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Fishery interactions and post-release survival rates of silky sharks caught in purse seine fishing gear

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Abstract

Juvenile silky sharks (*Carcharhinus falciformis*) comprise the largest component of the incidental elasmobranch catch taken in the western and central Pacific Ocean (WCPO) tuna purse seine fishery. Population analysis for this species has shown that high mortality on the juvenile life stages has the most impact on population growth. Several aspects of the biology and behavior of silky sharks were investigated during a research cruise on board a commercial purse seine vessel sponsored by the International Seafood Sustainability Foundation. Of particular pertinence to updating population estimates for this species were results we obtained concerning the post-release survival of sharks released at different stages in the fishing operation and the comparison of shark catch statistics collected by the scientific party, the fisheries observer and the vessel. To reveal the post release survival rates of juvenile silky sharks, we used a combination of electronic tagging (satellite linked pop-up archival transmitting tags) and blood chemistry analysis. During the cruise we interacted with a total of 295 juvenile silky sharks, deployed 28 satellite tags and completed blood chemistry analysis on 87 sharks. To identify the trends in survival probability, animals were sampled (both tagging and blood analysis) during every stage fishing operations, including animals that were captured while they were still free swimming inside the net and on FADs prior to being encircled by the purse seine. Consequently, we were able to obtain blood gas, metabolite and stress hormone (adrenaline) levels at various levels of stress. Our results indicate that pH and lactate are the best predictors of mortality and that survival precipitously declines once the silky sharks have been confined in the "sack" or the net just prior to loading. Sharks entangled in the net or released prior to loading have good chances of survival. Blood chemistry analysis revealed post release mortality rates of silky sharks captured in purse seine gear using current practices exceeds 84%. Counts of captured sharks made by the scientific party were markedly larger than then numbers reported in the vessel's log or by the on-board observer. This was probably due to the fact that the crew and observer have other tasks that take precedence over estimating shark bycatch. Future efforts to reduce the purse seine fishing impact on juvenile silky shark populations should be focused on avoidance and releasing animals while they are still free swimming in the net.

1. **Introduction**

The silky shark, *Carcharhinus falciformis*, comprises a large component of the elasmobranch bycatch in both purse seine and longline fisheries worldwide (e.g. Watson et al., 2008; Clarke et al., 2011). In the western and central Pacific Ocean (WCPO) Fish Aggregating Device (FAD) associated tuna purse seine fishery, silky sharks account for 95% of the shark bycatch (Lawson, 2011). Juvenile silky sharks aggregate in large numbers around these drifting objects and become incidentally caught in purse seines targeting skipjack, *Katsuwonus pelamis* and yellowfin tuna *Thunnus albacares* for the cannery (Filmalter et al., 2011) and shark catch rates are typically twice as high in the FAD associated versus the unassociated fishery (Clarke et al., 2011). Concerns about the silky shark bycatch rates in the associated purse seine fishery have been raised because of declining catch rate trends, declining size trends in some datasets, and increasing fishing effort (Clarke, 2011) which may suggest large increases in fishing mortality over the last two decades (Rice and Harley, 2012). Recently, a stock assessment of the silky shark in the WCPO statistical area estimated that spawning biomass, total biomass and recruitment had all declined, conclusions drawn from this are that fishing mortality has increased to levels far in excess of the maximum sustainable yield (Rice and Harley, 2013).

Several research priorities were identified in the stock assessment to fill data gaps regarding the biology of this species and the impact that purse seine fishing has on the population. The objective of this study is to address some of these management concerns using data collected during a chartered research cruise aboard a commercial tuna purse seiner in the WCPO. Specifically, to 1) quantitatively assess fishery induced shark mortality using physiological indicators of stress derived from blood chemistry analysis in combination with satellite linked pop-up archival transmitting (PAT) tags and 2) compare shark catch estimates obtained by the scientific party with those of the vessel's log book and the on board fisheries observer. Other results from the cruise allowed us to document the vertical behavior of silky sharks and, to a lesser extent, the degree of site attachment of sharks to FADs.

2. Methods

2.1 Field methods

Sharks were caught May through June 2012 during an International Seafood Sustainability Foundation (ISSF) sponsored cruise in the western and central Pacific Ocean (WCPO) on the American flag purse seine vessel m/v Cape Finisterre. To assess post release survival and to identify the point in the fishing operations when animals sustain injuries that result in mortality, we sampled and tagged animals that were landed during each stage of the fishing operations and prior to commencement of fishing operations. The fishing stages we identified for this experiment were: 1) Pre-Assessment - In order to establish a reference curve of blood biochemistry indicators and to release some sharks that were exposed to a minimal amount of handling, some sharks were captured using dip nets or baited hooks at FADs prior to the onset of fishing. 2) Encircled - sharks that were fished out of the net while still free swimming. These animals had been encircled by the purse seine and the net had been hauled to at least half net. These sharks were captured using pole and line, handlines and dipnets. They were sampled onboard the work boat and then released outside the purse seine net. 3) Entangled - sharks that had become entangled ("gilled") in the net and removed by the fishermen and so were landed relatively early in the net hauling process. 4) First Brail - sharks that came out of the first brail during the brailing stages. These sharks would have been on the top of the sack (at the end of net hauling and prior to loading the net becomes a long "sack" with the animals all tightly condensed on top of each other) and not subjected to crushing from the weight of the catch. 5) Later Brail - These sharks were landed during any subsequent brails and were confined in the sack for longer periods of time and subjected to crushing forces from the weight of whatever was on top of them. Most of the sharks were landed during the later brails because they would bury themselves in the bottom of the sack towards the end of the net haul and "sacking up" procedures (Hutchinson et al., 2012; Muir et al. 2012). Sharks that were recovered during the spill sample (Itano, 2012a) or recovered from the wet deck were also considered to have been landed during a later brail.

All sharks were placed upside down in a cradle and ventilated with running seawater while morphometrics were recorded, tags attached and during blood withdrawals. Sharks were then released over the side of the vessel and their post release behavior was observed. A release condition (excellent [4] - dead [0], see Hutchinson et al., 2012 for release condition designations) was recorded for each shark (Table 1). A combination of conventional ID tags, acoustic tags and satellite tags were used in this study. Conventional ID tags (wire through metal dart tag, Hallprint, South Australia) were applied to sharks that were still alive at the time of tagging. Acoustic transmitters, Vemco V13p R-coded 69 KHz acoustic tags (Amirix Systems Inc. Nova Scotia, Canada) were surgically implanted into the ventral cavity of three sharks at two different FADs to investigate fidelity and residence times at the FADs. Vemco VR2W acoustic receivers were attached to the drifting FADs and retrieved after ten and five days respectively. Three different types of satellite pop-up archival transmitting (PAT) were used to elucidate post release condition and habitat use in this study; X PAT (Microwave Telemetry Inc. Columbia, MD.), miniPAT and survival PAT or SPATs (Wildlife Computers Inc., Redmond, WA.). Satellite tags were externally attached to the dorsal musculature of candidate sharks.

