Post-release mortality of oceanic whitetip sharks caught by purse seiners – POREMO project

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Abstract

Oceanic whitetip shark (*Carcharhinus longimanus* – OCS) is a sensitive species present in the Indian Ocean that is classified as globally "Critically Endangered". OCS are occasionally bycaught by tuna purse seine fleets operating in the Indian Ocean. The retention of OCS is prohibited and despite the efforts made to handle and release those sharks, post-release mortality (PRM) of OCS needs to be assessed. In the frame of the POREMO project that is dedicated to this particular task, onboard observers deployed electronic tags (16 sPATs and 3 miniPATs) on OCS released by French, Spanish and Mauritian purse seiners in the western Indian Ocean between 2018 and 2023. Based on the 16 tags that reported data, we determined the overall PRM rate and explored the effect of fish condition upon release, individuals' size, sex, and time spent on deck before release on the PRM. We found that the overall PRM for OCS bycaught by purse seiners was 18.75 %. Our results show that PRM is dependent on fish condition upon release, with full survival for lively individuals (100 %) and poorer survival chances for the injured and moribund ones (20 and 0 %). The time that individuals spend on deck directly affects their condition at the time of release, subsequently influencing their likelihood of survival. Furthermore, the size of individuals size appears to enhance the survival prospects of injured and moribund individuals. Those results suggest that handling carefully and releasing promptly bycaught OCS would likely improve their PRM.

Keywords

Carcharhinus longimanus | Post-release mortality | Survival | Bycatch | Purse seine | Western Indian Ocean

1. Introduction

Oceanic whitetip sharks (*Carcharhinus longimanus* – OCS) are sensitive species present in the Indian Ocean that are classified as globally "Critically Endangered" by the IUCN (IUCN, 2023) and listed on the CITES Appendix II prohibiting trade on this species (CITES, 2023). OCS are occasionally bycaught in the Indian Ocean by tuna purse seine fleets, among other fishing gears (IOTC, 2022). Similar to most shark species, OCS are particularly vulnerable to overfishing due to their characteristics of low reproductive rates, slow growth, and late maturity (Cortés, 2000). OCS were therefore identified as a priority species for conservation by IOTC (IOTC, 2022).

Since 2014, IOTC prohibits the retention of OCS (Res. 13/06) as an incentive conservation and mitigation measure to avoid the catch and promote the live release of OCS specimens. While retention ban measures are generally considered insufficient for the recovery of shark populations (Tolotti et al., 2015), it is crucial, for assessing the effectiveness of this measure and usefulness of efforts made by vessel to carefully handle and release sharks (Wain et al., 2022), to assess the survival rate of released OCS. Moreover, post-released mortality is necessary to estimate the total fishing mortality on a given species, which is required for stock assessment purposes (Bowlby et al., 2021).

The POREMO (POst-RElease Mortality of Oceanic whitetip shark) project (2018-2023), under the coordination of IRD (France) and with co-funding from both IRD (France) and the European Commission (as part of the "Data Collection Framework"), specifically addressed the post-release mortality of OCS that are unintentionally caught and released by longliners and purse seiners in the Indian Ocean (Bach et al., 2018; Bach et al., 2019; Bach et al., 2021).

In this paper, we provide the final results of the post-release mortality study of OCS bycaught by purse seiners in the Indian Ocean, as part of the POREMO project. In addition to providing the overall mortality rate for OCS, we investigated the effect of the condition of individuals upon release, length of individuals, sex, and time spent on deck before release on the post-release mortality.

2. Material and methods

2.1. Data

Popup satellite archival tags manufactured by Wildlife Computers (Redmond, USA) were employed to evaluate the post-release mortality of OCS released by purse seiners (Bach et al., 2018). Two distinct models, namely the survival PAT (sPAT) and the miniPAT, were used. Tags were rigged with a 12 cm stainless-steel tether and were affixed with Domeier or large Titanium anchors (Table 1) to be implanted at the basis of the first dorsal fin (Bach et al., 2018). Tags were programmed for a period of 60 days and 180 days for sPATs and miniPAT, respectively (Table 1). At the onset of the project, 12 and 9 tags were allocated to the purse seine observer program coordinators from France (IRD) and Spain (AZTI) to be deployed on the respective fleets (Bach et al., 2018). Tagging kits including the protocol, tagging form, electronic tag (sPAT or miniPAT), tag applicator, and short tagging pole, were provided to observers (Bach et al., 2018). Information collected on the individuals on board purse seiners included the tagger's name, vessel name, date, tagging location, length of the individual (in cm), sex ("Female", "Male" or "Undetermined"), time spent on deck (in min), and fish condition upon release ("Alive good", "Alive injured", "Alive moribund") (Table 2; Figure 1). Individuals' size was collected as total length (TL in cm) and fork length (FL in cm). FL measures were converted to TL using the following conversion: TL = 1.224*FL (Compagno, 2001). Table 2 also includes the tag popup date (when it started transmitting data), the number of days at liberty, the tag release diagnostic ("Full deployment", "Premature", "Too deep" and "No transmission"), and our assessment of whether the individual died after being released based of the examination of depth profiles (Figure S1; see section 2.2).

