REVIEW ON THE EFFECT OF HOOK TYPE ON THE CATCHABILITY, HOOKING LOCATION, AND POST-CAPTURE MORTALITY OF THE SHORTFIN MAKO, *ISURUS OXYRINCHUS*

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SUMMARY

Due to the assessed vulnerability for the North Atlantic shortfin mako, Isurus oxyrinchus, ICCAT has identified the need to better understand the use of circle hooks as a potential mitigation measure in longline fisheries. We conducted a literature review related to the effect of hook type on the catchability, anatomical hooking location, and post-capture mortality of this species. We found twenty eight papers related to these topics, yet many were limited in interpretation due to small sample sizes and lack of statistical analysis. In regards to catchability, our results were inconclusive, suggesting no clear trend in catch rates by hook type. The use of circle hooks was shown to either decrease or have no effect on at-haulback mortality. Three papers documented post-release mortality, ranging from 23-31%. The use of circle hooks significantly increased the likelihood of mouth hooking, which is associated with lower rates of post-release mortality. Overall, our review suggests minimal differences in catchability of shortfin mako between hook types, but suggests that use of circle hooks likely results in higher post-release survival that may assist population recovery efforts.

KEYWORDS

Circle hook, J-hook, bycatch mortality, post-release mortality, mitigation

1. Introduction

Shortfin mako sharks, *Isurus oxyrinchus*, are globally distributed throughout tropical and temperate seas (Compagno 1984). Females reach maturity at 2.8 m (L_{F50}) (Natanson et al. 2020), and current age-at-length metrics estimate this maturity status is reached between 19 and 22 years of age (Natanson et al. 2006, Rosa et al. 2017). Due to its life history, the species is vulnerable to population depletion, and the North Atlantic shortfin mako stock is currently overfished and undergoing overfishing (Anonymous 2019). The status of the South Atlantic stock is undetermined. However, the Standing Committee on Research and Statistics (SCRS) recommended that precautionary measures should be considered due to the biological similarities to the Northern stock and overall vulnerability of the species. As such, the International Commission for the Conservation of Atlantic Tunas (ICCAT) has identified a need to reduce bycatch mortality for both shortfin mako stocks. In addition, ICCAT indicated the need to “assess the effectiveness of the use of circle hooks as a mitigation measure” (ICCAT Rec. [17-08]).

This review aims to consolidate information regarding performance metrics comparing circle hooks and conventional J-hooks or tuna hooks in longline fisheries with regards to shortfin mako catch and post-capture mortality. Specifically, this paper provides a review of available literature on the effects of hook type on i) catchability, ii) at-haulback mortality, iii) post-release mortality (PRM) and iv) anatomical hooking location. The goal of the review is to consolidate information regarding the role of hook type with respect to catch and mortality of shortfin mako in order to inform management decisions at ICCAT. Additionally, this review will identify gaps in our knowledge and provide direction for future research.

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2. Methods

We conducted a literature review using online sources that included peer-reviewed papers, reviews, meta-analyses, and SCRS documents related to the use of circle hooks as a bycatch mitigation measure for the shortfin mako. For the purpose of this review, catchability refers to catch (weight or count) per unit effort (hooks or hook-hours)(CPUE). We did not consider the variability in retention rates, such as accounting for potential differences in rates of bite-offs due to hook type (see Afonso et al. 2012). At-haulback mortality concerned observations of mortality upon retrieval of fishing gear, specifically if an animal was alive or dead at haulback.

Post-release mortality is calculated as the percentage of sharks that died after release from a fishing vessel as determined by using satellite tags and pre-determined indicators established by researchers. Mortality may also be linked to a body condition code to account for an animal's degree of injury. Post-release mortality studies that assess the effects of hook type are limited, and therefore our literature search was independent of hook type.

Anatomical hooking location refers to the location where a hook is embedded and was typically divided into three categories: mouth, gut, or foul hooking. Mouth hooking involves the hook being set within the mouth or jaw of the animal, while gut and foul hooking refer to the hook being set within the esophagus/stomach or on some exterior body feature, respectively.

Studies that included shortfin mako but with insufficient sample sizes, either through the author's own admission or our designation, are included for reference.

