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EVALUATION OF POST-RELEASE MORTALITY FOR PORBEAGLE AND SHORTFIN MAKO SHARKS FROM THE CANADIAN PELAGIC LONGLINE FISHERY

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SUMMARY

The majority of shark catches from the Canadian pelagic longline fleet are discarded alive at sea, making post-release mortality (PRM) estimates critical to understanding total fishing mortality. We found little evidence that at-vessel mortality has changed from 2001-2018, suggesting that capture characteristics are similar and previous satellite tagging can be combined with more recent tagging to describe PRM. Estimated rates were 14% for porbeagle (6% for healthy and 40% for injured) and 28% for shortfin mako (27% for healthy and 33% for injured), which is approximately ½ of the previous estimate for porbeagle and essentially the same for shortfin mako. We propose that this difference for porbeagle is related to handling characteristics during tagging, which switched from bringing animals on board to tagging in the water. This conclusion is supported by an analysis of recovery times for surviving animals where median recovery time was 1 day (shortfin mako) or 1.5 days (porbeagle) longer when the shark was tagged onboard as compared to in the water.

RÉSUMÉ

La majorité des prises de requins de la flottille canadienne de palangriers pélagiques sont rejetées vivantes en mer, ce qui rend les estimations de mortalité après remise à l'eau (PMR) essentielles pour comprendre la mortalité par pêche totale. Nous n'avons trouvé que peu d'éléments probants indiquant que la mortalité à bord des navires a changé entre 2001 et 2018, ce qui donne à penser que les caractéristiques de capture sont semblables et que le marquage par satellite antérieur peut être combiné avec un marquage plus récent pour décrire la PMR. Les taux estimés étaient de 14% pour le requin-taupe commun (6% pour les spécimens en bonne santé et 40% pour les spécimens blessés) et de 28% pour le requin-taupe bleu (pour les spécimens en bonne santé et 33% pour les spécimens blessés), soit environ ½ des estimations précédentes pour le requin-taupe commun et essentiellement les mêmes pour le requin-taupe bleu. Nous supposons que cette différence pour le requin-taupe commun est liée aux caractéristiques de manipulation pendant le marquage, qui est passé du hissage des animaux à bord de l'embarcation à leur marquage dans l'eau. Cette conclusion est étayée par une analyse des temps de récupération des animaux survivants pour lesquels le temps de récupération médian était d'un jour (requin-taupe bleu) ou d'un jour et demi (requin-taupe commun) de plus lorsque le requin était marqué à bord que lorsqu'il était marqué dans l'eau.

RESUMEN

La mayoría de las capturas de tiburones de la flota palangrera pelágica canadiense son descartadas vivas en el mar, lo que hace que las estimaciones de mortalidad posterior a la liberación (PMR) sean críticas para comprender la mortalidad total por pesca. Encontramos poca evidencia de que la mortalidad en los buques haya cambiado entre 2001 y 2018, lo que sugiere que las características de captura son similares y que el marcado vía satélite previo puede combinarse con un marcado más reciente para describir la PMR. Las tasas estimadas fueron del 14 % para el marrajo sardinero (6 % para los sanos y 40 % para los heridos) y del 28 % para el marrajo dientuso (27 % para los sanos y 33 % para los heridos), que es aproximadamente la mitad de la estimación anterior para el marrajo sardinero y esencialmente

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la misma para el marrajo dientuso. Proponemos que esta diferencia para el marrajo sardinero está relacionada con las características de manipulación durante el marcado, que pasaron de llevar animales a bordo a marcar en el agua. Esta conclusión se apoya en un análisis de los tiempos de recuperación de los animales supervivientes, donde el tiempo medio de recuperación fue de un día (marrajo dientuso) o 1,5 días (marrajo sardinero) y más largo cuando el tiburón fue marcado a bordo en comparación con el marcado en el agua.

KEYWORDS

Fishing mortality, live discards, tagging effects, post-release mortality, pelagic sharks

1. Introduction

In Canada, shortfin mako and porbeagle sharks are two species where license conditions in the pelagic longline fleet stipulate the mandatory release of all live bycatch, although dead animals may be landed. As live bycatch represents the majority of catches, post-release mortality (PRM) could represent the majority of total fishing mortality by Canadian fleets, as opposed to landings and dead discards (Campana *et al.* 2016). Given that both species are thought to be at low abundance based on their most recent assessments (ICCAT 2009, ICCAT 2018), there is an immediate need for accurate PRM estimates to account for mortality from discard events when calculating total annual removals.