2.2. Analyses

Post-release mortality was assessed based on the depth profiles collected by sPAT and miniPAT tags fitted on released OCS (Figure S1). Mortality was detected when the individual sank at depths below 1700 m or remained at the constant depth for 3 days above 1700 m (on the continental shelf for example). If a tag detached from an individual before the initially scheduled deployment time, possibly due to inadequate anchoring, the depth profile was examined to confirm whether the individual was exhibiting expected behavior.

Post-release mortality is the binomial response variable (0, 1) for which we tested the effect of various covariates: fish condition at release, individual's size, sex, and time spent on deck before release. We also calculated the overall mortality rate and mortality rate by modalities of certain categorical covariates.

We first investigated the effect of individuals' condition at release on mortality through a Pearson's Chi-squared test of independence. Then, we calculated mortality rates for the different health conditions ("Alive good", "Alive injured", and "Alive moribund").

The effect of individuals' size on mortality was tested by performing a logistic regression (generalized linear model - GLM). Initially, we incorporated all three condition modalities in the GLM, and subsequently focused the analysis on the two most compromised condition modalities: "Alive injured" and "Alive moribund".

To explore the effect of sex on mortality, we calculated mortality rates by sex categories ("Female", "Male", "Undetermined").

We tested the effect of time on deck on mortality through a logistic regression and a Welch's t-test (alternative to Student's t-test when variances are unequal). We then explored the effect of time on deck on the fish condition upon release. For this purpose, we performed a Student's t-test by comparing the time spent on deck for two condition modalities: "Alive good" and "Alive injured or moribund". To validate the initial assumptions of the Student's t-test, we checked whether the sample distribution conformed to a normal distribution using a Shapiro-Wilk test and checked the homoscedasticity with a Barlett's test.

3. Results

Nineteen (19) electronic tags (16 sPATs and 3 miniPATs) were deployed by 8 scientific observers on 9 purse seiners flagged EU.FRA, EU.SPA and MUS between 2018 and 2023 in the western Indian Ocean (Table 1; Figure 1). Sixteen (16) tags transmitted and reported data (84 %; Table 1).

Three out of 16 tagged OCS succumbed following their release, resulting in an overall post-mortality rate of 18.75 % (Table 2; Figure S1). The individual tagged with sPAT#46216 died immediately after release while those tagged with sPAT#56563 and miniPAT#49081 died after 3 days (Figure S1; Table 2). Among the 13 individuals that survived, 8 tags exhibited premature detachment (62 %; Table 2).

Mortality is dependent on the individuals' condition at release with 0 % post-release mortality for those assessed as "Alive good" upon release, 20 % for the injured individuals, and 100% for the moribund ones (Figure 2). The Pearson's Chi-squared test confirmed that fish condition drives mortality (Chi-squared = 10.749; df = 2; p = 0.004634).

Tagged individuals ranged between 109 and 220 cm TL (Table 2; Figure 3); 74 % were juveniles (median $L_{maturity}$ = 190 cm TL; Séret et al., 2022). There was no effect of individuals' size on the mortality including all tagged individuals (estimate = -0.008987; p = 0.728; Figure 4). When considering injured and moribund individuals only, there seems to be a decreasing effect of size on the mortality (Figure 5) which remains however non-significant based on the logistic regression model (estimate = -0.07801; p = 0.272).

Sex was only assessed for 11 individuals of the 16 tags that transmitted data (69 %; Table 2; Figure 6). Mortality rates for OCS females and males are respectively 12 % (N = 8) and 0 % (N = 3) (Figure 6).

The time that individuals spent on deck before release was collected for 14 individuals out of 19 tagged; it ranged between 2 and 10 min (Figure 7). Time on deck does not influence post-release mortality according to the GLM (p = 0.76; Figure 8) as well as the Welch's t-test (t = -0.30979; df = 4.344; p = 0.771; Figure 9). Nonetheless, fish condition at release seems to be directly impacted by the time spent on deck (Figure 10), which is only significant when comparing individuals in "Alive good" condition versus pooled individuals in injured and moribund conditions (Figure 11) based on the Student's t-test (t = -2.4142; df = 12; p = 0.03266).

4. Discussion

The rate of non-reporting tags (16 %) is rather comparable to other tagging experiments using electronic popup satellite archival tags (e.g., Musyl et al., 2011; Sabarros et al., 2015). Apart from actual technical component failure, tags generally do not report when they are unable to transmit data to satellites, potentially due to being situated under marine debris on the surface or being predated therefore ingested by random predators (Sabarros et al., 2015). In one particular case (sPAT#56562), we suspect that the tag failed to transmit due to battery depletion, given that it was deployed at least 4 years after the beginning of the project.

A substantial portion of the tags (62 %) exhibited premature detachment from the sharks, a circumstance likely attributed to poor anchoring. While we rigged most of the tags (89 %) with Domeier anchors that are supposedly easier to implant (Bach et al., 2019), premature detachments can be understood in the light of the fact that even though observers underwent training, they may not possess expert-level proficiency in tagging techniques. Nonetheless, this had no impact on our ability to assess mortality in all tagged OCS for this project.

The overall post-mortality rate of 18.75 %, for the first time assessed for OCS in the Indian Ocean, is comparable to that of other shark species released by purse seiners, such as the silky shark (e.g., Poisson et al., 2014a; Filmalter et al., 2015; Hutchinson et al., 2015; Eddy et al., 2016; Onandia et al., 2021).