Blood samples consisted of a 3 mL sample taken via caudal venipuncture. Blood chemistry analysis was conducted to quantify concentrations of key physiological indicators of stress (Heberer et al. 2010). Blood pH, electrolytes; Na+, K+, Cl−, Ca2+, metabolites; glucose and lactate, and hematocrit (Packed Cell Volume, PCV) were tested onboard the vessel after collection using the CG 4+ and CHEM 8+ cartridges with the I-STAT portable automated blood chemistry analyzer (Abbott Laboratories, IL. USA). Blood was diluted 1:1with dH_2O to get within the reportable ranges of the CHEM 8+ cartridge. Parameters measured using this cartridge (Na+, K+, Cl−, Ca2+, glucose) are reported as the dilute values. Hematocrit was quantified using the StatSpin hematocrit rotor and centrifuge. A 2 mL whole blood subsample was centrifuged at 10,000 g for 6 minutes to separate plasma from red blood cells and stored at -20°C for later analysis of adrenaline (stress hormone) levels. To determine the amount of circulating catecholamines in the blood, adrenaline levels were quantified using an Adrenaline (Epinephrine) enzyme-linked immunosorbant assay (ELISA) kit following manufacturer specifications (Eagle Biosciences, Nashua, NH.) and read using a Spectramax 2 spectrophotometer at the Hawaii Institute of Marine Biology.

2.2 Data Analysis

2.2.1 *Stress Physiology and Post Release Survival*

Survival and mortality events for PAT tagged animals were interpreted using the transmitted depth records from the PATs. The PATs were programmed to record temperature, depth, and light level data at specific time intervals. Deployment periods were pre-programmed at 30 days for SPATs and between 100-360 days for X-PAT and miniPATs. On the scheduled pop-off dates, the tags detach from the leader, float to the surface and transmit the archived data to the Argos satellite system. In the event of a mortality where the animal sinks through the water column, the PATs have an external guillotine device that severs the tag attachment before the tag reaches crushing depths of ~1700 m. Depth records that exceeded 1600 m indicated the animal had died and was sinking (Figure 1). The “survival” PATs transmit the daily maximum and minimum depths and temperatures experienced by the sharks for the 30 day deployment. They are programmed to identify the fate of the tag and thus the animal by one of three designations; 1) Floater: the tag begins to transmit because it was shed by the animal (e.g., due to attachment failure). 2) Sinker: the animal dies and sinks to depths greater than 1600 meters or dies and remains on the ocean floor at a constant depth. 3) Survivor: the SPAT completes the deployment, the tag initiates a release at 30 days.

In this study, animals that survived ≥ 10 days are considered to have survived the fishing interaction. Animals (tags) that sank to the critical depth (1700 m) within that time period were considered mortalities. Tags that were shed within the 10 day period were not used in the post release survival analysis. Two-tailed t-tests and Mann-Whitney U tests, the nonparametric equivalent, were used to determine which blood parameters (pH, Na^+, Cl^-, Mg^{2+}, Ca^{2+}, and K^+, glucose, lactate, blood hematocrit [PCV], and adrenaline; Table 2) differed significantly between survivors and moribund animals (determined from animals that were both blood sampled and satellite tagged; Table 3). Regression models were used to fit the significantly different blood parameters to the survival data. Using lactate and pH levels, a simple logistic regression model and maximum likelihood estimation was used to predict the probability of survival (*pi*) for animals that had blood drawn but were not satellite tagged (Table 4, Figs 2A & 2B). The fitted values were then used to predict survival (and mortality) rates by landing stage and release condition for all of the sharks captured during the cruise (Tables 5 & 6). Adrenaline analyses are ongoing.

2.2.2 *Catch Comparisons*

A comparison of the silky shark catch rates recorded by the scientists, the observer and in the vessel logbook was also conducted to elucidate any differences in reported shark interactions (Fig. 3). To investigate the effect that the size (tonnage) of the catch had on mortality rates, linear regression analysis of predicted mortality rates for each set and set sizes derived from the observer data was also conducted (Fig. 4).

2.2.3 *Habitat Use and Behavior*

Transmitted miniPAT tag data were processed and analyzed for vertical movement behavior using IgorPro 6.3 (WaveMetrics Inc. Portland, Or.; Figs. 5 & 6) Raw light level and sea surface temperature (SST) data were used to model horizontal movement (not discussed in this paper). Three silky sharks were also implanted with acoustic tags at two different FADs to reveal residency periods at a FAD (Fig. 7) and or departure times from the FAD (Fig. 8).

3 Results

During the 2012 WCPO Bycatch Project cruise (for cruise details see Itano et al. 2012a) 295 juvenile silky sharks aged 0 - 4 (115.2 ± 17.5 cm mean total length) were captured (Hutchinson et al. 2012). Age at length information was derived from Joung et al. (2006). Landing stage and release condition information was recorded for each shark (Table 1). Twenty-eight silky sharks landed during different stages of the fishing operation were tagged with satellite tags (15 SPATs, 11 miniPATS and 2 MT X-PATs; Table 3). The two MT X PATs did no report whereas all the SPATs and miniPATs reported. Blood samples were collected from 87 sharks, 17 of these were also satellite tagged to establish biochemical stress indices of post release mortality for this species. Three sharks that were caught during the FAD pre-assessments were also implanted with acoustic tags at two different FADs. Two of these were double tagged with a miniPAT and one had blood taken. To date none of the animals tagged with conventional ID tags have been recaptured and or reported.

3.1 *Post Release Mortality*

Survival was validated using the depth records from satellite tagged sharks. Table 3. shows the tag deployment periods for 28 sharks, the stage they were landed in, release condition and PAT fate. Differences in blood chemistry levels between satellite tagged sharks ($n = 17$) that survived the fishing encounter (tag deployment ≥ 10 days, $n = 9$) and those that died post release (0-9 days, $n = 5$) were revealed using two sample t-tests. Two of the tags on animals that had also been blood sampled did not report and one was shed after only 5 days so these were not used in this analysis. Lactate, pH, dilute potassium and dilute calcium levels were the only measured blood parameters that differed significantly between survivors and mortalities (Table 2). Lactate and pH were found to be the best predictors of survival, but are so highly correlated they don't add anything to the model. Simple logistic regression models of both pH and lactate were conducted (Table 4). Lactate was chosen as the best predictor of survival for several reasons, primarily because pH levels are temperature dependent and the I-stat analyzers thermostat each sample to 37°C, whereas lactate levels have been shown to be temperature independent (Gallagher et al. 2010). Additionally, the reportable ranges for pH on the CG4+ cartridge are between 6.5 and 20.0, where anything outside these ranges is reported as either < 6.5 or > 20.0.

Maximum likelihood estimates (b_o and b_1; Table 4) of pH and lactate were found and substituted into the response function $\hat{\pi} = \frac{\exp(bo + b1 * X)}{1 + \exp(bo + b1 * X)}$ to obtain the fits (probability of survival) for all animals that had blood drawn but had not been satellite tagged. Survival was set at $\hat{\pi} > 0.5$, the value of the blood parameters at $\hat{\pi} = 0.5$ corresponded to a pH level of 6.815 and a lactate level of 11.31 mmol/L (Figures 2A and 2B). When determining survival rates by landing stage and release condition only lactate values were used. Animals with a lactate value of 11.31mmol/L and higher were considered moribund. The survival means were found by landing stage and release condition for blood sampled sharks and then applied to the rest of the data set ($n = 295$ sharks) to extrapolate mortality rates for all of the sharks encountered during this cruise (Table 5 & 6).