3. Results

Twenty eight papers regarding the effect of circle hooks on shortfin mako catch and PRM were reviewed **(Tables 1-3)**. These included papers from both the Atlantic and Pacific Oceans. We considered Domingo et al. (2012) as two papers because the authors conducted independent studies on American and Spanish style longline configurations. The twenty-eight studies included data from a combination of experimental and fisheries-based sources. Certain studies did not perform statistical analyses and in these situations, we indicate that the effect of hook type was "not tested." Throughout the literature, catch rates were estimated using either number of fish or weight, thereby limiting interpretation of sample size.

3.1 Catchability

Twenty-four studies assessed the effect of hook type on shortfin mako catchability **(Table 1)**. Nine studies lacked an adequate sample size to run statistics, two did not test for significant differences, and nine studies found no statistical difference between treatments. Two research studies found that catchability significantly varied by hook type, yet with different results: Domingo et al. (2012) found CPUE higher on circle hooks whereas Mejuto et al. (2008) found that J hooks had higher CPUE relative to circle or semicircular hooks. Two meta-analyses found catch rates were significantly higher with circle hooks for the shortfin mako (Reinhardt et al. 2018; Rosa et al. 2020).

3.2. At-haulback mortality

Eleven studies addressed at-haulback mortality; five lacked the sample size to run statistics, one did not test for significant differences, and three found no significant differences **(Table 2)**. Of the three studies that found no significant differences, Carruthers et al. (2009) considered survival at release and not explicitly at haulback, which could allow for handling practices to affect mortality. Two meta-analyses found at-haulback mortality rates were significantly lower for the shortfin mako while using circle hooks (Reinhardt et al. 2018; Rosa et al. 2020). Overall these data indicate that the use of circle hooks either decreases or has no effect on at-haulback mortality.

3.3 Post-release mortality (PRM)

Three studies assessed the PRM of the shortfin mako from commercial longlines or replicated commercial fishing conditions with experimental controls; hook type was not considered for any study **(Table 3)**. Bowlby et al. (2020), a working paper submitted to ICCAT, provides an update on an initiative to quantify PRM for the shortfin mako and included tagging data from Campana et al. (2016). The average rates of PRM per study were 28% (n= 48, Bowlby et al. 2020), 22.9% (n= 35, Miller et al. 2020) and 30.8% (n= 26, Campana et al. 2016).

The effect of body condition on PRM is unclear, which is most likely due to limited sample sizes. Miller et al. (2020) categorized the body condition of tagged sharks as perfect, moderate, severe or NA. Twenty-seven of the 35 sharks from the study were assigned a body condition, with 16, seven and four being labeled as perfect, moderate and severe, respectively. No patterns between condition and PRM were found, with the same % of sharks dying from the "perfect" and "severe" category.

3.4 Anatomical hooking location

Four studies addressed anatomical hooking location; two studies lacked an adequate sample size to run statistics and two found that sharks caught on circle hooks (10° offset in one study) were significantly more likely to be mouth hooked as compared to gut or foul hooked (Carruthers et al. 2009, Epperly et al. 2012) **(Table 3)**. Epperly et al. (2012) also found that gut and foul hooking were more lethal than mouth hooking. These data suggest hooking location can have significant effects on the release condition of the shortfin mako.

4. Discussion

While certain meta-analyses have found hook type to result in significantly higher catch rates, we were unable to reach these conclusions by examining individual studies. Our investigation revealed inconclusive findings with regards to the effect of hook type on the catchability of the shortfin mako. In regards to at-haulback mortality, two meta-analyses found that mortality rates were significantly lower due to the use of circle hooks. Individual studies found no significant differences in regards to at-haulback mortality. These data suggest circle hook use either decreases or has no effect on at-haulback mortality. The increase in sample size associated with meta-analyses is potentially the primary factor driving the significance that we observed.

The only unequivocal finding was that hook type affects anatomical hooking location, indicating that use of circle hooks was more likely to result in mouth-hooking (Carruthers et al. 2009, Epperly et al. 2012). Mouth hooking is less lethal that gut or foul hooking (Epperly et al. 2012) and thus circle hook use presumably results in higher post-release survival as compared to other hook types. French et al. (2015) compared the effects of hook type on PRM of the shortfin mako in a recreational fishery and found hooking location and physical injuries associated with J-hooks likely contributed to increased levels of PRM, further lending support to the conservation value of circle hook use.