Even though sharks are generally assumed to have a high capacity to recover from injuries (e.g., Chin et al., 2015), our results indicate that OCS individuals released in a more compromised health state (injured and moribund) exhibit significantly lower survival probabilities (20 % and 0 % respectively) compared to lively individuals with no visible injuries (100 %). This trend aligns with findings observed in other shark species, such as the silky shark (e.g., Poisson et al., 2014a; Eddy et al., 2016; Onandia et al., 2021). OCS were released within 2 to 10 min and we noticed that the more time an individual spends time on deck before being released at sea, the more its health condition is likely to be compromised, and ultimately survival, even though the direct link between time on deck and mortality was not significant. Unfortunately, the information about the individual being directly sorted on the upper deck or passing through the lower deck (well deck) and being released through the garbage chute or carried back up to the upper deck, was not collected. The path individuals are going through during sorting operation varies depending on the vessel configuration and how the crew perform sorting operations (Anonymous, 2023; Briand et al., in prep). We anticipate that passing through the lower deck would inevitably extend the duration of time spent on board, and it is highly likely that the route specimens take on board would impact the condition of the fish upon release. However, we also may assume that injuries may also occur independently of the time that an individual spends on board, especially before even arriving on deck, during the net hauling (e.g., entanglement, passing through the power block) and brailing operations (e.g., compression and suffocation in the brail). The impact of individual length on post-release mortality is only significant when considering the two comprised health states (injured and moribund): larger individuals exhibit increased survival probabilities even though the size range is limited (148-220 cm TL). This phenomenon might be attributed to the notion that larger individuals are more resistant and are potentially more conspicuous within the brail, thereby increasing the chances to be removed quickly from the brail and minimizing the likelihood of them ending up on the lower deck. Furthermore, smaller sharks could potentially be more vulnerable to compression within the brail than their larger counterparts. Nevertheless, this outcome is intriguing, especially when considering the conventional assumption that smaller individuals can be handled more safely and easily by fishermen. Sex remained indeterminate in a significant portion of individuals (31 %) due to instances where observers inadvertently omitted this data collection. Given the constrained count of identified females and males within our dataset, we refrained from testing for the potential impact of sex on post-release mortality.

Based on those results, we highlight the importance of following good practices for safely handle and release sharks that have been developed specifically for the purse seine to limit short term death due to injuries during the pursing, brailing, sorting, and discarding processes (Poisson et al., 2014b; Wain et al., 2022). This includes better manipulation by hand for small sharks as well as avoiding lifting individuals by the tail, head, or gills. Also, our results highlight that time is key and that released individuals would benefit from being directly sorted on the upper deck and avoiding going through the lower deck so they can be promptly released to maximize their chances of post-release survival.

5. Acknowledgements

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7. Tables

Table 1. Electronic tags rigging and configuration

PTT Id	Serial Number	Tag Type	Tagware	Tether	Anchor	Deployment period
46202	17P0571	sPAT	2.4q	Stainless steel	Domeier	60 days
46205	17P0574	sPAT	2.4q	Stainless steel	Domeier	60 days
46214	17P0605	sPAT	2.4q	Stainless steel	Domeier	60 days
46216	17P0631	sPAT	2.4q	Stainless steel	Domeier	60 days
46217	17P0651	sPAT	2.4q	Stainless steel	Domeier	60 days
46218	17P0673	sPAT	2.4q	Stainless steel	Domeier	60 days
46223	17P0681	sPAT	2.4q	Stainless steel	Domeier	60 days
46231	17P0712	sPAT	2.4q	Stainless steel	Domeier	60 days
46264	17P0720	sPAT	2.4q	Stainless steel	Domeier	60 days
46265	17P0722	sPAT	2.4q	Stainless steel	Domeier	60 days
46276	17P0723	sPAT	2.4q	Stainless steel	Domeier	60 days
46277	17P0726	sPAT	2.4q	Stainless steel	Domeier	60 days
46278	17P0727	sPAT	2.4q	Stainless steel	Domeier	60 days
46281	17P0739	sPAT	2.4q	Stainless steel	Domeier	60 days
56563	17P0679	sPAT	2.4q	Stainless steel	Ti	60 days
56562	17P0630	sPAT	2.4q	Stainless steel	Ti	60 days
49013	17P0480	MiniPAT	2.4n	Stainless steel	Domeier	180 days
49080	17P0675	MiniPAT	2.4n	Stainless steel	Domeier	180 days
49081	17P0676	MiniPAT	2.4n	Stainless steel	Domeier	180 days