Animals landed during the pre-assessments and after having simply been encircled showed 100% post-release survival, indicating that there was no significant effect from the tagging and blood sampling procedures. We also found high (68.7%) survival rates for animals that had become entangled in the net whereas survival was 16.7% for sharks that came up in the first brail. Post release survival rates were lowest (6.67%) for animals landed in later brails. This culminated in an overall post release survival rate of 15.83% for sharks landed during current typical fishery operations (i.e., pre-assessments and encircled landings excluded) which corresponds to an over-all post release mortality rate of 84.17% (Table 5) for purse seine captured silky sharks.

We found that observing and documenting the release condition of the animal is a reliable predictor of post- release fate. Animals that were released in excellent condition (RC = 4) had a 92% survival rate while animals that appeared non-responsive or dead (RC = 0) survived only 3% of the time (Table 6).

3.2 *Catch comparisons*

The shark catch data reported by the observer, the vessel logbook and the scientific team were compared for sets 14- 31 (Figure 3). Sets 1-13 were omitted because the observer and scientists were sharing catch data. A one-way ANOVA revealed significant differences in reported shark catch rates between the scientists, the observer and the vessel's logbook ($F = 9.592$, $p = 0.0005$). Tukey - Kramer multiple comparisons showed that both the observer and the vessel reported significantly fewer sharks than the scientists (observer vs. scientists: -4.722, $p < 0.05$ and vessel vs. scientists: -7.611, $p < 0.001$). While the observer consistently recorded more sharks than the vessel per set, the difference was not significant (2.889, $p > 0.05$).

The current paradigm of thought is that mortality rates of silky sharks captured in purse seines may be dependent on the size of the catch (tonnage). For this reason we investigated the relationship between catch sizes and predicted mortality rates of silky sharks. Using regression analysis we found catch size (tonnes) does not explain a significant component of the shark mortality rates (equation: mortality rate = 0.622 + 0.00233 total catch, $F_{1,26} = 2.39$, $p = 0.134$, $r^2 = 0.084$; Fig.4).

3.3 *Habitat Use, Movement Behavior and FAD Fidelity*

The satellite transmission data acquired from 28 PATs deployed on juvenile silky sharks resulted in 575 days of data. Our analysis revealed juvenile silky sharks show diel vertical patterns within the upper 100m of the water column with irregular deeper dives beyond the thermocline (Figure 5). Preferred daytime depths are shallower (0-40 m) than night time depths (60-80 m) with increased dive frequencies beyond 100 m at night (Figure 6). All animals spent the greatest proportion of their time within the upper mixed layer, which extends to about 110 m in this region. Tag data also showed silky sharks occupying a very narrow temperature range of 29.5°C (Figure 9). Further analyses of the satellite transmission data are ongoing. The acoustic data set revealed short term FAD fidelity during the duration of the receiver deployments with repeated evening departures by two of the three silky sharks tagged at two different FADs. There were regular pre-sunset departures from the FAD by both animals every evening (Figures 7 & 8).

4 Discussion

We conducted post release mortality experiments on sub adult silky sharks released from a commercial purse seine vessel performing typical commercial tuna fishing operations. Direct measurement of survival was obtained by attaching satellite tags to sharks released at different stages of the fishing process. Blood samples were also taken from these sharks and their post-release survival was compared with the levels of various stress indicators present in their blood. We found that by also taking blood samples from many additional sharks, we were able to extrapolate the survival rates observed in the tagged sharks and thereby obtain overall estimates of silky shark survival.

4.1 *Post release mortality*

Many of the stress blood chemistry parameters did not show a clear relationship with mortality. However, lactate, pH, calcium and potassium levels were significantly different in tagged sharks that survived the interaction and those that did not. Calcium concentrations were excluded from the regression analysis due to the fact that dilution of the blood by greater than 20% causes significant changes to the calcium results. Increased lactate levels also result in decreases of the calcium concentration (i-Stat Operator procedure manual). Lactate or pH were the best predictors of survival while potassium did not improve the model and so was also excluded from further analysis. Lactate and pH both fit the data but are highly correlated so the choice of one over the other to fit the model was determined biologically and by the limitations of the portable blood gas analyzer.

Lactate is formed during anaerobic respiration and accumulates in the tissues. Animals that struggle violently will generate a buildup of lactate ions in the blood which may also result in blood acidemia or metabolic acidosis. Acidosis of the blood is also caused by acid-base perturbations from decreased ventilation and increased CO_2 concentrations. This respiratory acidosis can usually be identified using both pH levels and CO_2:O_2 ratios. Unfortunately in this data set, the temperature alterations of the shark blood samples confound the interpretation of the cause of the blood acidosis. Because blood gas levels are temperature dependent, increasing sample temperature from ambient to 37°C by the analyzer caused changes to pH levels. Accordingly, lactate levels were chosen to predict silky shark mortality rates for animals that were not satellite tagged.

Animals captured via hook and line from inside the net had 100% post release survival rates and thus the simple act of encirclement by the net does not affect the survival of these sharks. Also, animals that had become entangled in the net had higher survival rates (68.4%) than animals that were landed during the first brail (16.7%) and then those landed in subsequent brails (6.67%). Initially we thought the sharks would demonstrate a much higher survival rate if landed during the first brail opposed to any of the later brails. This would have meant that the shark was still swimming at the surface, was not subject to the pressure of the weight of the catch above it and would have been released back into the open water after a much shorter period of time. But what we observed underwater during the natural behavior experiments (see Muir et al. 2012) was the sharks were swimming against the net near the end of the net haul procedure and drowning. At that point they would slide down the edge of the net and become buried in the bottom before the fishers even began sacking up the net at the end of the net haul (Muir et al. 2012). This may explain why only a small proportion of sharks were landed in the first brail (n = 30) opposed to later brails (n = 211). This also may explain why the size of the haul did not have a significant effect on the mortality rates as was previously thought. From this we can conclude that the combination of the shark's inability to ventilate and the stress of confinement, kill the sharks before the crushing forces from the weight of the catch above it. Thus, once the animal has been confined in the sack, its chances of survival have been severely compromised. This result highlights the importance of early release as through an escape panel (Itano et al. 2012b) while the animals are still free swimming. Obviously, avoiding the encirclement of sharks altogether is the best means of reducing the impact this fishery has on juvenile silky sharks.

4.2 *Catch Comparisons*

Comparison of the number of captured sharks observed by the scientific party and those reported by the vessel and fishery observer revealed that there are reporting discrepancies regarding the number of sharks impacted by this fishery. We found catch rates were significantly underreported by both the observer and the vessel logbook. There did not appear to be any deliberate underreporting and differences are most likely due to the nature of the fishing operation; brails are loaded quickly (0.5 ton min^{-1}, pers. obs.), vessel operators are not paying attention to undesirable species and observers are occupied conducting the grab sampling (identifying and measuring five fish from each brail) duties and documenting all bycatch and catch length data. The use of the "hopper" and having the operator close the trap door to slow down the descent of the catch in to the wells greatly enhanced our ability to see and then pull sharks for sampling before they went down the chute. Regardless of the causes, the differences in reporting rates that we observed should be given appropriate attention when conducting stock assessments based on observer and logbook catch data.