Current estimates for post-release mortality for shortfin mako and porbeagle from pelagic longline fleets are limited. A recent meta-analysis applied a random effects model to the PRM results from 4 studies on shortfin mako and estimated PRM to be 25% (95% CI = 14,42%; Musyl & Gillman 2019). There was no similar estimate for porbeagle as multiple studies have yet to be completed. Previous Canadian estimates of PRM were 27% (10% for healthy sharks, 75% for injured) for all captured porbeagle and 31% (30% for healthy sharks, 33% for injured) for all captured shortfin mako (Campana *et al.* 2016). Condition was accounted for because it has been found to be a good predictor of subsequent mortality for several commercially fished species (e.g. Benoit *et al.* 2010, Skomal 2007, Ellis *et al.* 2017). However, sample sizes for injured animals were extremely low (n = 4 and n = 3, respectively) and estimated rates may not be representative.

Several tagging programs for pelagic sharks, including Canada's, have shifted towards tagging in the water as opposed to bringing animals on board in an effort to minimize handling effects. This affords a unique opportunity to assess how handling influences recovery time from datasets where the method of capture remains consistent. Longer recovery times are associated with processes that cause greater physical and physiological trauma to released animals (Ellis *et al.* 2017). Stresses associated with handling would be low relative to those associated with the capture process itself and are unlikely to be a large component of PRM (Campana *et al.* 2009, Musyl & Gilman 2019). However, handling effects are rarely evaluated for satellite tag studies yet have important implications for study design and conclusions on how the capture process affects shark bycatch.

2. Methods

2.1. Tagging

Details on the tag types and tagging methodology used previously to evaluate PRM for shortfin mako and porbeagle from the Canadian pelagic longline fishery can be found in Campana *et al.* (2016). We will refer to that tagging as the early period and our tagging as the recent period for the remainder of this document. We used essentially the same methodology as in Campana *et al.* (2016), albeit with a different type of satellite tag. In brief, shortfin mako and porbeagle sharks were captured from pelagic longline sets and tagged by fisheries observers or science personnel with short-term archival survival tags (Lotek PSATLIFE). The majority of tagging took place during regular commercial fishing for Swordfish in 2017-2018, with a limited number of porbeagle (n = 11) tagged during a pelagic shark survey in 2017. In all cases, captures occurred from pelagic longline gear fished for a minimum soak time of 6 hours. The fleet switched over to using circle hooks in the early 2000s and all captures in 2017-2018 were on circle hooks. For animals that were tagged in the water, the line was cut as close to the hook as possible for release. For animals that were brought onboard, measurements and tagging took 1-2 minutes while the animal's gills were being irrigated with seawater. In this instance, hooks were removed before release. The tags were attached to the sharks by angling the dart anchor into the pterygiophores in the dorsal musculature, immediately beside the posterior end of the first dorsal fin (Campana *et al.* 2016, Musyl *et al.* 2011). Individuals of both species were chosen opportunistically for tagging, but efforts were made to include a range of sizes and both sexes for each species.

PSATLIFE tags record pressure (0.05% resolution), temperature (± 0.2 °C) and light intensity every 5 minutes for the 28-day deployment. Mortalities are inferred from continual records at a constant depth for multiple days (indicative of a dead animal on the bottom) or pop-ups following progressively increasing depth records up to the tag crush depth of 2000 m (Musyl *et al.* 2011). For these analyses, data collected for the previous study (2001-2013; Campana *et al.* 2016) were truncated to 28 days to be comparable. As such, these results only apply to mortality events that occur immediately following capture/handling and would not represent delayed mortality resulting from internal damage causing cessation of feeding.