Table 2. Electronic tags' deployment details and mortality assessment

PTT Id	Deployment date	Latitude	Longitude	Tagger	Vessel	Country	Fork Length (cm)	Total Length (cm)	Sex	Time on deck (min)	Fish condition	Popup date	Days at liberty	Diagnostic	Mortality
46202	09/01/2020	-8.067	48.867	Houareau	Belle Rive	MUS	-	109	M	2	Alive good	09/02/2020	31	Premature	No
46205	14/04/2019	-24.614	42.824	Dejoie	Galerna Dos	EU.SPA	-	164	U	10	Alive injured	15/06/2019	62	Full deployment	No
46214	18/06/2021	-0.768	58.532	Wain	Bernica	EU.FRA	-	190	F	10	Alive injured	02/08/2021	45	Premature	No
46216	18/11/2018	-3.441	47.722	Muir	Talenduic	EU.FRA	145	177	U	3	Alive injured	21/11/2018	3	Too deep	Yes
46217	18/11/2018	-3.441	47.722	Muir	Talenduic	EU.FRA	180	220	U	3	Alive injured	18/01/2019	61	Full deployment	No
46218	12/10/2018	-3.862	50.605	Pernak	Bernica	EU.FRA	-	164	M	5	Alive injured	10/11/2018	29	Premature	No
46223	27/08/2018	-3.415	53.053	Pernak	Bernica	EU.FRA	-	136	U	5	Alive good	26/10/2018	60	Full deployment	No
46231	04/09/2018	0.172	51.220	Houareau	Draco	EU.SPA	-	160	F	-	Alive good	05/10/2018	31	Premature	No
46264	03/09/2018	0.008	51.609	Houareau	Draco	EU.SPA	-	200	F	-	Alive good	02/11/2018	60	Full deployment	No
46265	08/08/2018	-5.186	62.178	Houareau	Albacora Cuatro	EU.SPA	145	177	F	-	Alive good	06/10/2018	59	Premature	No
46276	09/08/2018	-5.303	61.054	Houareau	Albacora Cuatro	EU.SPA	130	159	F	-	Alive good	17/09/2018	39	Premature	No
46277	03/09/2018	0.008	51.609	Houareau	Draco	EU.SPA	-	200	F	-	Alive good	-	-	No transmission	-
46278	20/05/2019	-19.990	40.211	Houareau	Inter Tuna Tres	EU.SPA	-	150	F	2	Alive good	19/07/2019	60	Full deployment	No
46281	08/05/2019	-14.917	44.092	Houareau	Inter Tuna Tres	EU.SPA	-	180	M	3	Alive good	24/06/2019	47	Premature	No
56563	17/10/2021	1.021	50.033	Passicos	France Terre	EU.FRA	-	160	F	8	Alive moribund	17/10/2021	0	Too deep	Yes
56562	31/01/2023	6.340	61.138	Bourasseau	Bernica	EU.FRA	-	153	F	3	Alive good	-	-	No transmission	-
49013	19/02/2019	6.683	55.583	Houareau	Albacora Cuatro	EU.SPA	-	165	F	3	Alive good	10/04/2019	50	Premature	No
49080	03/11/2021	0.920	57.838	Rohée	Trevignon	EU.FRA	-	206	M	5	Alive good	-	-	No transmission	-
49081	26/09/2021	-2.533	55.778	Rohée	Trevignon	EU.FRA	-	148	U	5	Alive moribund	29/09/2021	3	Too deep	Yes