The total PRM among studies ranged from 22.9 and 30.8%. For the respective studies, there was no significant relationship observed between body condition and PRM. The lack of any discernable trends is likely due to low sample size. Campana et al. (2016) for example, only tagged three injured sharks and Miller et al. (2020) only classified four as severe. However, the effect of hook type on body condition and hooking location indicates that sharks captured with circle hooks are healthier upon release and likely have lower rates of PRM. In other pelagic species, such as the blue shark, *Prionace glauca,* 96% of individuals that were gut hooked were injured or dead and 97% of mouth hooked sharks were deemed healthy (Campana et al. 2009).

The increased rate of gut hooking associated with the use of J hooks has been hypothesized to allow hooked animals to more easily bite off the gangion. The perceived higher catch rates associated with circle hooks are likely not due to hooking efficiency, but decreased bite offs and increased retention (Afonso et al. 2012). Sharks that bite off the leaders and swim away with a trailing leader while gut hooked may experience a higher level of mortality that overrides the lower retention rates associated with J hooks.

Our findings were inconclusive in regards to differences in catchability when comparing hook types. The use of circle hooks either decreases or has no significant effect on at-haulback mortality. Anatomical hooking location was found to differ by hook type, with circle hooks resulting in more mouth hooking, which was shown to be less lethal than gut or foul hooking. Sharks that are gut hooked and evade capture via bite offs may also have high levels of mortality. Collectively, the use of circle hooks has the potential to reduce PRM and future research should prioritize studying what factors affect these rates.

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Table 1 – Summary table of details for each paper related to catchability. Any significant differences are in boldface. Sample size relates to the number of shortfin mako used for any statistical tests. Studies that found statistical significance are detailed in the comments column.

Paper	Type	Region	Study period	Tests	# of hooks	# of hooks per treatment	Sample size	Results	Comments
Afonso et al. 2011	Research	Equatorial Atlantic	2004-2007	18/0 (0° offset) circle v. 9/0 (10° offset) J-style	7800	3900	6	Lack of sample size	
Afonso et al. 2012	Research	Southwestern Equatorial Atlantic	2011	17/0 (10° offset) circle v. 10/0 (10° offset) J-style	17000	8500	4*	Lack of sample size	*Species ID not confirmed; Listed as *Isurus* spp.
Amorim et al. 2015	Research	Southern Atlantic	2008-2012	17/0 (0° offset) circle v. 17/0 (10° circle) v. 9/0 (10° offset) J-style	446400	148800	726	No significant differences	
Andraka et al 2013	Research	Eastern Pacific	2004-2010	16/0 (with offset) circle v. Nos. 38/40 (with offset) Tuna*	356674	177942 v. 178732	34	No significant differences	*Offset not disclosed
Coehlo et al. 2012	Research	Equatorial Atlantic	2009-2011	17/0 (0° offset) circle v. 17/0 (10° offset) circle v. 9/0 (10° offset) J-style	305352	101784	Not disclosed, CPUE per treatment is documented	No significant differences	
Curran & Bigelow 2011	Research	North Pacific	2005-2006	18/0 (0° or 10° offset) circle v. 3.6 sun Japanese tuna style* v. 9/0 J-style*	2773427	N/A	194	Not tested	*Offset not disclosed
Domingo et al. 2012 (American style)	Research	Southwestern Atlantic	2008-2010	18/0 (10° offset) circle v. 9/0 (10° offset) J-style	39822	19911	59*	**Significant difference**	Relatively small sample size
Domingo et al. 2012 (Spanish style)	Research	Southwestern Atlantic	2007	18/0 (10° offset) circle v. 17/0 (0° offset) J-style	45142	22571	16	Lack of sample size	
Fernandez-Carvalho et al. 2015	Research	Tropical Northeast Atlantic	2008-2011	17/0 (0° offset) circle v. 17/0 (10° offset) circle v. 9/0 (10° offset) J-style	254520	84840	2.3% of total weight (retained)	No significant differences	
Foster et al. 2012	Research	Western North Atlantic	2002-2003	18/0 (0° and 10° offset) circle v. 20/0 (10° offset) circle v. 10/0 (0°	973734	Varies from	700	No significant differences	

