SCIENTIFIC COMMITTEE
SEVENTEENTH REGULAR SESSION

Electronic Meeting
11-19 August 2021

Review of potential mitigation measures to reduce fishing-related mortality on silky and oceanic whitetip sharks (Project 101)

WCPFC-SC17-2021/EB-WP-01

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21 July 2021

Executive Summary

The paper develops and applies a model for how silky (*Carcharhinus falciformis*) and oceanic whitetip (*C.longimanus*) shark might interact with longline gear in the Western and Central Pacific Ocean (WCPO) and potential reductions in mortality with two different management measures: 1) removal of shark lines and 2) transition from branchlines with wire leaders to monofilament leaders. Using Regional Observer Program (ROP) data, the study compared absolute values of total catch and total mortality across scenarios and the relative change in fishing related mortality from the status-quo option given a conversion from wire to monofilament leaders, no shark lines used and both a conversion to monofilament leaders and no shark lines. The analysis also explores reduction rates of both shark species under a variety of management scenarios, including banning both shark lines and wire leaders. The study provides an update to Harley et al. (2015) by using recently available observer information (2010–2018) on longline gear characteristics and spatial distribution of effort (2015–2019). The study used previous assumptions (Harley et al. 2015) on: 1) results of previous studies on catchability and survival and 2) spatial differences in the density of the two species.

The key conclusions of the current analyses are:

- Banning shark lines has the potential to reduce fishing mortality by 2.6% and 5.4% for silky shark and oceanic whitetip shark, respectively. These percentages are lower than predicted estimates from Harley et al. (2015) which may be explained by a decrease in use of shark lines in more recent observer data.
- Banning branchline wire leaders has the potential to reduce fishing mortality by 28.2% and 35.8% for silky shark and oceanic whitetip shark, respectively. These percentages are higher than estimates from Harley et al. (2015) and are perhaps due to improved characterization of gear use in the distant-water longline fisheries.
- Banning both shark lines and wire leaders has the potential to reduce fishing mortality by 30.8% and 40.5% for silky shark and oceanic whitetip shark, respectively.
- Submission of ROP observer data has increased in recent years. Future analyses would benefit from both in-zone and ROP data to estimate catchability effects for shark lines, wire and monofilament leaders and further characterize WCPFC member longline gear characteristics.

Introduction

MSY -based reference points from stock assessments for silky shark (*Carcharhinus falciformis,* Clarke et al. 2018) and oceanic whitetip shark (*C. longimanus*, Tremblay-Boyer et al. 2019) indicated that the stocks were experiencing overfishing($F_{current}/F_{MSY} > 1$) and oceanic whitetip shark is in an overfished state ($SB_{current}/SB_{MSY} < 1$). As a consequence from earlier assessments, the Western and Central Pacific Fisheries Commission (WCPFC) prohibited the retention of these species (WCPFC 2011, 2013, 2014, 2019).

Harley et al. (2015) conducted analytical work of existing longline observer data to:

1. Develop a process model of how silky and oceanic whitetip shark can interactwith longline fishing gear, including the key factors likely to influence life status;
2. Develop a spatial surface of total longline fishing effort in terms of hooks deployed with particular gear configurations;
3. Develop a spatial surface of silky and oceanic whitetip shark abundance so that the location of deployment of fishing gear relative to the density of the two shark species can be taken into account, e.g., fishing patterns in areas of highest abundance will be more important to the overall longline impact than fishing in areas of low density;
4. Use information from previous analyses and the literature to parameterize the model in terms of values (or probability distributions) for catchability and survival etc.;
5. Develop several management intervention scenarios, e.g., a total prohibition on the use of shark lines, wire traces, and shallow hooks etc.; and
6. Evaluate the scenarios with the model and compare key outcomes.