8. Figures

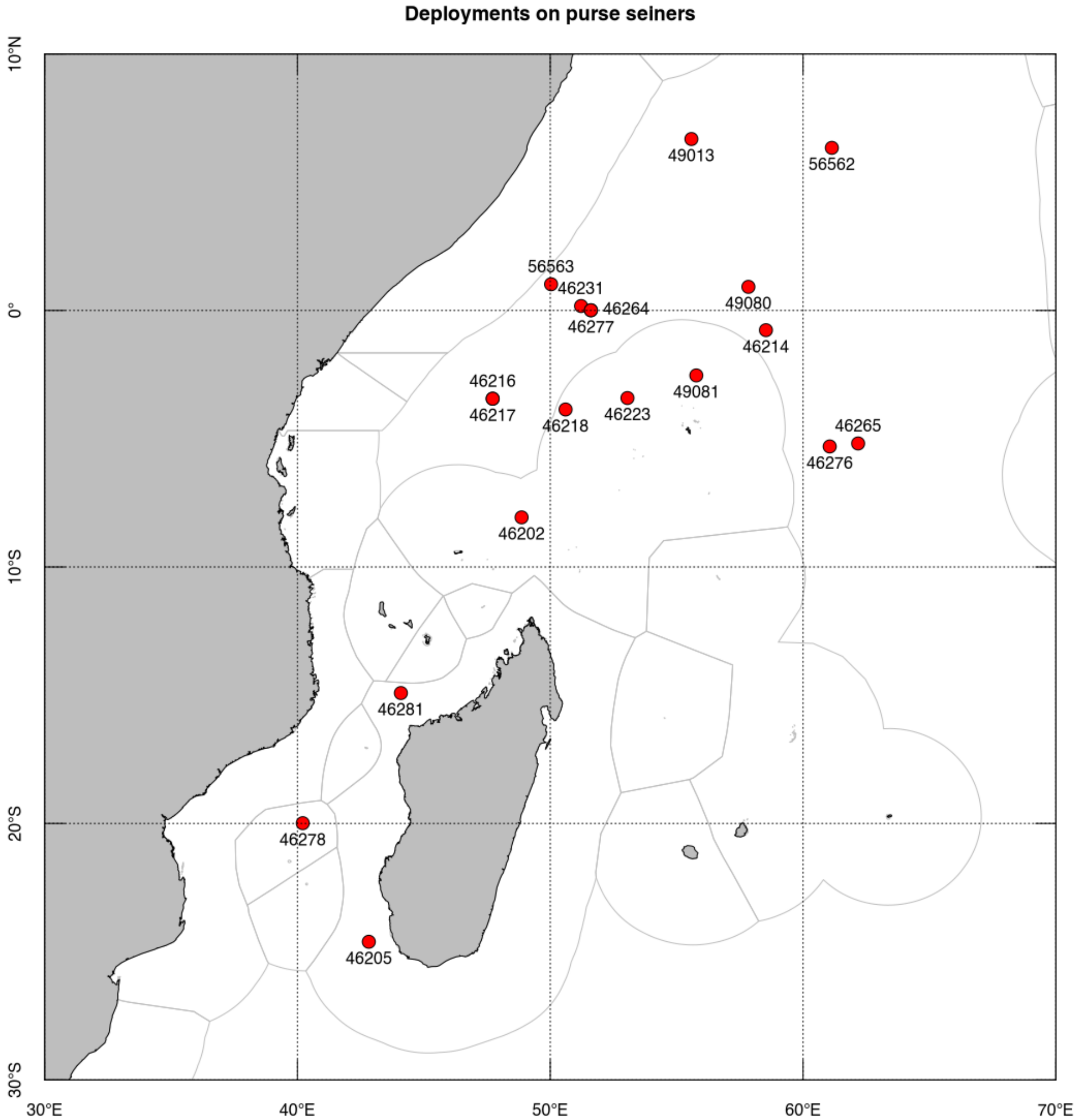


Figure 1. Map of tag deployments on OCS released by purse seiners in the western Indian Ocean between 2018 and 2023