The tagging data gave survival in continuous time (days until death) with right-censored observations from individuals that lived until the end of the observation period (28 days). The observations are censored because the ultimate time of death of the individual is unknown, yet they are known to be alive until the end of the observation period. We fit a parametric survival mixture model (SMM) to these continuous data via Maximum Likelihood, assuming a Weibull distribution and logit link as described in Benoit *et al.* (2012). These are two-component models that estimate the probability of surviving beyond time (t) for two separate vitality classes. The asymptote of the survival function represents the estimated post-release mortality rate for each vitality class (here healthy and injured animals) and confidence intervals were calculated using the normal approximation.

The satellite tags also recorded the depth and temperature profiles of sharks while alive, which provided an opportunity to assess behavioral changes associated with handling (tagging effects). Handling effects can only be differentiated if the capture method is kept constant while two types of handling methods are employed simultaneously, or vice versa for capture effects (Beardsall *et al.* 2013). Recovery from physiological stresses for multiple pelagic species has been linked to changes in diving behavior, reflecting generally lower activity levels upon release (Skomal & Chase 2002, Whitney *et al.* 2016). Our objective was to quantify the length of the recovery period during which the behaviour of shortfin mako or porbeagle was impaired, using three criteria for impairment: (1) number of days where the maximum observed dive depths remained 60 m or less, indicating an animal that remained close to the surface, (2) number of days of near-zero variability in minimum and maximum depths, indicating an animal that is not moving vertically in the water column, and (3) abrupt decreases in variability from a breakpoint analysis of mean daily dive variance, identifying the portion of the movement track characterized by similar diving behavior. We used bootstrap re-sampling (10,000 draws) to characterize the median difference plus 90% confidence interval in recovery times between individuals tagged in the water vs. those tagged onboard.

2.2. Fishery characterization

The pelagic longline fishery in Atlantic Canada targets Swordfish (*Xiphias gladius*) or tropical tunas, primarily bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*). Starting in 2001, the condition (alive, dead or unknown) of all sharks kept or discarded from pelagic longline sets was recorded by at-sea observers through the Scotia-Fundy Observer Programme (SFOP). Since 2010, additional monitoring requirements have been put in place and the condition of live shark discards are further categorized as healthy or injured upon release (Campana *et al.* 2016).

Bycatch of shortfin mako or porbeagle from a total of 1620 sets examining 8711 individual sharks (4370 porbeagle and 4341 shortfin mako) were used to characterize the annual proportion of catches alive or dead at vessel (2001-2018). A subset of these (3094 porbeagle and 1669 mako; 2010-2018) gave information on the condition of discards, scored as: healthy, injured, dead or unknown. Systematic changes in the annual proportion alive or dead would indicate systematic changes in fishing practices affecting the condition of bycatch. A binomial Generalized Linear Model was used to examine trends in the proportion dead at vessel, using year as a continuous predictor and a logit link. Comparison with an intercept-only model (indicative of no trend over time) was done using ANOVA and a Chi-square test. Years in which > 50% of the individuals were scored as 'unknown' were removed prior to fitting the models (porbeagle only; 2013-2015).

A similar multinomial model was not fit to evaluate changes in the condition of discards (healthy, injured, dead or unknown) for two reasons. First, > 50% of catches were scored as 'unknown' condition in 2012 – 2015 for porbeagle, representing essentially half of the available time series (2010-2018). Condition of discards can be difficult to determine because the majority of animals are cut off the line while still in the water, limiting observation time and increasing the subjectivity of classifications (Campana *et al.* 2016, Ellis *et al.* 2017).

However, this is true for all years of data collection, and suggests that abrupt increases in the proportion 'unknown' represents an observer effect. Second, voluntary release of live shortfin mako by the pelagic longline fleet started in 2015, and it is likely that proportionately more injured or dead animals were landed rather than discarded after that time. The landings data do not score condition, so it is not possible to directly evaluate this assumption.

3. Results

There was no indication that the proportion of sharks dead at vessel has changed from 2001-2018, excluding 2012-2015 when observers tended not to classify condition (**Figure 1**), with the fixed effect of year being non-significant in the binomial regressions for porbeagle (P = 0.461) or shortfin mako (P = 0.758). Although it is possible that fishing and capture methods have led to differences in the proportion of animals that escape from the gear, their effects on retained catch appear similar over time. This suggests that tagging data from the early and recent tagging periods can be meaningfully combined to increase sample size.