The WCPFC adopted CMM 2014-05 (superseded by 2019-04), whereby longline fisheries targeting tuna and billfish comply with either: 1) do not use or carry wire trace as branchlines or leaders; or 2) do not use branchlines running directly off the longline floats or drop lines, known as shark lines. Harley et al. (2015) conducted Monte Carlo simulation modeling for potential measures to reduce impacts to silky and oceanic whitetip sharks in the WCPO. The study considered: 1) banning of shark lines and removal of shallow hooks to reduce the initial interactions with longline gear, 2) banning wire leaders to increase the ability of sharks to bite-off the leader, and 3) conversion of tuna hooks to circle hooks. Harley et al. (2015) concluded that either banning shark lines or wire traces (leaders) would not result in sufficient reductions in fishing mortality.

The purpose of this study is to develop a silky and oceanic whitetip shark process model and Monte Carlo analysis in a similar framework as Harley et al. (2015) to improve understanding of outcomes from potential mitigation methods and management scenarios.

Methods

The analysis developed a process model for silky and oceanic whitetip shark that included catch components as the number of fish encountering the gear and fate (e.g. survival) components on the mortality after a gear interaction. The study provides an update to Harley et al. (2015) by using recently available observer information (2010–2018) on longline gear characteristics from the WCPFC Regional Observer Program (ROP). Observer data pertinent to the study included 110,154 longline sets by country flag with a daily tally of hooks deployed (effort), hook type (J, tuna, or circle), use of wire or monofilament leaders and use of shark lines or no shark lines. Table 1 illustrates the proportion of gear use characteristics by flag considered in the Monte Carlo analysis. The spatial distribution of effort (2015–2019) was developed from 20ºN to 20ºS and 140ºE to 150ºW. Approximately 10% of total longline effort was not included due to 5º cells that were considered confidential by flag.

The study used previous assumptions (Appendix 1) on: 1) results of studies on catchability and survival and 2) spatial differences in the density of the two species. Due to time constraints, there was no update to the catchability estimates based on ROP data, such as parameter estimates for hook type, leader type, and use of shark lines. Additionally, Harley et al. (2015) analyzed the effect of removing shallow hooks. This study did not estimate the mitigation effects of removing shallow hooks as the implementation of such a measure in the WCPFC Convention Area is probably not a realistic option. The code used in Harley et al. (2015) was implemented in R (Version 3.6.2).

Monte Carlo simulations were conducted for two species as described below:

- Apply the ‘management scenario’ to the base fishing effort to create a new effort layer. In each scenario, hooks from a ‘restricted’ gear category were redistributed to permissible gear categories, e.g., if wire leaders was restricted, then all wire leader effort was transferred to monofilament leaders and other characters such as hook-type were not changed.
- Apply the catch and fate models 5,000 times – each simulation has different draws from each input distribution.
- Keep track of catch, mortality, and survival at every stage of the catch and fate models.

The study aimed to characterize fleet gear specifics and compared absolute values of total catch and total mortality across scenarios and the relative change in fishing related mortality from the status-quo option given a conversion from wire to monofilament leaders, no shark lines used and both a conversion to monofilament leaders and no shark lines.

Results

Gear characteristics

Flag specific gear characteristics (Table 1) differed from Harley et al. (2015). In general, vessels from 2010 to 2018 still preferred to use wire leaders and some fleets had a greater proportion of circle hooks with very little use of J-hooks. Harley et al. (2015) documented that 11 of the 13 flags used shark lines, while six of the 13 flags in this study used shark lines with a diminishing proportion.

Silky shark

When comparing total mortality from a scenario to catch from the status-quo, there is an estimate of relative fishing mortality. Banning shark lines has the potential to reduce fishing mortality by 2.6% for silky shark (Table 2). These percentages are lower than estimates from Harley et al. (2015) (Table 2), presumably due to a decrease in use of shark lines in more recent observer data.

Banning branchline wire leaders has the potential to reduce fishing mortality by 28.2% for silky shark (Table 2). These percentages are higher than estimates from Harley et al. (2015) and are perhaps due to improved characterization of gear used in the distant-water longline fisheries. Mitigation achieved their percentage reductions in different ways, removal of wire leaders through increased bite-offs and removal of shark lines through reduced catches (Figure 1). Banning both wire and shark lines resulted in a 30.8% reduction in fishing mortality.