				offset) Japanese tuna v. 9/0 (10-30° offset) J-style		22790-326288			
Galeana-Villaseñor et al. 2008	Research	Northeast Pacific	2004	15/0 (0° offset) circle v. 8/0 (0° and 18° offset) tuna style v. 8/0 (0° offset) J-style	2400	N/A	10	Lack of sample size	
Galeana-Villaseñor et al. 2009	Research	Northeast Pacific	2005-2006	16/0 (0° offset) circle v. 9/0 (11° offset) J-style	22560	N/A	44	No significant differences	
Ingram et al. 2005	Working Paper	Gulf of Mexico and Northwest Atlantic	1999-2000	Circle v. J-style	254500	N/A	3	Lack of sample size	
Kerstetter & Graves 2006	Research	Gulf of Mexico and Northwest Atlantic	2003-2004	16/0 (0° offset) circle v. 9/0 (10° offset) J-style	30600	15300	8	Lack of sample size	
Kim et al. 2006	Research	Eastern Pacific	2005	18/0 (0° offset) circle v. 15/0 (0° offset) circle v. 4.0 (0° offset) traditional tuna style	44100	14700	1*	Lack of sample size	*Labeled "Mako shark"
Mejuto et al. 2008	Working Paper	North and South Atlantic	2005-2006	18/0 (10° offset) semicircular v. 17/0 (8° offset) circle v. 16/0 (10° offset) J-style	430299	143353 v. 143473 v. 143473	1364	**Significant difference**	*Higher CPUE with J-hooks
Pacheco et al. 2011	Research	Equatorial South Atlantic	2006-2007	18/0 (0° offset) circle v. 9/0 (10° offset) J-style	50170	25085	6	Lack of sample size	
Sales et al. 2010	Research	Southwestern Atlantic	2004-2008	18/0 (10° offset) circle v. 9/0 (0° offset) J-style	145828	72914	216	No significant differences	
Ward et al. 2009	Research	South Pacific	2005-2008	13/0, 14/0, 16/0, 18/0 (all 5° offset) circle v. 2.8-3.5 sun (with 5° offset) Japanese-style	95150	47575	13	No significant differences	
Watson et al. 2005	Research	Western North Atlantic	2002	18/0 (0 and 10° offset) circle v. 9/0 (20-25° offset) J-style	427382	71000 (142000 for control)	335	Not tested	
Yokota et al. 2006	Research	Western North Pacific	2005	4.3 and 5.2 sun (10° offset) circle v. 3.8 sun (10° offset) Japanese tuna	35027	N/A	27	Lack of sample size	

Godin et al. 2012	Meta-analysis	N/A	N/A	Circle hook v. J-hook	N/A	N/A	N/A	No significant differences	6 studies
Reinhardt et al. 2018	Meta-analysis	N/A	N/A	Circle hook v. J-hook	N/A	N/A	N/A	**Significant difference**	12 studies referenced; significantly more captures on circle hook
Rosa et al. 2020	Meta-analysis	N/A	N/A	Circle hook v. J-hook	N/A	N/A	N/A	**Significant difference**	10 studies referenced; significantly more captures on circle hook

Table 2 – Summary table of details for each paper related to at-haulback mortality. Any significant differences are in boldface. Sample size relates to the number of shortfin mako used for any statistical tests. Studies that found statistical significance are detailed in the comments column.