Although tagging was opportunistic, the size distribution of tagged individuals was similar in the recent and early tagging periods (**Figure 2**) and spanned the size distribution of commercial landings from the pelagic longline fishery. Similar numbers of males and females were tagged for shortfin mako (46% female) but not porbeagle (79% female). The sex ratio in commercial catches tends to be approximately 50:50 for both species, so we are unsure why so many more females were encountered during tagging for porbeagle. In the recent tagging period, there was a 40% non-transmission rate for the PSATLIFE tags as well as several premature pop-offs. Only 18 of the 31 tags deployed on porbeagle transmitted, giving data on 8 healthy and 10 injured animals. Only 15 of the 25 tags deployed on shortfin mako transmitted, giving data on 11 healthy and 4 injured animals (**Table 1**). This non-transmission rate is quite high relative to that reported for either Wildlife Computers or Microwave Telemetry satellite tags (Musyl *et al.* 2011). When combined with the early tagging data, total sample sizes were 48 healthy and 15 injured porbeagle and 41 healthy and 7 injured shortfin mako. Additional tagging is anticipated in 2019, but results weren't available for this manuscript.

Combining individuals from both condition classes, the probability of mortality was not related to animal size or to the location of hooking based on binomial regression (all coefficients $P > 0.1$). However, we do not discount the possibility that these relationships could exist and be measureable from more data, particularly on injured animals. The sparse data also affected fits from the survival mixture models in that confidence intervals for the survival functions were wide, completely overlapping between condition categories for shortfin mako and partially overlapping for porbeagle. The asymptotes for the survival functions suggest post-release mortality rates of 0.27 (CI = 0.15, 0.44) for healthy and 0.33 (CI = 0.08, 0.73) for injured shortfin mako and 0.06 (CI = 0.02, 0.17) for healthy and 0.40 (CI = 0.19, 0.65) for injured porbeagle. The probability of a live release being injured was 0.14 (CI = 0.08, 0.20) for shortfin mako and 0.17 (CI = 0.09, 0.26) for porbeagle. Accounting for the relative frequency of the condition categories in the commercial catches gives a weighted mean PRM mortality rate of 0.28 for shortfin mako and 0.15 for porbeagle. Interestingly, we obtained essentially identical estimates of PRM using a survival model that did not consider vitality class, 0.28 (CI = 0.14, 0.39) for shortfin mako and 0.14 (CI = 0.05, 0.22) for porbeagle. This supports the idea that healthy and injured animals were tagged in proportion to their frequency in the catch.

The majority of sharks that died after tagging did so very quickly, typically within hours. For the few animals that took longer to expire, there was a marked difference in their dive track characteristics as compared to individuals that survived tagging. These animals tended to remain at constant, relatively shallow depths rather than demonstrating the cyclical dive patterns that are typically recorded (example given in **Figure 3**). For the animals that survived, median recovery times were 1 day longer for shortfin mako (CI = 0, 5.5 days) and 1.5 days longer for porbeagle (CI = -1.5, 5) tagged onboard a vessel. Although both confidence intervals include zero, the majority of the probability mass was positive, consistent with the idea that bringing an animal out of the water results in greater physiological stress.

4. Discussion and Conclusions

Mimicking the capture and release practices of a commercial fishery is critical when trying to quantify the mortality rate of bycatch after release (Musyl *et al.* 2009). In the Canadian pelagic longline fishery, shark discards tend not to be brought on deck; rather, the gangions are cut once a species has been identified. Thus, it is likely that tagging done in the recent time period was more representative of practices by the fleet because discards were tagged quickly in the water, rather than after more extensive measurements while onboard. Compared to previous PRM estimates for this fishery (Campana *et al.* 2016), incorporating recent data dramatically reduced overall PRM values for porbeagle (*c.f.* 14% and 27%) but not shortfin mako (*c.f.* 28% and 31%). Interestingly, 50% (13 of 26) of shortfin mako in the early period were tagged in the water, while all porbeagle (n = 45) were tagged onboard. Although increasing the amount of data on injured porbeagle (n = 4 in the early period vs. n = 10 in the recent period) would have been expected to increase the reliability of the estimate, such a dramatic reduction in the PRM rate (75% in the early period vs. 30% in the recent period) suggests additional factors were important.