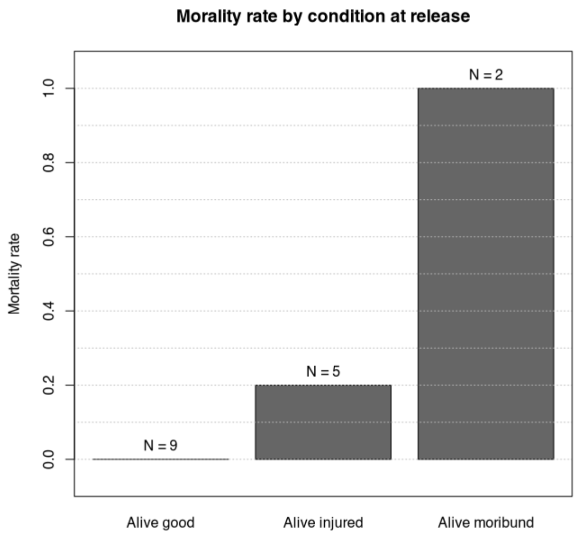


Figure 2. Mortality rate by OCS health condition at release

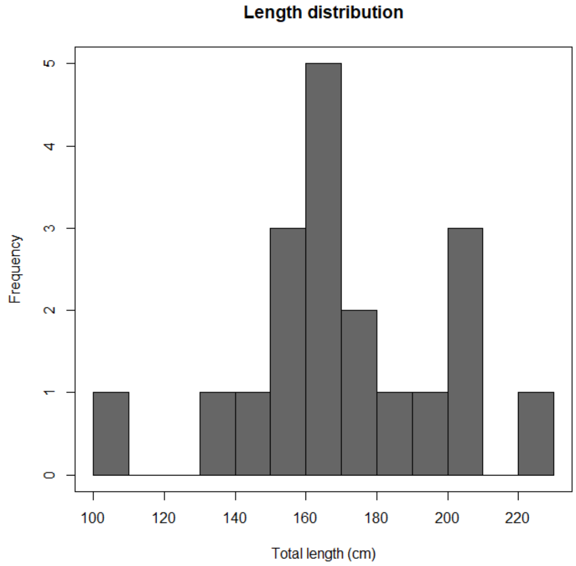


Figure 3. Length distribution of tagged OCS

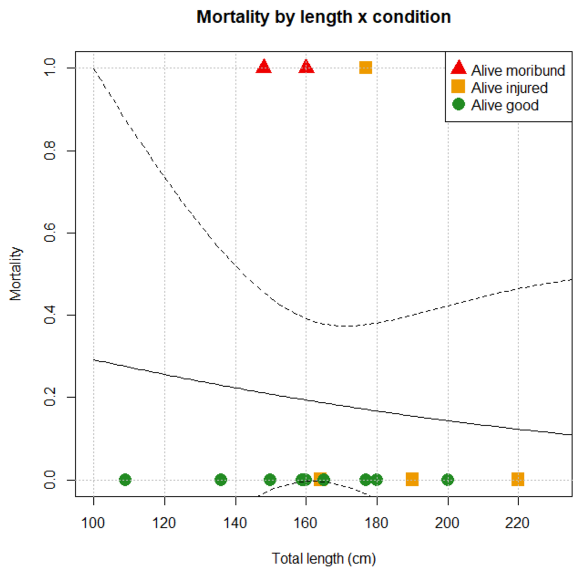


Figure 4. Mortality by length (total length in cm) and condition at release

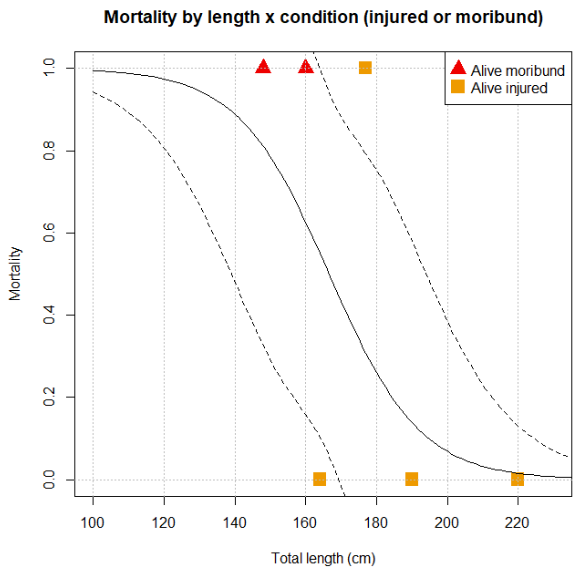


Figure 5. Mortality by length (total length in cm) and condition at release (injured or moribund)

