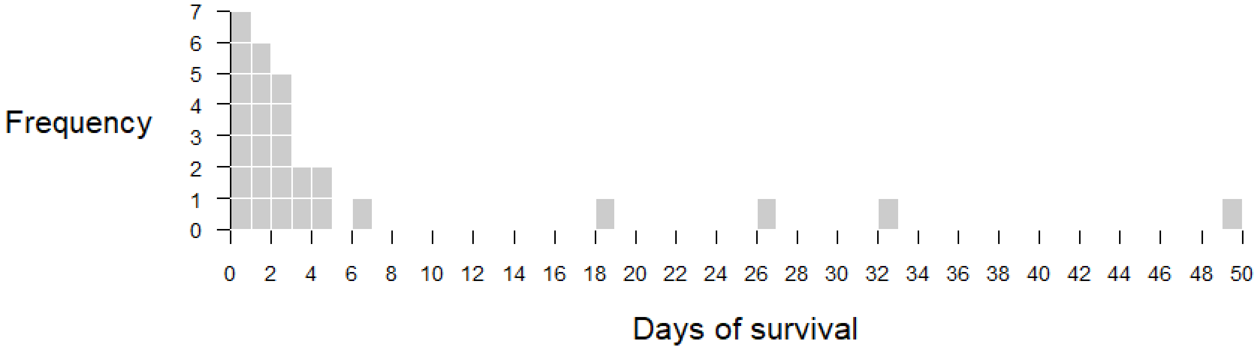

Figure 2. Distribution of survival time for all deployed and reported sPATs for adult bigeye and yellowfin tuna captured by longline.

Table 1. Summary of release, fate, and covariates of tagged longline caught fish

PTT Tag No.	Species	Fork Length	Date 2020	Fish Condition	Survived	Mortality due to Capture & Tagging	Days Survived	Float No.	Hook No.
170602	Bigeye	119	9/12	Bleeding	0	1	3	40	9
170603	Bigeye	118	9/12		0	1	0	48	6
208704	Bigeye	103	25/11	Eye damage	0	1	2	66	14
208705	Bigeye	127	29/11		0	1	Unknown	101	NA
208706	Yellowfin	117	22/11		0	1	18	18	17
208707	Bigeye	127	28/11		0	1	Unknown	60	14
208708	Bigeye	124	25/11		0	1	2	49	4
208709	Bigeye	127	6/12		0	1	Unknown	55	15
208710	Bigeye	145	5/12		0	1	2	93	16
208711	Bigeye	127	7/12	Slow on release	0	1	1	55	16
208712	Bigeye	113	27/11	Slow on release	1	0	Unknown	19	6
208713	Bigeye	127	4/12	Slow on release	0	1	0	89	23
208714	Bigeye	126	7/12	Bleeding	0	1	2	72	6
208715	Bigeye	132	30/11		0	1	3	2	12
208716	Yellowfin	136	7/12		0	1	0	74	23
208717	Yellowfin	116	25/11		0	1	6	58	23
208718	Bigeye	114	3/12	Eye damage	0	1	0	78	11
208719	Yellowfin	124	26/11	Slow on release	0	1	0	45	21
208720	Bigeye	120	27/11	Slow on release	0	1	26	116	9
208721	Bigeye	129	29/11		0	1	4	71	6
208722	Bigeye	130	4/12		0	1	1	80	12
208723	Bigeye	126	29/10		0	1	2	110	9
208724	Yellowfin	134	30/11	Slow on release	0	1	Unknown	71	11
208725	Bigeye	127	3/12		0	1	0	86	9
208726	Bigeye	126	7/12	Slow on release	0	1	1	92	17
208727	Bigeye	119	3/12		0	1	1	80	16
208728	Bigeye	124	30/11		0	1	4	5	14
208729	Bigeye	117	1/12	Slow on release	0	1	1	73	16
208730	Bigeye	103	22/11		0	1	1	31	15
208731	Bigeye	139	2/12	Slow on release	0	1	Unknown	32	NA
208732	Yellowfin	136	3/12	Slow on release	0	1	0	15	16
208733	Bigeye	120	29/11	Slow on release	0	0	49	5	9