Our finding of longer recovery times for individuals tagged onboard provides further evidence that PRM for injured porbeagle in the early time period might have been lower if individuals had been tagged in the water. Tagging effects are presumed to be low relative to the effects of capture, as evidenced by high survival rates after tagging, the similarities in shark condition at capture as when released, as well as animal care protocols while on deck (e.g. continuous respiration with sea water, covering the animal's eyes; summarized in Musyl *et al.* 2019). However, tagging onboard increases the amount of time that an animal is under duress (more measurements and biological samples are typically taken) and has the potential for physiological damage associated with lifting the animal out of the water as well as that associated with a shark's inability to support its own weight while onboard (Musyl *et al.* 2009). Although cortical steroid levels (indicative of stress response) typically drop while an animal is on deck (e.g. Talwar *et al.* 2017), physiological damage to the animal plus behavioural changes after tagging would not be shown by changes in blood chemistry (Skomal 2007). There are very few evaluations of different handling strategies for shark bycatch (Molina & Cook 2012), making it difficult to provide guidance on best practices. Our results suggest that more representative data from satellite tagging can be obtained if sharks are tagged in the water.

Qualitative visual assessments of shark condition are commonly used as an indicator of the extent of physical injury caused by the capture process, and condition has been found to be an important predictor of mortality for several shark species (Ellis *et al.* 2017, Talwar *et al.* 2017). We found minimal evidence of this for shortfin mako as PRM estimates from the survival mixture model for healthy and injured sharks were similar with highly overlapping confidence intervals, yet stronger evidence for porbeagle. In the Canadian pelagic longline fishery, at-sea observers typically have very little opportunity to assess shark condition prior to the animal being released. In some cases, the gangion will have been cut before the animal has even broken the surface of the water, limiting observation time and increasing the subjectivity of classifications (Campana *et al.* 2016). It is not overly surprising that these data may not accurately reflect the extent of physical injury experienced by the shark. Although tracking shark condition and determining covariates with injury and mortality is important for developing mitigation options for a particular fishery (Molina & Cooke 2012, Ellis *et al.* 2017), it increases the complexity of the modeling approaches necessary to estimate PRM. Given that we obtained essentially identical results from a survival model that did not account for vitality class, it may be preferable to focus on representative tagging rather than on improving the accuracy of condition classifications for PRM studies that inform fisheries assessment.

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Table 1. Tagging summary from deployments in 2017 and 2018.

Species	Condition	Total	Did not transmit	Lived	Died	N
Shortfin mako	Healthy	17	6	10	1	11
Shortfin mako	Injured	8	4	3	1	4
Porbeagle	Healthy	14	6	8	0	8
Porbeagle	Injured	17	7	7	3	10