4.3 *Movement Behavior and FAD Fidelity*

Understanding the movement behavior, habitat use and FAD residence times is important when conceptualizing bycatch mitigation techniques. Movement data garnered through the use of the electronic tags gave us some insight into the vertical and horizontal behavior of juvenile silky sharks captured on FADs. The most pertinent result for this fishery was that juvenile silky sharks stay in the upper 100 m of the water column. Their depth preferences keep them within the vertical range of the purse seine nets at all times of the day. Even with the diel shifts that we observed, where sharks are deeper at night (~70 m) and shallower during the day (0-40 m), their vertical structure remains within the upper mixed layer which extends to 110m in this region. Purse seine net depths measured using temperature depth recorders (TDR) placed at three different places on the net during the cruise gave net depths ranging from 142 m at the shallower edges to over 200m in the center (Itano et al. 2012). Essentially juvenile silky sharks do not exhibit behaviors that identify an escape from the net in time or space.

There is a general lack of knowledge on the associative behavior of juvenile silky sharks at FADs but in the WCPO purse seine fishery twice as many silky sharks are captured in FAD associated sets than unassociated sets (Clarke et al. 2011) and aggregations of juvenile silky sharks at FADs have been documented in several studies (e.g. Lennert-Cody et al. 2000;Watson et al. 2008; Filmalter et al. 2011). A study of ten juvenile silky sharks acoustically tagged in the Indian Ocean at drifting FADs (Filmalter et al. 2011) found continuous residence times (CRT = periods of absence not exceeding 24 hours) of 0.42 to 10.7 days. Our small acoustic data set of three sharks tagged at two different FADs proved inconclusive in elucidating FAD residence times in the WCPO. This was due in part to low retention and mysterious depth data from shark 54247 tagged at FAD object 33 who disappeared from the detection range of the receiver after only nine hours. Sharks 54249 and 3656 were continuously present at FAD object 30 but the residency study was artificially terminated when the receiver was removed from the FAD after only 6 days. Sharks tagged at FAD object 30 did exhibit repeated evening departures that occurred pre-sunset and lasted 1-6 hours throughout the night. This phenomenon was also seen in the Indian Ocean where all departures longer than three hours only occurred at night (Filmalter et al. 2011).

5 Conclusions and Recommendations

Our analysis revealed high overall post-release mortality rates of 84.3 % under current fishing practices. Post release survival was dependent on when in the fishing process the shark was landed. We also found that simply encircling the animals in a purse seine does not cause mortality. Our results indicate that early release (entangled sharks, or through an escape panel) could significantly reduce the impact FAD-based purse seine fishing has on silky shark populations. Particularly because all of the sharks encountered during this cruise were juveniles and a demographic study conducted by the IATTC showed that juvenile survival (ages 0-5) had the greatest impact on silky shark population growth (Ramon, pers. comm.). We recommend engaging the industry in developing gear improvements through different net designs for the selective release of encircled sharks. We documented a significant difference in the estimates made by the vessels crew, the observer and the scientific party of the number of sharks captured in the fishing operation. We suggest that these discrepancies be factored into future assessments of silky shark populations.

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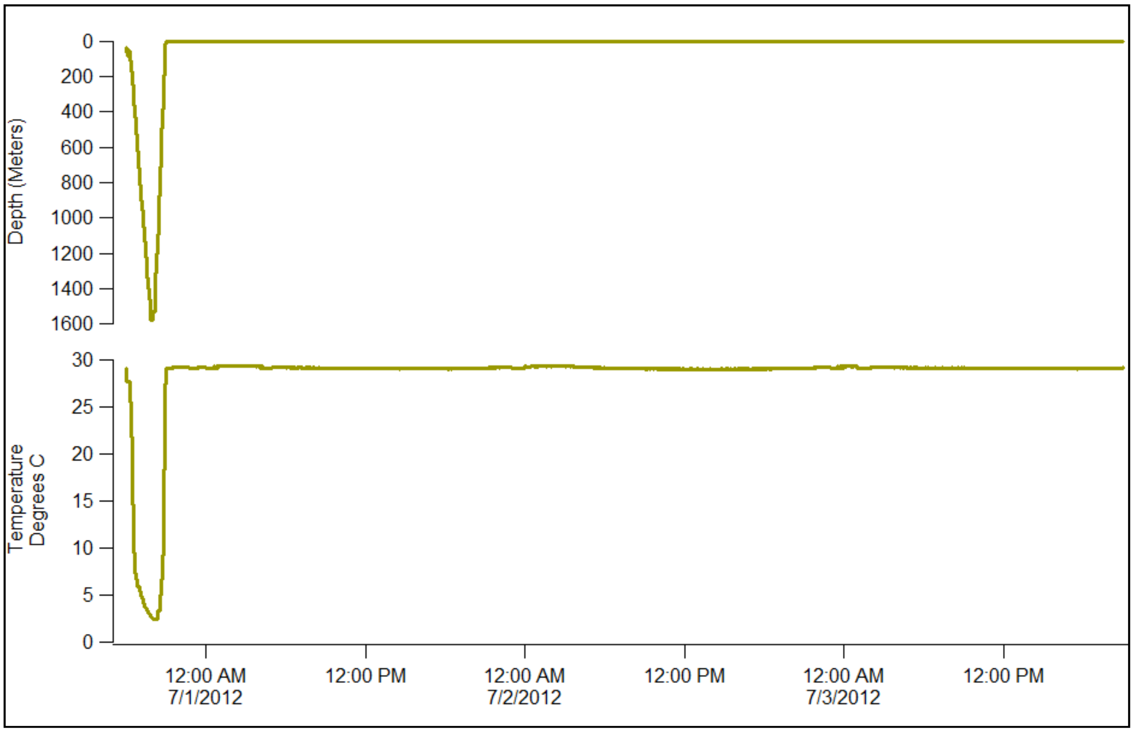
Figure 1. An example PAT record of a post release mortality. The top graph shows the depth time series data and the bottom is the temperature. This shark, CF 62941 died immediately post release and sank through the water column. From the depth record you can see that the tag severed the attachment at ~1600 meters and floated to the surface.



Release Condition	Pre-Assess	Encircled	Tangled	1st Brail	Brail	Total
Excellent (4)	9	6	24	0	0	39
Good (3)	1	0	5	1	9	16
Fair (2)	0	1	3	5	12	21
Poor (1)	0	0	1	7	26	34
Dead (0)	0	0	3	14	148	165
Unknown	0	0	1	3	16	20
Total	10	7	37	30	211	295

Table 1. Number of sharks landed during each stage of the fishing operation and the condition they were released in.

Blood Parameter	pH		Lactate mmol/L		Potassium mmol/L (dilute)		Calcium mmol/L (dilute)		Glucose mg/dL (dilute)		Sodium mmol/L (dilute)		PCV	
Post release	S	M	S	M	S	M	S	M	S	M	S	M	S	M
Mean (SD)	7.146 (0.207)	6.618 (0.125)	3.84 (3.59)	14.02 (1.20)	4.88 (0.963)	6.775 (0.81)	1.466 (0.0856)	1.685 (0.0904)	42.2 (5.26)	52.25 (9.25)	142 (7.55)	143 (2.16)	24.67 (2.74)	25.20 (1.83)
n	9	5	9	5	5	4	5	4	5	4	5	4	9	5
p - Value	0.000*		0.000*		0.018*		0.01*		0.125		0.792		0.672	

Table 2. Mean values of the stress parameters for sharks whose post-release (survivor [S] or moribund [M]) status was derived from the depth records of the PATs.