Oceanic whitetip shark

Banning shark lines has the potential to reduce fishing mortality by 5.4% for oceanic whitetip shark (Table 2). Similar to silky shark, these percentages are lower than estimates from Harley et al. (2015) (Table 2), likely due to a decrease in use of shark lines in more recent observer data.

Banning branchline wire leaders has the potential to reduce fishing mortality by 35.8% for oceanic whitetip shark (Table 2). Removal of wire leaders increased bite-offs and removal of shark lines through reduced catches (Figure 2). Banning both wire and shark lines resulted in a 40.5% reduction in fishing mortality.

Discussion

The silky and oceanic whitetip shark process model and subsequent Monte Carlo simulations provided an update to the Harley et al. (2015) estimates. From both studies, banning both wire and shark lines resulted in similar reductions in fishing mortality, ~30% for silky shark and ~40% for oceanic whitetip shark (Table 2). However, the contributions to reducing fishing mortality were different between studies due to the mitigation of banning shark lines and branchline wire leaders.

This study illustrated a decrease in use of shark lines, which led to a corresponding reduction in fishing mortality for silky shark (2.6%), and oceanic whitetip shark (5.4%) if shark lines were banned. Harley et al. (2015) estimated a larger effect on fishing mortality if shark lines were banned for silky shark (14.7%) and oceanic whitetip shark (23.3%). This study observed a greater use of wire leaders in the WCPO with a larger reduction in fishing mortality for silky shark (28.2%) and oceanic whitetip (35.8%). Harley et al. (2015) estimated a smaller reduction in fishing mortality for silky shark (17.6%) and oceanic whitetip shark (23.3%) if wire leaders were banned.

The Harley et al. (2015) Monte Carlo study noted that critical gaps existed in gear configurations and an absence of observer data pertaining to the major distant-water fleets (e.g., Japan, Korea, Taiwan, and China). This study used observer data (2010–2018), which represents better coverage in the distant-water fleets with 49,066 sets or 44.5% of sets for all fleets. This study was based on ROP data and additional observer data could be available from non-ROP or in-zone data.

The Monte Carlo analysis is sensitive to estimates of leader bite-offs due to differences in hook type whereby tuna and J-hooks are ingested and have a greater probability of bite-off compared to circle hooks with lip hooking. This analysis retained the same silky and oceanic whitetip catchability assumptions with leader and hook type. Future work could consider additional GLM analyses similar to Caneco et al. (2014) to estimate factors affecting shark catchability and condition on longline retrieval.

Future projections based on the 2019 WCPO oceanic whitetip stock assessment were carried out using the Stock Synthesis forecast module (Rice et al. 2021). The forecast period was implemented with the same model configurations from the 2019 oceanic whitetip stock assessment (Tremblay-Boyer et al, 2019). The projection framework could consider additional scenarios such as the impact of banning shark lines and wire leaders and both from this study.

Estimates of the probability of post-release mortality (PRM) are also available from a large electronic tagging study on five species (blue, bigeye thresher, oceanic whitetip, shortfin mako, and silky sharks) of pelagic sharks in the Hawaii deep-set and American Samoa longline fisheries in the central Pacific Ocean (Hutchinson et al. 2021). The study illustrated post-release survival rates at 1, 30, 60, 180, and 360 days. Results indicated high survival for 1 to 60 days if the sharks are in good condition at release, the branchline is cut to release them from the gear, and trailing gear is minimized. These PRM estimates could also be considered in oceanic whitetip projections.

Recommendations:

- Continue Project 101, with the following potential modifications to the Monte Carlo analysis:
- Relevant members consider authorizing the release of their non-ROP longline data (facilitated through SPC) for this study, specifically to provide more complete gear configurations by flag, and allow analyses similar to Caneco et al. (2014) to estimate factors affecting shark catchability and condition on longline retrieval to be conducted using a more complete dataset.
- Conduct the Monte Carlo analyses with inputs on catchability, condition on longline retrieval and gear configurations by flag.
- Conduct projections with inputs on the impact of banning shark lines and wire leaders or both and estimates of the probability of post release mortality (Hutchinson et al. 2021).