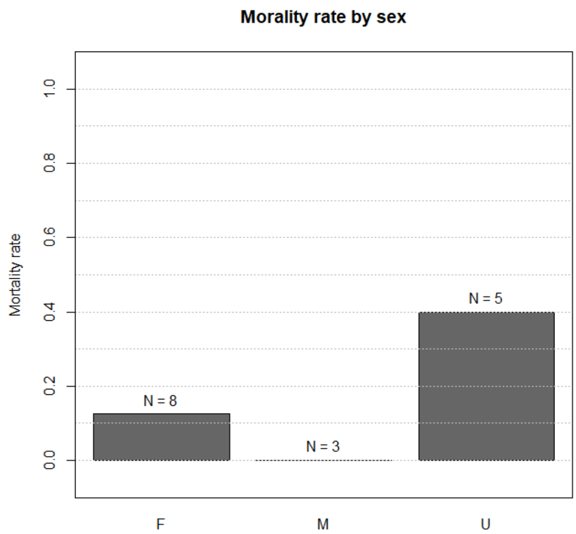


Figure 6. Mortality rate by sex. F: female; M: male; U: Undetermined

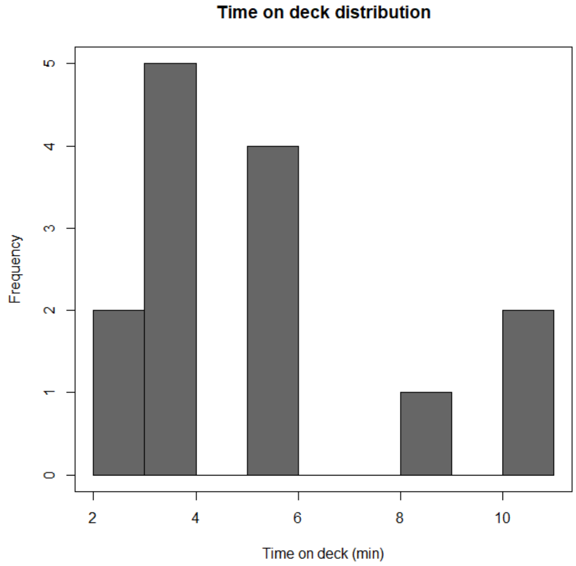


Figure 7. Distribution of the time (min) that OCS spent on deck before release

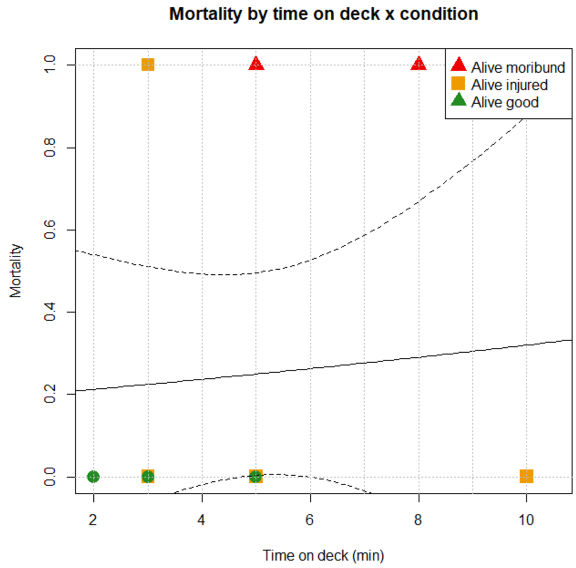


Figure 8. Mortality by time on deck (min) and condition at release

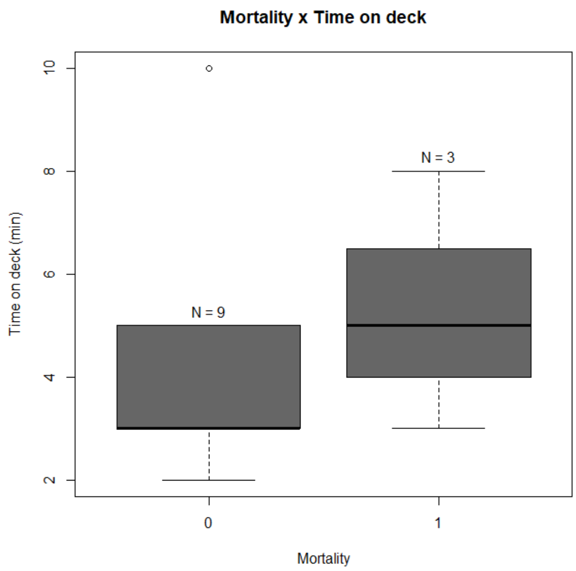


Figure 9. Effect of time on deck on OCS post-release mortality

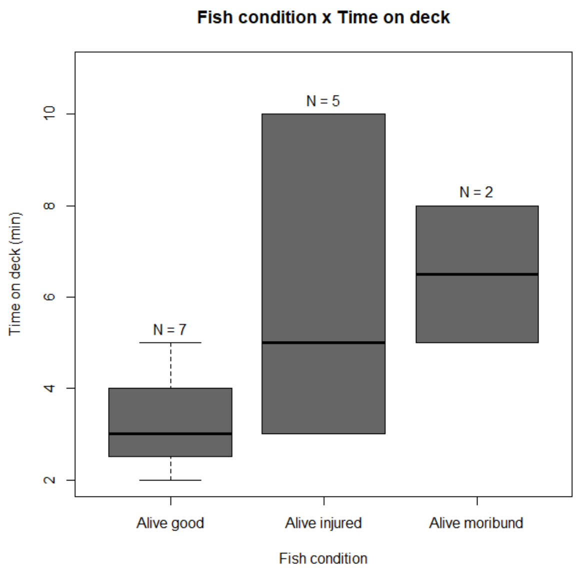


Figure 10. Fish condition (3 modalities) x time on deck

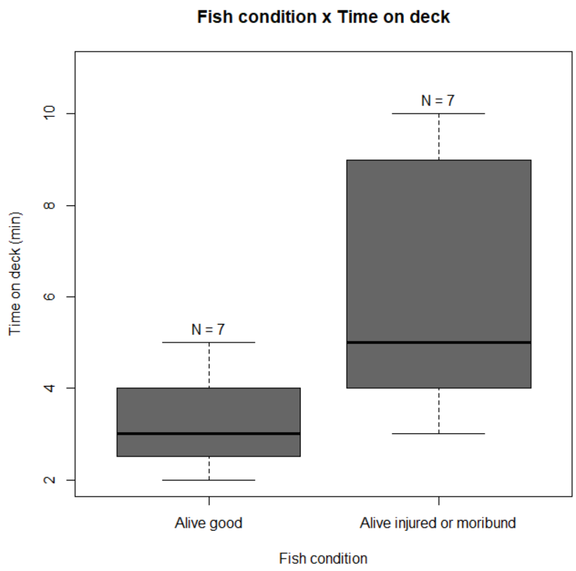
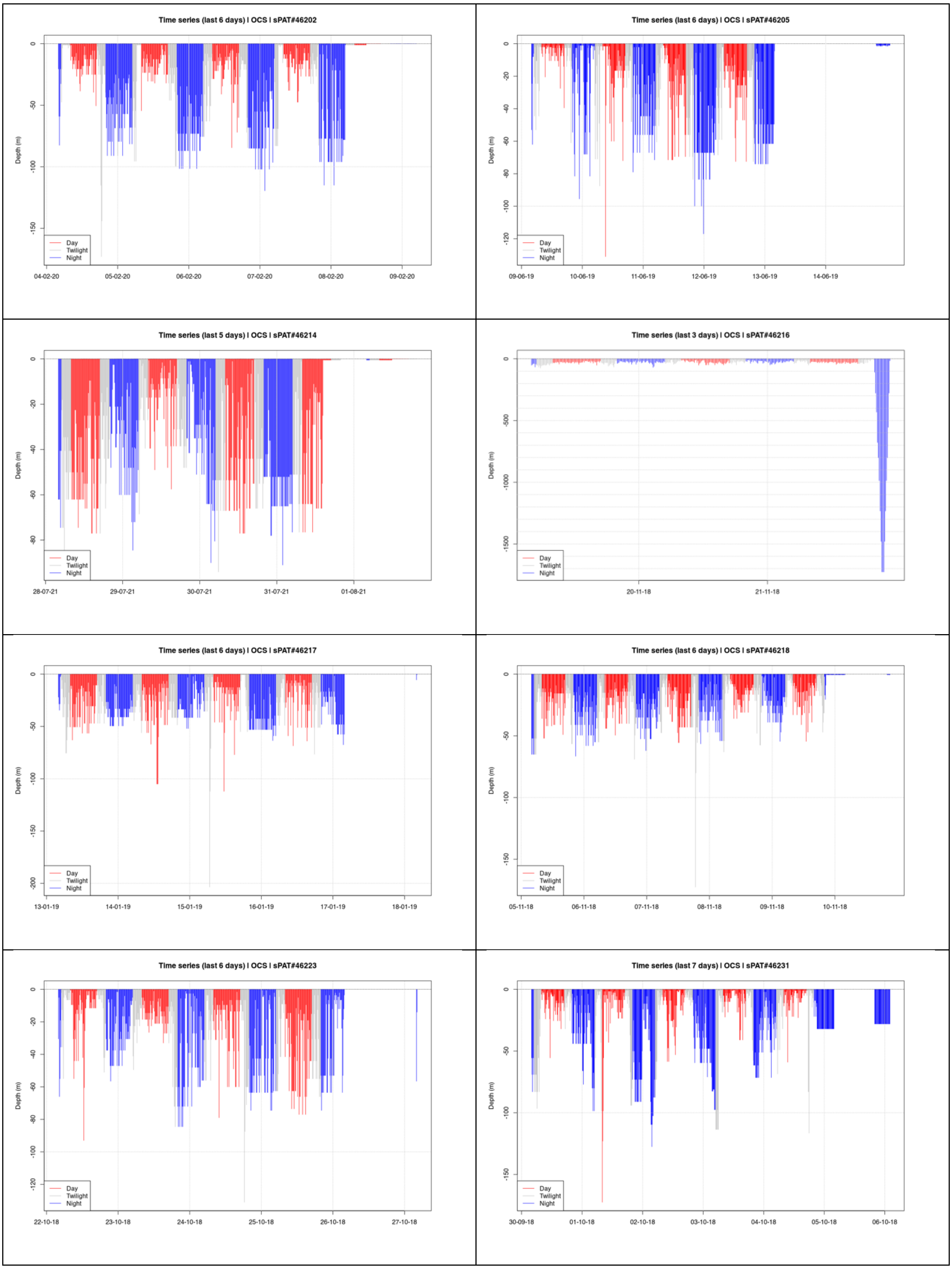