Tag Type	PTT-ID	Fishing Stage	Blood Taken	Release Condition	Pat Fate	Deployment (Days)	Sex	TL
MT PAT	19899	Entangled	Yes	4	No data	-	F	128
MT PAT	52210	Entangled	Yes	4	No data	-	M	128
miniPAT	54245	Pre-Assess	No	4	Floater	26	M	105
miniPAT	54246	Encircled	No	2	Floater	34	M	104
miniPAT	54247	Pre-Asses	No	4	Floater	3	M	104
miniPAT	54305	Encircled	No	4	Floater	6	M	127
miniPAT	54249	Pre-Assess	No	4	Floater	15	M	93
miniPAT	54267	Entangled	Yes	4	Floater	5	F	116
miniPAT	54270	Entangled	Yes	4	Sinker	129	M	145
miniPAT	54274	Entangled	No	4	Floater	32	M	144
miniPAT	62937	Entangled	Yes	4	Floater	10	M	122.5
miniPAT	62936	Entangled	Yes	4	Survivor	100	M	133
miniPAT	62941	Entangled	Yes	3	Sinker	0	F	136
sPAT	117916	Entangled	Yes	4	Sinker	25	M	123
sPAT	117917	1st Brail	Yes	0	Sinker	0	F	128
sPAT	117918	Entangled	No	1	Sinker	0	M	107
sPAT	117919	Entangled	Yes	4	Survivor	30	U	110
sPAT	117920	1st Brail	No	2	Sinker	0	F	128
sPAT	117921	Entangled	Yes	4	Survivor	30	M	116
sPAT	117922	Brail	Yes	2	Survivor	30	M	137
sPAT	117923	Entangled	Yes	3	Sinker	15	M	125
sPAT	117924	1st Brail	No	1	Sinker	0	M	105
sPAT	117925	Encircled	No	4	Survivor	30	F	104
sPAT	117926	Pre-Assess	Yes	4	Sinker	30	F	119
sPAT	117927	Brail	Yes	0	Sinker	0	M	111
sPAT	117928	1st Brail	Yes	0	Sinker	0	F	111
sPAT	117929	Entangled	No	4	Floater	23	M	93
sPAT	117930	Brail	Yes	1	Sinker	0	M	107

Table 3. Table of all animals that were tagged with satellite tags. The stage of the fishing operations when the animals were landed, if they were blood sampled, their release condition, PAT fate, PAT deployment periods, the sex of the animal and the total length (cm) of each animal are also given.

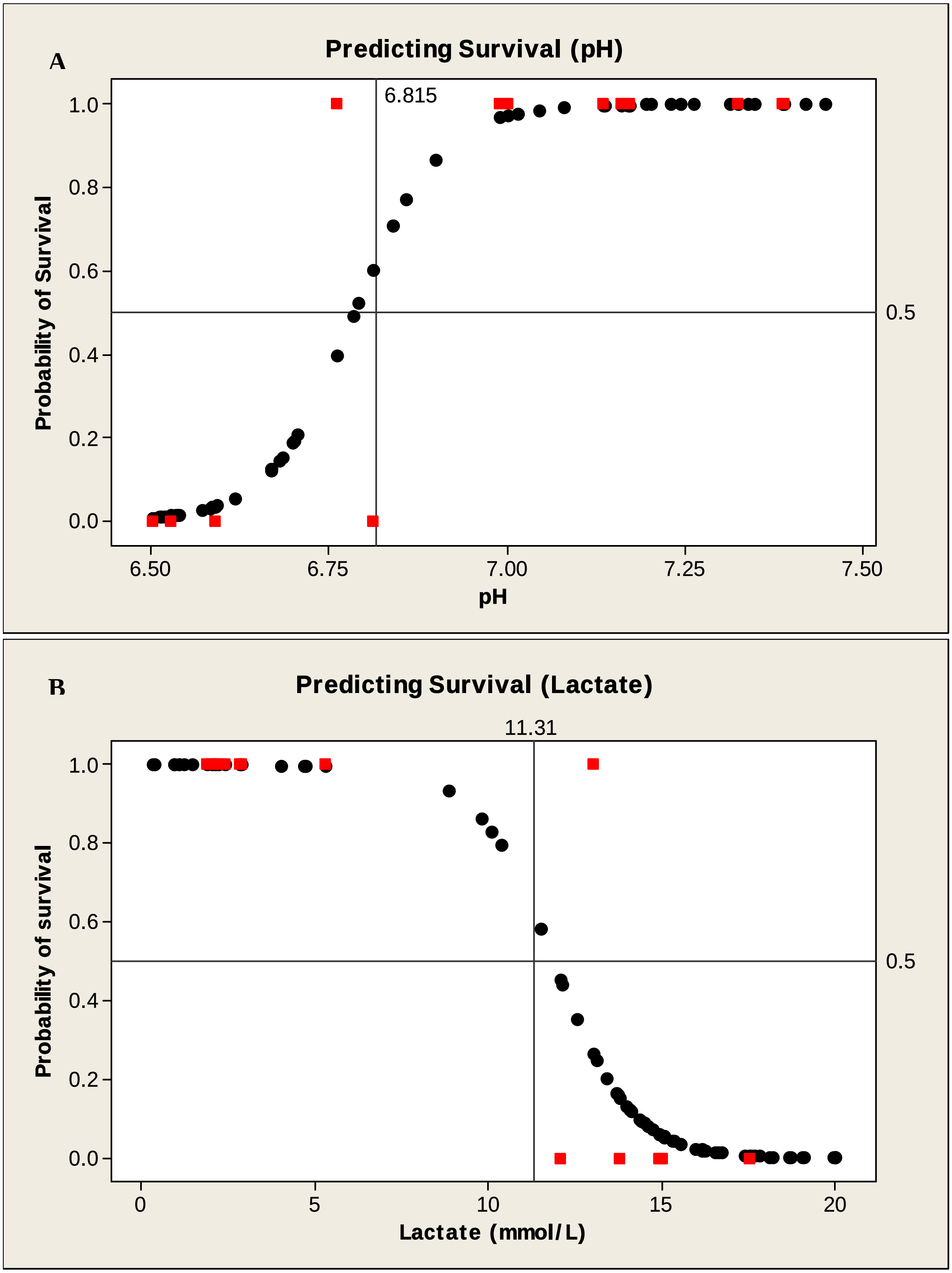


Figure 2. Binary regression curves for pH levels (A) and Lactate mmol/L concentrations (B) of satellite tagged animals that either survived the fishing interaction (1) or died post release (0) in red. The fitted values in black represent animals that had blood drawn but were not satellite tagged. Pi values > 0.5 indicate an animal that is predicted to have survived the fishing event.

Table 4. Logistic regression model parameters for pH and Lactate.