Acknowledgments

We thank the Regional Observer Program for the data collection that made this study possible. We thank Shelton Harley for providing the R code.

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Table 1. Proportion of longline gear use characteristics by vessels for the flags based on observer data (2010–2018) considered in the Monte Carlo analysis.

		Branchline leader type		Hook type				
	Observed sets	Wire	Mono	J	Tuna	Circle	Shark line	No Shark line
Cook Islands	487	1	0	0	0.043	0.957	0	1
China	6,277	0.922	0.078	0.013	0.449	0.539	0.124	0.876
Fiji	13,219	0.887	0.113	0.032	0.081	0.887	0.023	0.977
FSM	684	1	0	0	0.015	0.985	0	1
Japan	5,722	0.358	0.642	0	0.937	0.063	0	1
Korea	4,527	0.708	0.292	0.121	0.136	0.743	0.016	0.984
Marshall Islands	234	1	0	0.036	0.103	0.861	0	1
French Polynesia	3,477	0.834	0.166	0.066	0.416	0.518	0	1
PNG	52	0	1	0	1	0	1	0
Taiwan	32,540	0.798	0.202	0.264	0.241	0.495	0.004	0.996
USA	40,694	0.950	0.050	0	0.023	0.977	0	1
Vanuatu	2,138	0.924	0.076	0.039	0.464	0.497	0	1
Samoa	103	0.641	0.359	0	0	1	0.010	0.990
Total	110,154							

Table 2. Overall mortality rate (deaths/catch) for silky and oceanic whitetip shark based on the status quo and each management scenario from the Monte Carlo analysis of the present study and Harley et al. 2015.

Management scenario	This study – median mortality reduction percentage		Harley et al. 2015 – median mortality reduction percentage	
	Silky shark	Oceanic whitetip shark	Silky shark	Oceanic whitetip shark
No shark lines	2.6%	5.4%	14.7%	23.3%
No wire leaders	28.2%	35.8%	17.6%	23.3%
No shark lines and no wire leaders	30.8%	40.5%	29.4%	40.0%