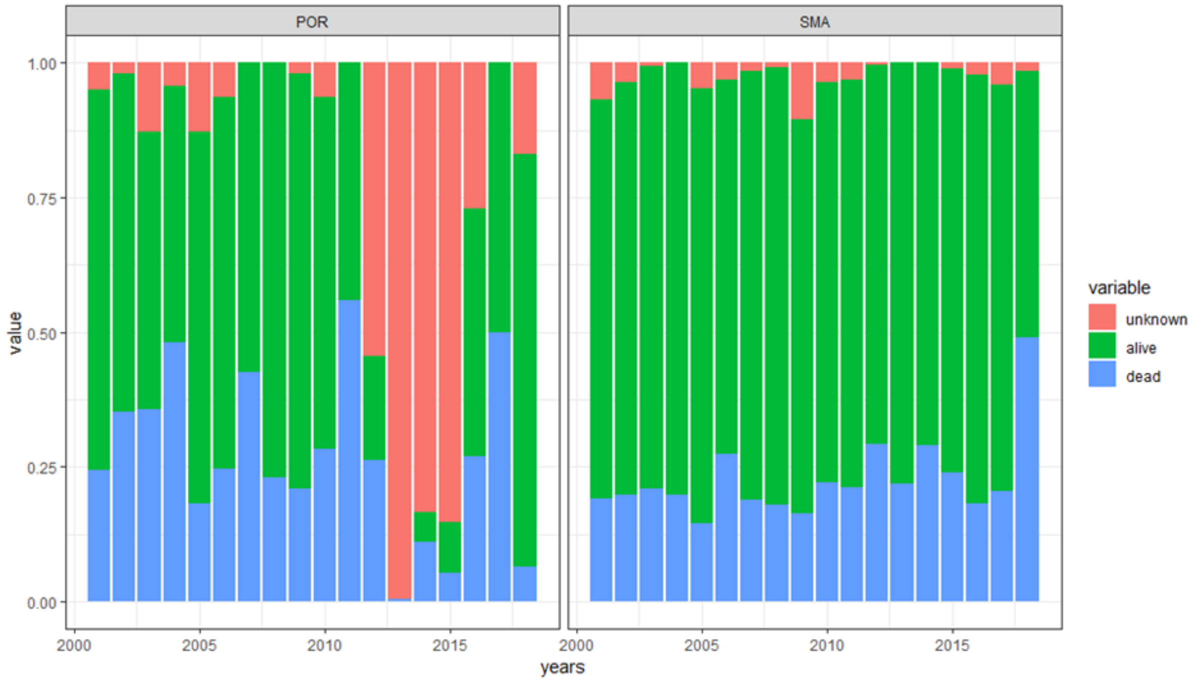

Figure 1. A stacked barplot showing the proportion of bycatch (kept and discarded) of porbeagle (left panel) and shortfin mako (right panel) that was scored as alive, dead or unknown by at-sea observers.

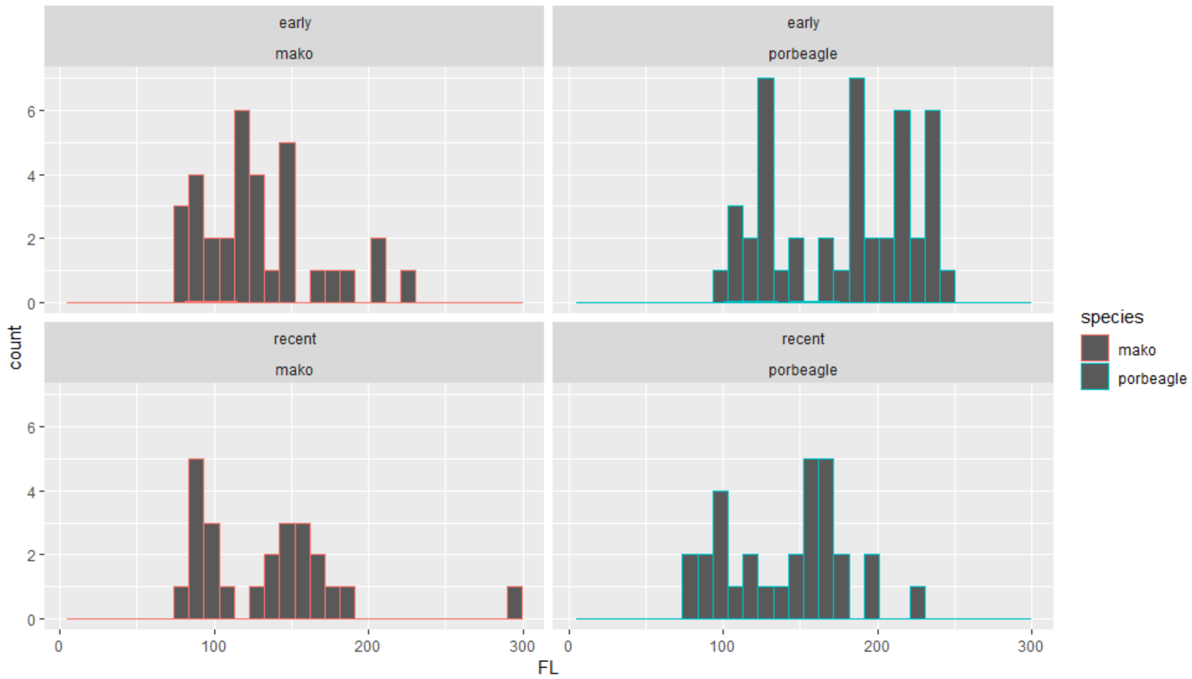

Figure 2. The size distribution of shortfin mako (left two panels) and porbeagle (right two panels) tagged in the early (top panels) and recent (bottom panels) time periods.