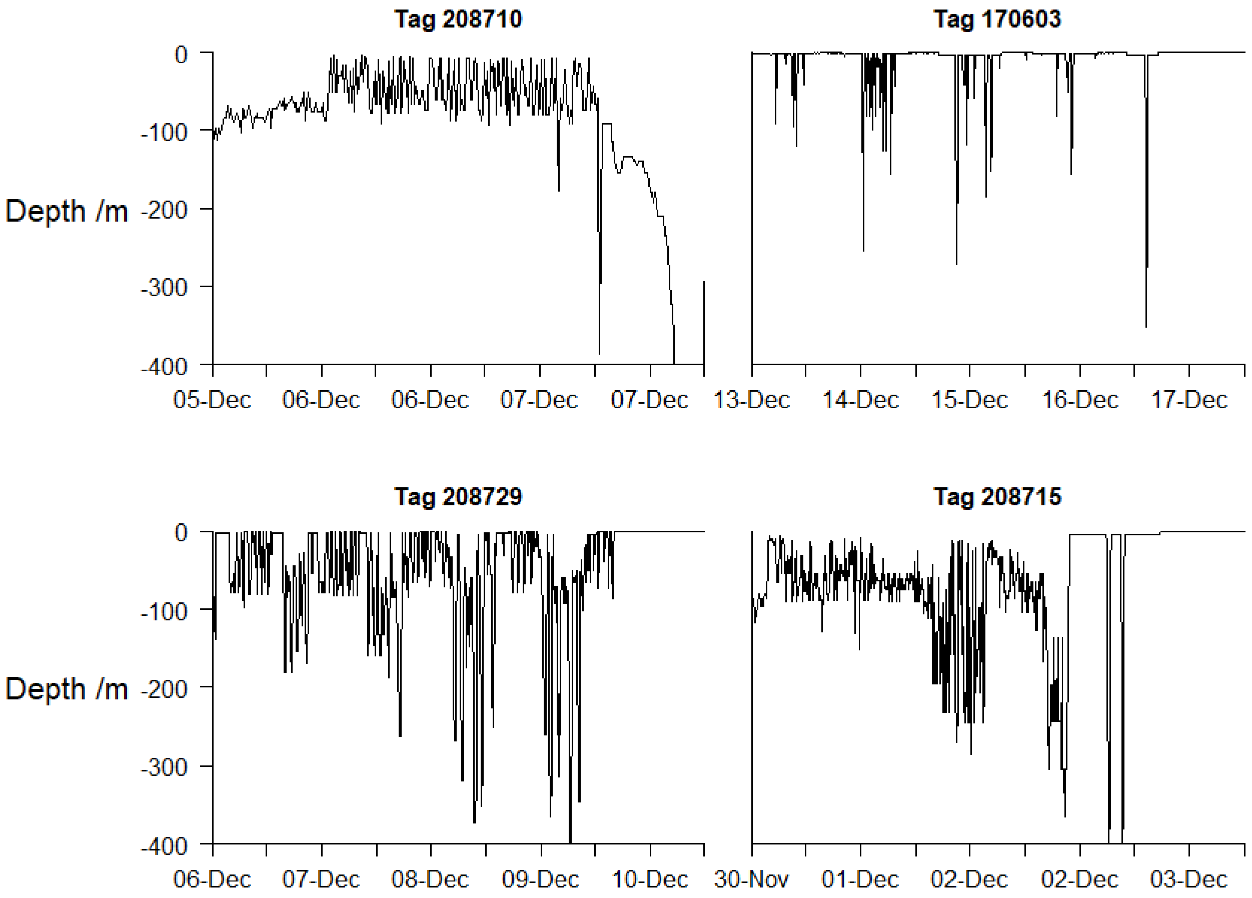

Figure 3. Examples of classified bigeye tuna mortalities from pre-pop up, high resolution dive profiles prior to sPAT data transmission. Clockwise from top left: Depth holding with extended shallow behaviour prior to sinking, ingestion by a surface oriented, shallow-swimming predator, ingestion (inferred by light level data) by a predator with diurnal behaviour, premature release and floating of the tag followed by something dragging the tag to depth.