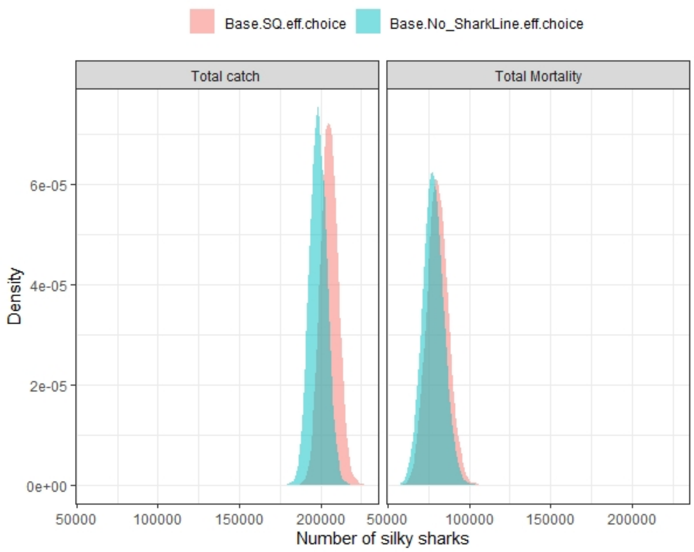


Figure 1a. No shark lines

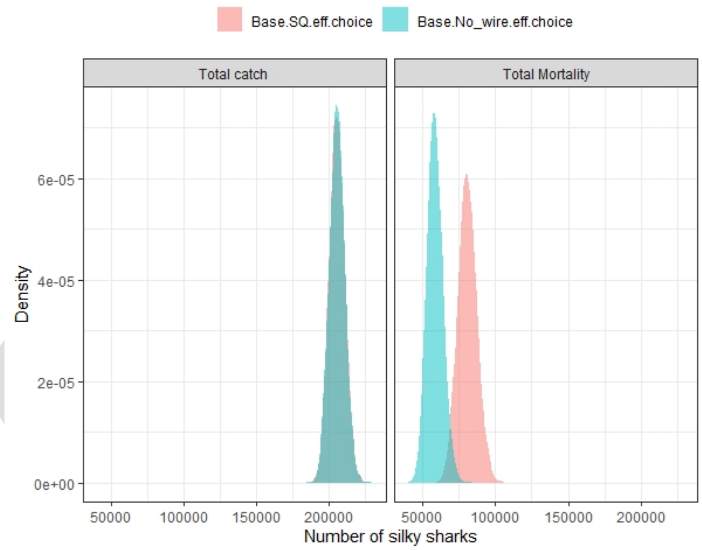


Figure 1b. No wire leaders

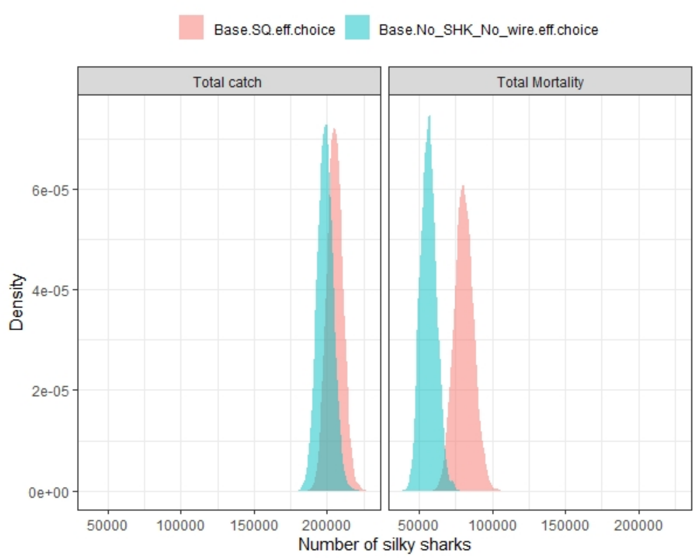


Figure 1c. No shark lines and no wire leaders

Figure 1. One-off comparisons for silky shark between the status quo (Base.SQ) and each management scenario in terms of the Monte Carlo distributions of catch (left side of the panel) and mortality (right side of the panel).