Predictor	Coefficient	$Coef_{SE}$	Z	P	Odds Ratio	95% Confidence Interval	
Lactate							
b_0	10.5757	12.1086	0.87	0.382			
b_1	-0.891	0.918	-0.97	0.332	0.41	0.07	2.48
pH							
b_0	-113.234	79.3490	-1.43	0.154			
b_1	16.6885	11.6950	1.43	0.154	17688946	0	1.59E17

	Lactate	pH
Log-likelihood	-2.227	-1.980
G	13.794	14.289
DF	1	1
P	0.000	0.000

Goodness of Fit Tests	Lactate	pH	Lactate	pH	Lactate	pH
Method	χ^2		DF		P	
Pearson	3.891	3.17081	12	11	0.985	0.988
Deviance	4.45499	3.96058	12	11	0.974	0.971
Hosmer- Lemeshow	3.56064	2.58915	8	8	0.894	0.957

Landing Stage	Pre-Assess	Encircled	Tangled	1st Brail	Brail	Total	Total Excluding P & E
n	10	7	37	30	211	295	278
Predicted Survival	100%	100%	68.4%	16.7%	6.67%	20.68%	15.83%
No. Survivors	10	7	25	5	14	61	44
Total mortality rate for juvenile silky sharks landed during typical fishing stages = 84.17%							

Table 5. Number of animals landed during each stage and the predicted survival for each stage. Total survival for regular fishing operations is given in the last column by removing the animals landed during the pre-assessents and those that had been encircled but released outside the net.

Release Condition	Excellent	Good	Fair	Poor	Dead
n	39	16	21	34	165
Predicted Survival	91.67%	11.49%	6.897%	0%	2.94%
Survivors	35.75	1.84	1.45	0	4.85

Table 6. Predicted survival estimated from release condition. Some animals were released without a release condition recorded.

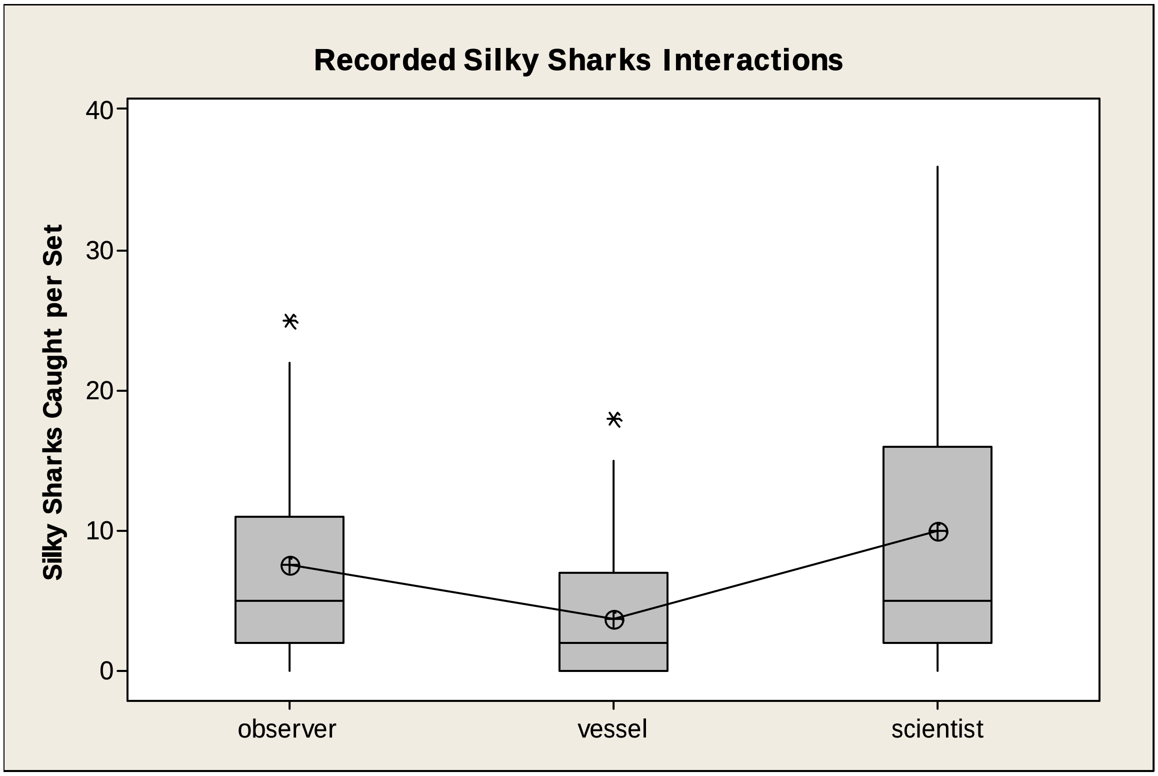


Figure 3. Shark catch comparisons between the fishery observer, vessel logbook and the scientists.