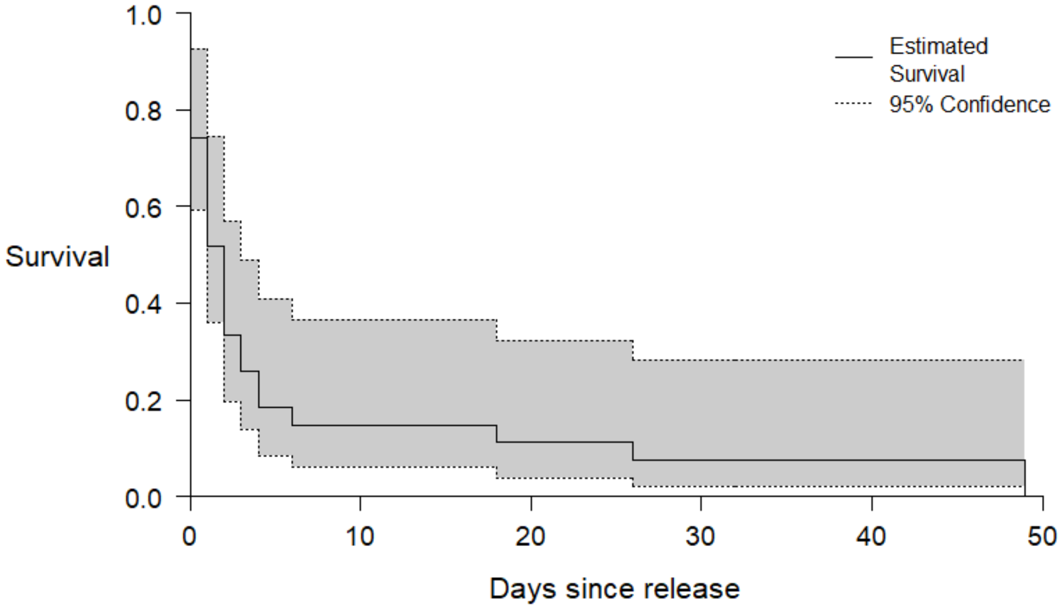

Figure 4. Kaplan-Meier survival curve using a conservative dataset of all reporting sPAT tags for adult bigeye and yellowfin tuna captured by longline.

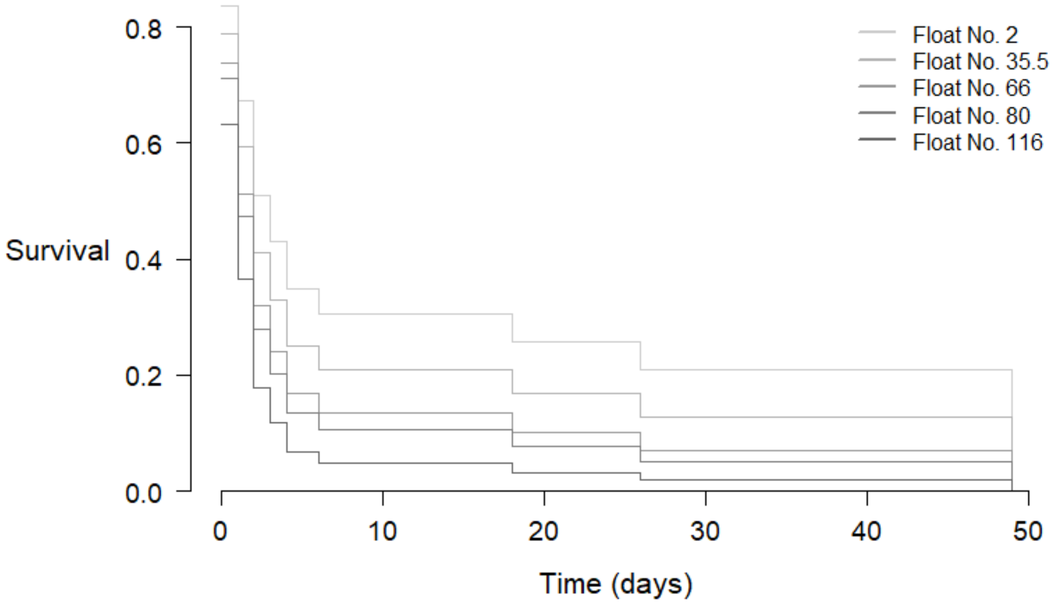

Figure 5. Kaplan-Meier estimated survival curves when assuming premature floating tags as censored events and float number as a covariate of the hazard function. Estimated survival is shown with increasing float number (later haul time).