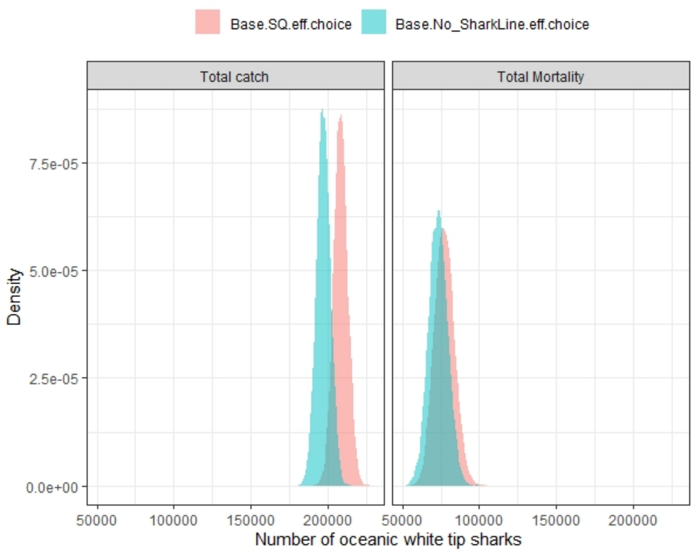


Figure 2a. No shark lines

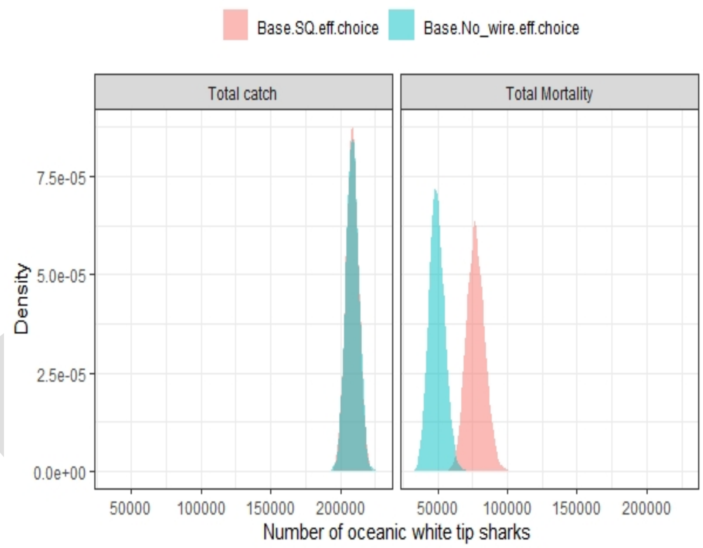


Figure 2b. No wire leaders

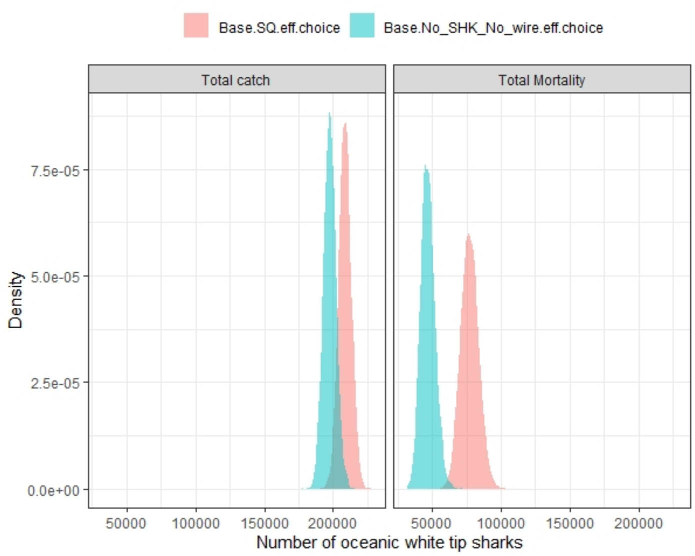


Figure 2c. No shark lines and no wire leaders

Figure 2. One-off comparisons for oceanic whitetip shark between the status quo (Base.SQ) and each management scenario in terms of the Monte Carlo distributions of catch (left side of the panel) and mortality (right side of the panel).

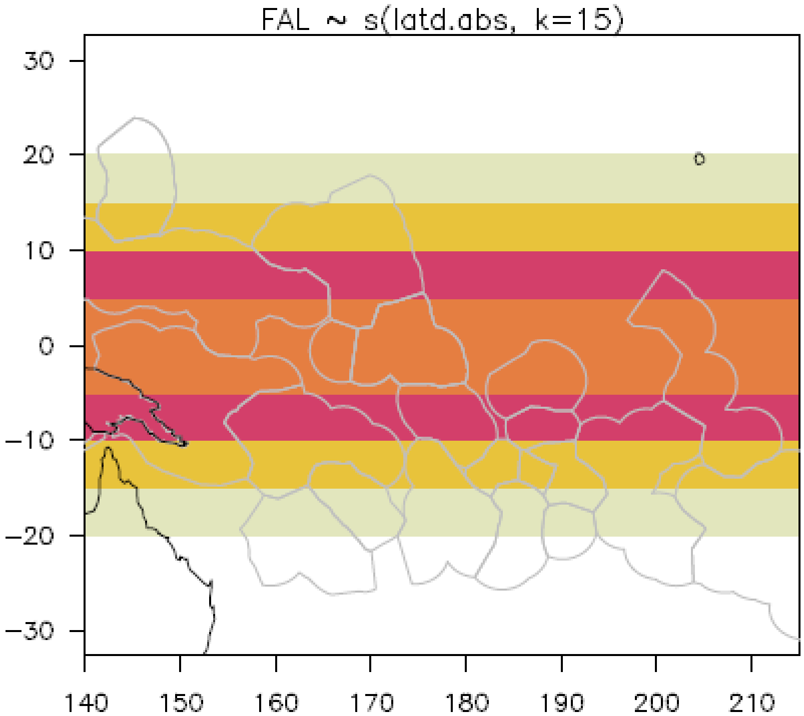
Appendix 1. Parameter estimates from Tables 2 and 3 in Harley et al. (2015). Predicted relative abundance surfaces for silky shark and oceanic whitetip shark from Figure 3 in Harley et al. (2015).