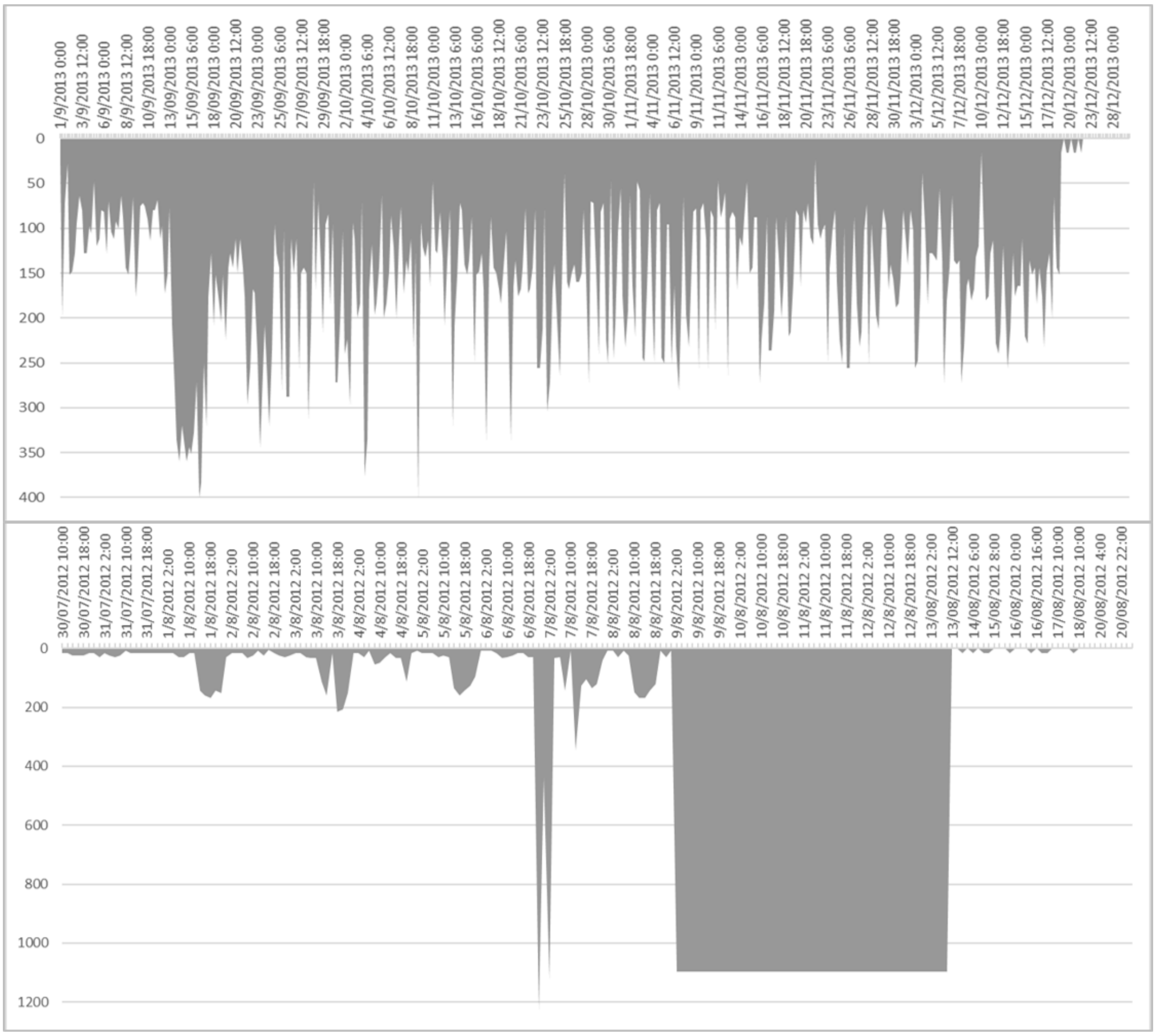

Figure 3. A comparison of the diving behavior from a shortfin mako that survived satellite tagging (top panel) and one that died (bottom panel). The depth range that each animal moved through is shown in grey shading. The mortality event in the bottom panel starts on 9 August 2012 and is indicated by the constant depth for 5 days.