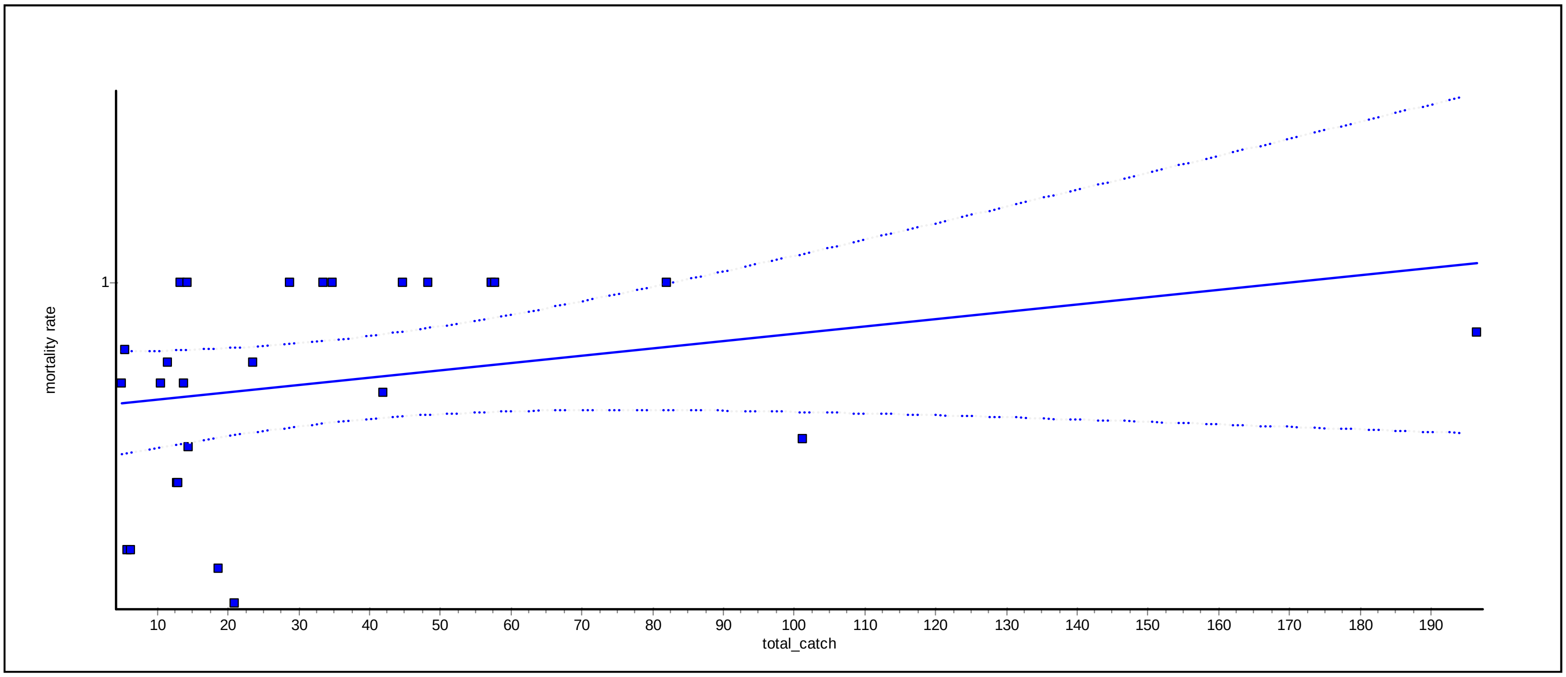


Figure 4. Predicted silky shark mortality rates versus the size of the catch (tonnes) for each set.

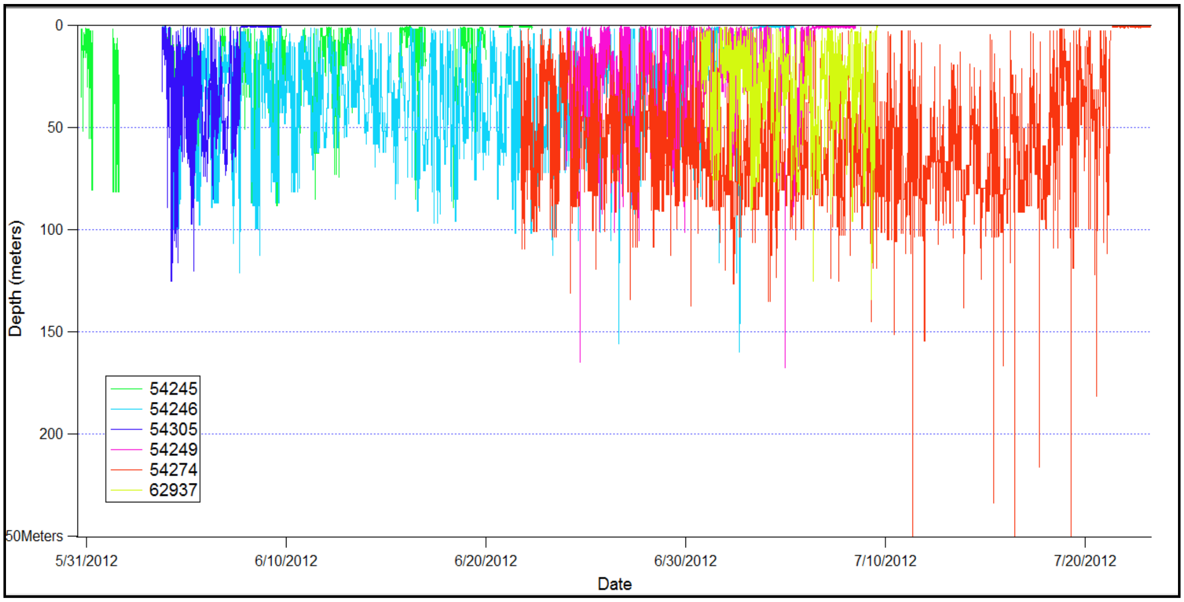


Figure 5. Depth time series data for six silky sharks tagged with miniPATs.

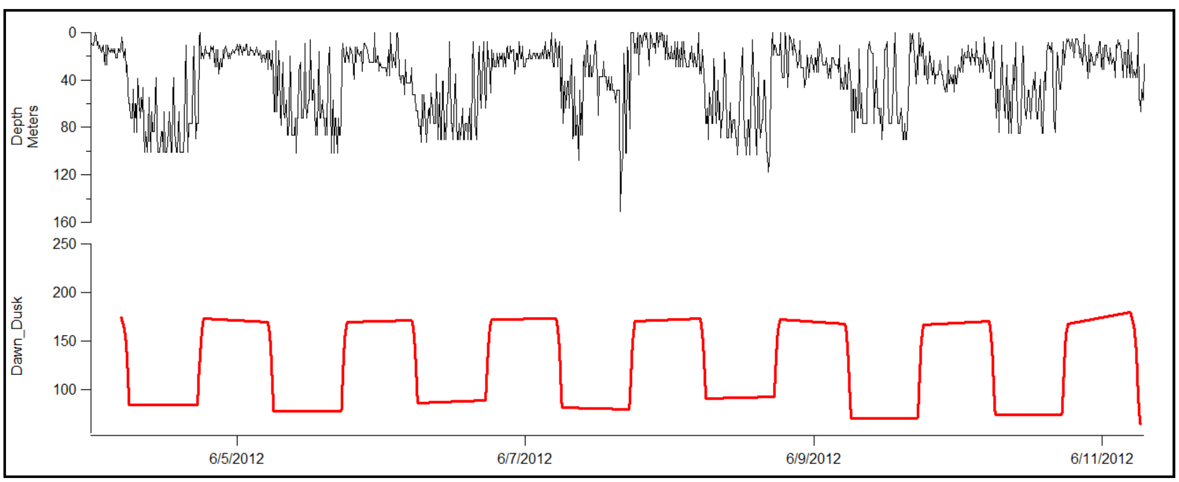


Figure 6. Diel vertical movements of silky shark 54246. The top graph (black line) gives the depth time series of one silky shark over a period of seven-24 hour day/night cycles. The bottom line (red) shows light levels to infer day and night via dawn and dusk times.