Table 2: Parameters and distributions underpinning the simulations for silky shark. Lognormal distribution parameters are expressed on the log-scale. Beta parameters are expressedas a mean (*p* conceptually probability of success) and *n* which controls variance (conceptually the number of trials). Large *n* implies high-precision low-variance.

			Silky shark (FAL)	
Simulation component		Distribution	Params.	Notes
Effort/Number of hooks		N/A	N/A	SPC provisioned
Basket size		N/A	30	Est SPC data (Caneco et al., 2014)
Catch rate (per 100 hooks):	Shark lines	Lognormal	$\mu = -0.78330$ $\sigma = 0.05189$	Est SPC data (Caneco et al., 2014)
	Shallow hooks	Lognormal	$\mu = -4.56537$ $\sigma = 0.03520$	Est SPC data (Caneco et al., 2014)
	Deep hooks	Lognormal	$\mu = -3.98790$ $\sigma = 0.02983$	Est SPC data (Caneco et al., 2014)
Prob. lip-hook (else gut) given:	J-hook	Beta	$p = 0.2$ $n = 14$	Afonso et al. (2011) est. from plot
	T-hook	Beta	$p = 0.33$ $n = 14$	Little information SPC prelim est.
	C-hook	Beta	$p = 0.7$ $n = 14$	Afonso et al. (2011) est. from plot
Prob. bite-off given:	Mono leader and lip-hooked	Beta	$p = 0.33$ $n = 190$	Afonso et al. (2012) [5]
	Mono leader and gut-hooked	Beta	$p = 0.40$ $n = 32$	Ward et al. (2008)
	Wire leader	N/A		Assume negligible
Prob. mort. given bite-off:	Lip-hooked	Beta	$p = 0.0323$ $n = 20$	Little information SPC prelim est.
	Gut-hooked	Beta	$p = 0.0625$ $n = 20$	Little information SPC prelim est.
Prob. mort. at landing:	Lip-hooked	Beta	$p = 0.1974$ $n = 11,470$	Est. SPC data (Caneco et al., 2014) [6]
	Gut-hooked	Beta	$p = 0.1974$ $n = 11,470$	Est. SPC data (Caneco et al., 2014)
Prob. release in water (vs. brought-on, then released)		Beta	$p = 0.5$ $n = 10$	Little information speculative & broad
Prob. mort. given:	Water release and lip-hooked	Beta	$p = 0.15$ $n = 100$	Musyl et al. (2011)
	Water release and gut-hooked	Beta	$p = 0.19$ $n = 100$	Campana et al. (2009)
	Landed release and lip-hooked	Beta	$p = 0.34$ $n = 100$	Clarke et al. (2011)
	Landed release and gut-hooked	Beta	$p = 0.44$ $n = 100$	Clarke et al. (2011)

Table 3: Parameters and distributions underpinning the simulations for oceanic whitetip shark. Lognormal distribution parameters are expressed on the log-scale. Beta parameters are expressedas a mean (p conceptually probability of success) and n which controls variance (conceptually the number of trials). Large n implies high-precision low-variance.