Figure 11. Fish condition (2 modalities) x time on deck

9. Supplementary material



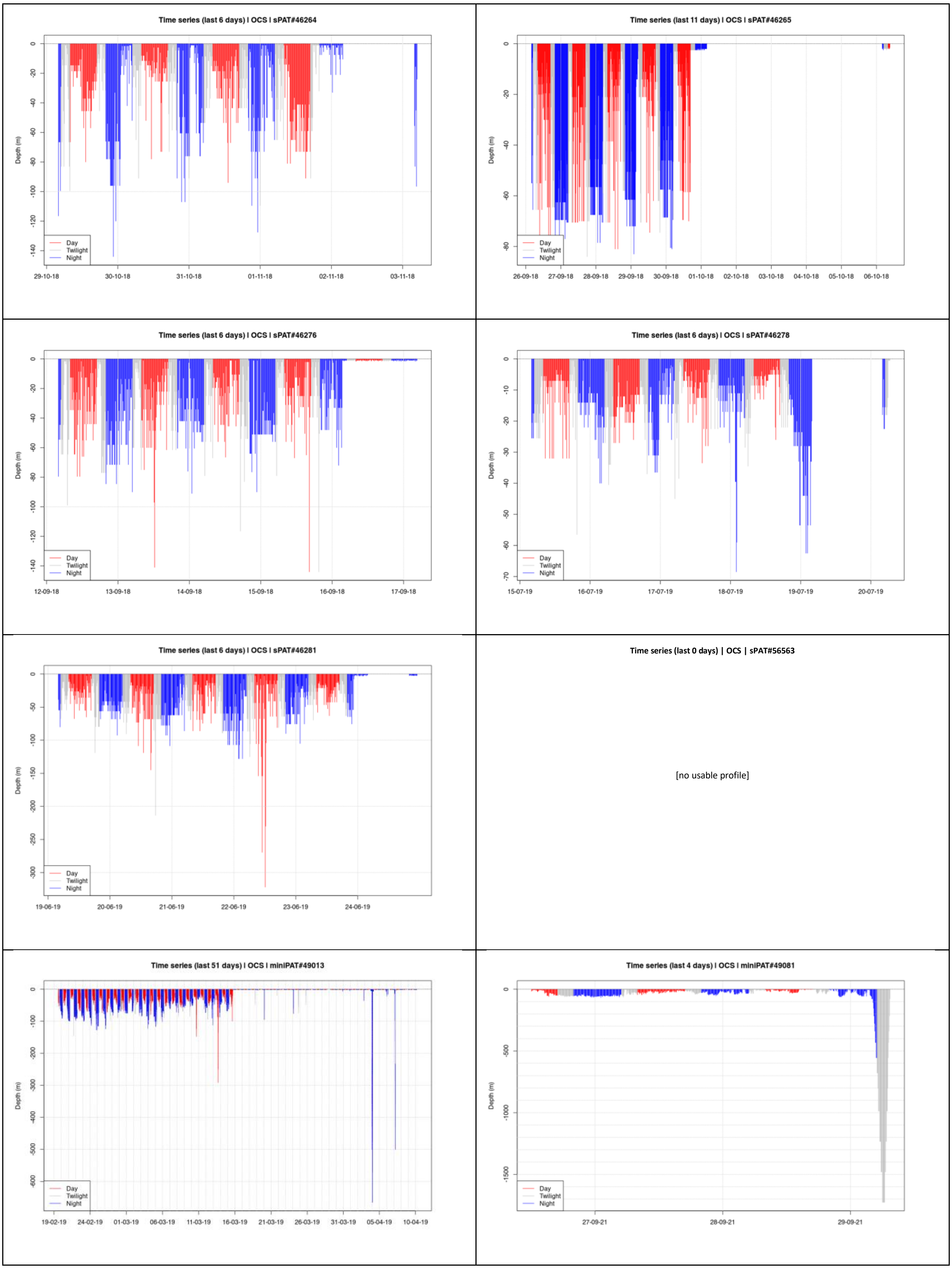


Figure S1. Depth profiles of tagged OCS used to estimate survival/mortality (N = 16)