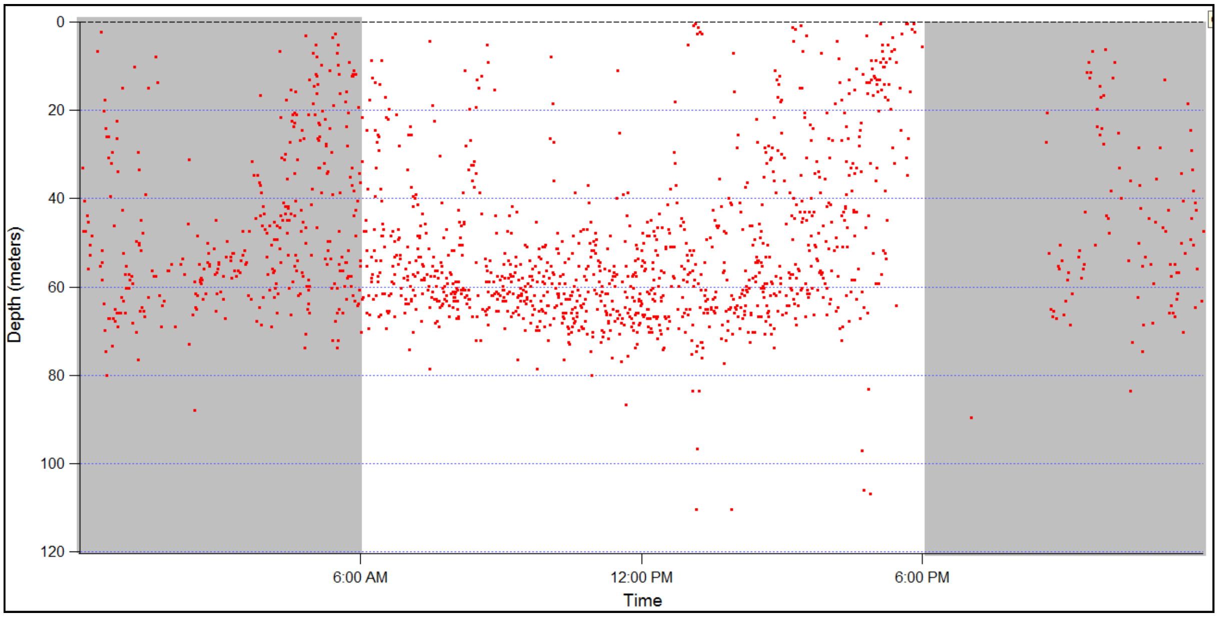


Figure 7. Acoustic detections of two silky sharks tagged at FAD object 30. Each detection is plotted over a 24 hour time period. Grey shading indicates nighttime, white is daytime. The depth of the animal at each detection is plotted on the vertical axis.

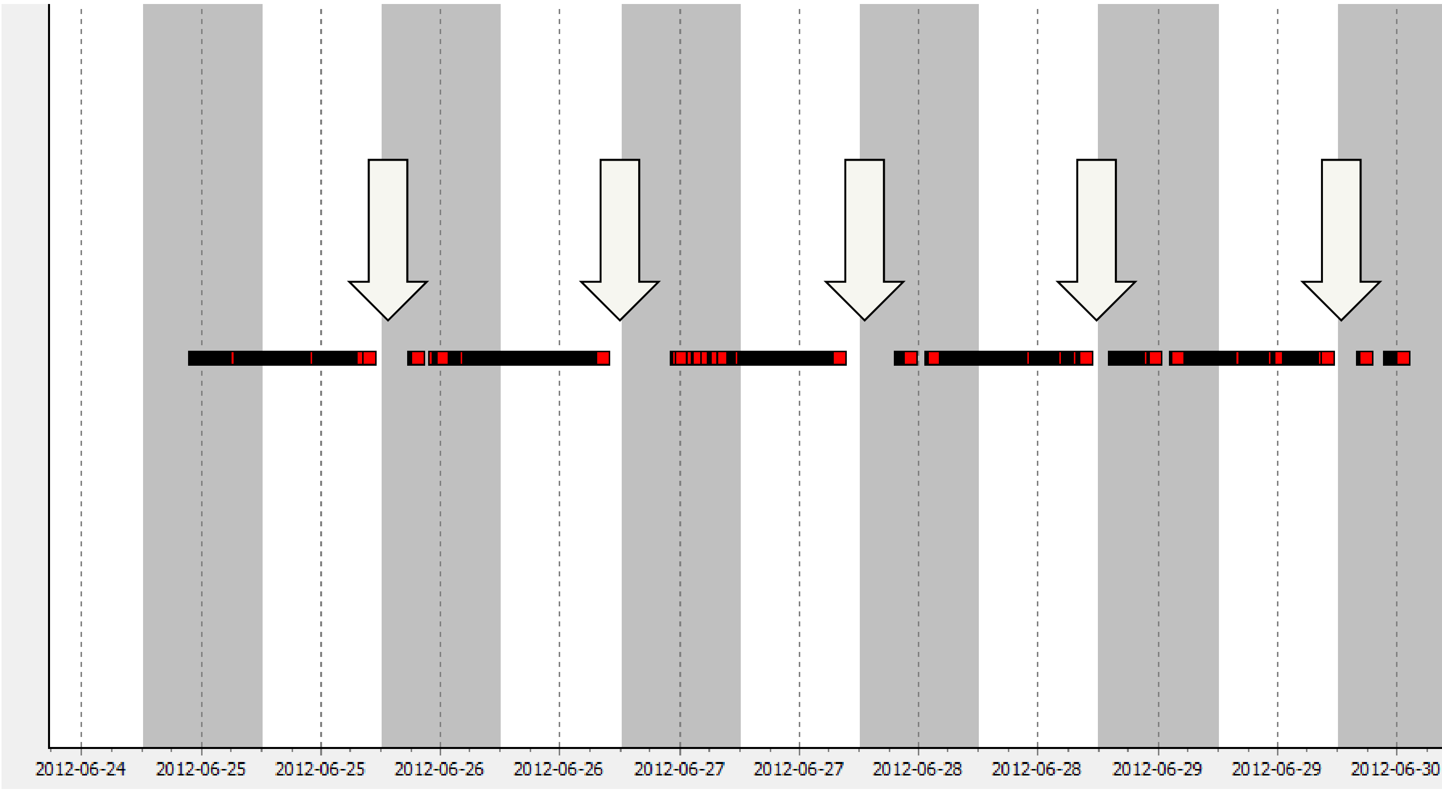


Figure 8. The 6 day acoustic receiver deployment time series on FAD object 30 showing all detections over time. Arrows point to periods of quiet or no detections that correspond to repeated evening departures from the FAD.

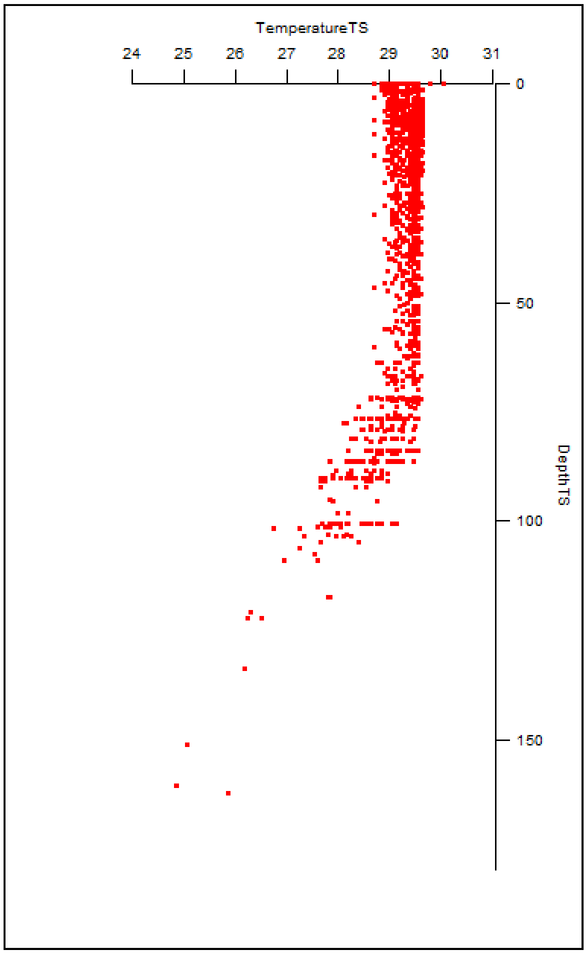


Figure 9. Typical temperature ranges of 29.5 °C for silky sharks tagged during this cruise.