		Oceanic whitetip shark (OCS)		
Simulation component		Distribution	Params.	Notes
Effort/Number of hooks		N/A	N/A	SPC provisioned
Basket size		N/A	30	Est SPC data (Caneco et al., 2014)
Catch rate (per 100 hooks):	Shark lines	Lognormal	$\mu = -0.47969$ $\sigma = 0.04487$	Est SPC data (Caneco et al., 2014)
	Shallow hooks	Lognormal	$\mu = -4.94498$ $\sigma = 0.03262$	Est SPC data (Caneco et al., 2014)
	Deep hooks	Lognormal	$\mu = -4.16491$ $\sigma = 0.02528$	Est SPC data (Caneco et al., 2014)
Prob. lip-hook (else gut) given:	J-hook	Beta	$p = 0.3$ $n = 12$	Afonso et al. (2011) est. from plot
	T-hook	Beta	$p = 0.33$ $n = 12$	Little information SPC prelim est.
	C-hook	Beta	$p = 0.9$ $n = 12$	Afonso et al. (2011) est. from plot
Prob. bite-off given:	Mono leader and lip-hooked	Beta	$p = 0.33$ $n = 190$	Afonso et al. (2012) [7]
	Mono leader and gut-hooked	Beta	$p = 0.72$ $n = 14$	Ward et al. (2008)
	Wire leader	N/A		Assume negligible
Prob. mort. given bite-off:	Lip-hooked	Beta	$p = 0.0323$ $n = 20$	Little information SPC prelim est.
	Gut-hooked	Beta	$p = 0.0625$ $n = 20$	Little information SPC prelim est.
Prob. mort. at landing:	Lip-hooked	Beta	$p = 0.1867$ $n = 6,361$	Est. SPC data (Caneco et al., 2014) [8]
	Gut-hooked	Beta	$p = 0.1867$ $n = 6,361$	Est. SPC data (Caneco et al., 2014)
Prob. release in water (vs. brought-on, then released)		Beta	$p = 0.5$ $n = 10$	Little information speculative & broad
Prob. mort. given:	Water release and lip-hooked	Beta	$p = 0.15$ $n = 100$	Musyl et al. (2011)
	Water release and gut-hooked	Beta	$p = 0.19$ $n = 100$	Campana et al. (2009)
	Landed release and lip-hooked	Beta	$p = 0.34$ $n = 100$	Clarke et al. (2011)
	Landed release and gut-hooked	Beta	$p = 0.44$ $n = 100$	Clarke et al. (2011)



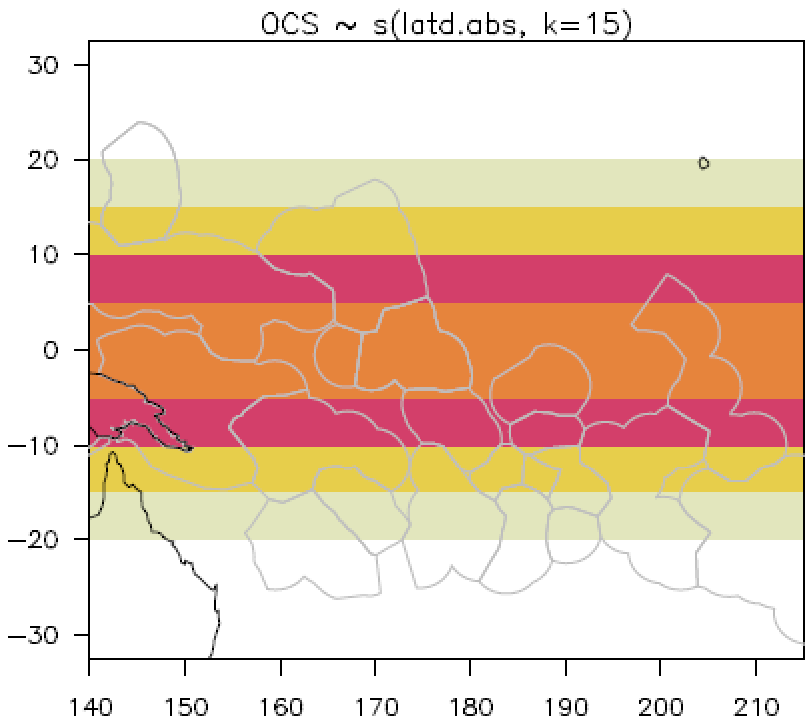


Figure 3: Predicted relative abundance surfaces for silky shark (FAL; top) and oceanic whitetip shark (OCS;bottom) for the absolute value of latitude model.