Paper	Type	Region	Study period	Tests	# of hooks	# of hooks per treatment	Sample size	Results	Comments
Afonso et al. 2011	Research	Equatorial Atlantic	2004-2007	18/0 (0° offset) circle v. 9/0 (10° offset) J-style	7800	3900	6	Lack of sample size	
Afonso et al. 2012	Research	Southwestern Equatorial Atlantic	2011	17/0 (10° offset) circle v. 10/0 (10° offset) J-style	17000	8500	4*	Lack of sample size	Species ID not confirmed; Listed as *Isurus* spp.
Carruthers et al. 2009	Research	Northwest Atlantic	2001-2004, 2005-2006	16/0 (0° offset) circle v. 8/0 or 9/0 (20-30° offset) v. 8/0 or 9/0 (0° offset)	950000	596 v. 70 v. 193 sets per treatment	389	No significant differences*	*Based upon survival at release
Curran & Bigelow 2011	Research	North Pacific	2005-2006	18/0 (0° or 10° offset) circle v. 3.6 sun Japanese tuna* v. 9/0 J-style*	2773427	N/A	194	Not tested	*Offset not disclosed

Epperly et al. 2012	Research	Western North Atlantic	2002-2003	18/0 (0° and 10° offset) circle v. 9/0 (10-30° offset) J-style	813157	N/A	550	No significant differences*	*Hooking location significantly affected at-haulback mortality
Kerstetter & Graves 2006	Research	Gulf of Mexico and Northwest Atlantic	2003-2004	16/0 (0° offset) circle v. 9/0 (10° offset) J-style	30600	15300	8	Lack of sample size	
Pacheco et al. 2011	Research	Equatorial South Atlantic	2006-2007	18/0 (0° offset) circle v. 9/0 (10° offset) J-style	50170	25085	6	Lack of sample size	
Ward et al. 2009	Research	South Pacific	2005-2008	13/0, 14/0, 16/0, 18/0 (all 5° offset) circle v. 2.8-3.5 sun (with 5° offset) Japanese-style	95150	47575	19	No significant differences	
Yokota et al. 2006	Research	Western North Pacific	2005	4.3 and 5.2 sun (10° offset) circle v. 3.8 sun (10° offset) Japanese tuna	35027	N/A	27	Lack of sample size	
Reinhardt et al. 2018	Meta-analysis	N/A	N/A	Circle hook v. J hook	N/A	N/A	N/A	**Significant difference**	6 studies referenced; significantly lower mortality on circle hooks
Rosa et al. 2020	Meta-analysis	N/A	N/A	Circle hook v. J hook	N/A	N/A	N/A	**Significant difference**	7 studies referenced; significantly lower mortality on circle hooks

Table 3 – Summary table of details for each paper related to hooking location and post-release mortality. Any significant differences are in boldface. Sample size relates to the number of shortfin mako used for any statistical tests. For PRM studies, sample size is the number of tags that successfully transmitted data. Studies that found statistical significance are detailed in the comments column.

Paper	Type	Region	Study period	Tests	# of hooks	# of hooks per treatment	Sample size	Results	Comments

Bowlby et al. 2020	Working Paper	Northwest Atlantic	2001-2018	Quantifying PRM	N/A	N/A	48	28%*	Data overlap with Campana et al. 2016
Carruthers et al. 2009	Research	Northwest Atlantic	2001-2004, 2005-2006	16/0 (0° offset) circle v. 8/0 or 9/0 (20-30° offset) v. 8/0 or 9/0 (0° offset) J-style	950000	596 v. 70 v. 193 sets per treatment	1189 (additional samples from observer data 2001-2006)	**Significant difference**	More like to be mouth hooked on circle hooks
Campana et al. 2016	Research	Northwest Atlantic	2010-2014	Quantifying PRM	N/A	N/A	26	30.8% mortality	
Epperly et al. 2012	Research	Western North Atlantic	2002-2003	18/0 (0° and 10° offset) circle v. 9/0 (10-30° offset) J-style	813157	N/A	550	**Significant difference**	Mouth hooking more likely with 10° offset circle hook. Gut and foul hooking more lethal than mouth hooking.
Kerstetter & Graves 2006	Research	Gulf of Mexico and Northwest Atlantic	2003-2004	16/0 (0° offset) circle v. 9/0 (10° offset) J-style	30600	15300	8	Lack of sample size	
Miller et al. 2020	Working Paper	North and South Atlantic	2015-2019	Quantifying PRM	N/A	N/A	35	22.9% mortality	
Pacheco et al. 2011	Research	Equatorial South Atlantic	2006-2007	18/0 (0° offset) circle v. 9/0 (10° offset) J-style	50170	25085	6	Lack of sample size	