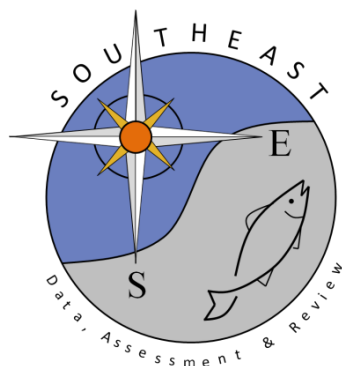


An Updated Literature Review of Post-Release Live-Discard Mortality Rate Estimates in Sharks for use in SEDAR 101

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An Updated Literature Review of Post-Release Live-Discard Mortality Rate Estimates in Sharks for use in SEDAR 101

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SUMMARY

This working paper summarizes a literature database reviewed for post-release live-discard mortality (PRLDM) rates in sharks. The literature database was reviewed for estimates of delayed discard-mortality rates (M_D) and immediate (i.e. at-vessel or acute) discard-mortality rates (M_A) for sandbar sharks (*Carcharhinus plumbeus*) and closely related Dusky sharks (*Carcharhinus obscurus*). Previous SEDAR Assessment Process (AP) and Data Workshop (DW) PRLDM rate decisions for sharks were also summarized.

Methods

A literature database of post-release live-discard mortality (PRLDM) rates in sharks (Courtney et al. 2021; 121 existing records and 10 new records) was searched for sandbar sharks (*Carcharhinus plumbeus*). Some PRLDM rates identified for closely related dusky sharks (*Carcharhinus obscurus*) were also identified and summarized.

Previous SEDAR Assessment Process (AP) panels (NMFS 2012, 2013a, 2013b, 2017, 2018, 2020, 2024) emphasized that PRLDM rates are only applied to live discards, and they used an equation from Hueter and Manire (1994) to describe the relationship between total discard mortality and PRLDM:

$$(1) \text{ Total discard mortality rate} = (\text{Dead-discard rate}) + (\text{PRLDM}) * (\text{Live-discard rate}).$$

The same approach was used here. However, in order to be consistent with more recent literature, as described below, the following equation was also used interchangeably:

$$(2) \text{ MT} = \text{MA} + \text{MD} * \text{SA},$$

where MT = Total discard-mortality rate, defined as the immediate plus delayed discard-mortality rate resulting from the fishing event; MA = Immediate (i.e., at-vessel or acute) discard-mortality rate resulting from the fishing event; MD = PRLDM = Delayed discard-mortality rate resulting from the fishing event, defined as the proportion released alive that die as a result of the fishing event; and SA = Acute survival rate (i.e., the proportion released alive).

Results

Table 1 provides a summary of delayed discard-mortality rate, M_D , estimates obtained for sandbar sharks and dusky sharks from the literature review.

Table 2 provides a summary of delayed discard-mortality rates, M_D , obtained for pelagic sharks from meta-analyses (Musyl and Gilman 2019). Musyl and Gilman (2019) used random-effects meta-analysis to synthesize post-release live-discard mortality (PRLDM) rate estimates available from 33 previous studies of seven pelagic shark species captured, tagged and released with 401 pop-up satellite archival tags for three gear types (longline, purse-seine, rod & reel).

Table 3 provides a summary of predicted mean total discard mortality (TDM) obtained from meta-analysis of obligate ram-ventilating and stationary respiring elasmobranchs (Dapp et al. 2016c). Dapp et al. (2016c) used meta-analysis of immediate mortality (IM; 83 species) and post-release mortality (PM; 40 species) to synthesize TDM of obligate ram-ventilating elasmobranchs and stationary respiring elasmobranchs caught in longline, gillnet and trawl gear types using Bayesian models (immediate mortality) and non-parametric tests (gillnet post-release mortality). Dapp et al. (2016c) obtained PM as the arithmetic average PM by gear except for three approximation scenarios of post-release mortality for trawl caught obligate ram-ventilating species, which were underrepresented in the analysis.

Table 4 provides a summary of previous SEDAR shark post-release live-discard mortality, PRLDM, rate decisions from recent SEDAR domestic shark stock assessments.

Table A.1 provides a summary of the literature database reviewed for post-release live-discard mortality, PRLDM, rate estimates available for sharks. Records identified with a study species were further examined to determine if the record provided estimates of delayed discard-mortality rates, M_D , immediate (i.e. at-vessel or acute) discard-mortality rates, M_A , or the species name appeared in some other context (e.g., physiological stress response to capture, meta-analysis, etc.).

Table A.2 provides a summary of delayed discard-mortality rates, M_D , in sharks by gear type obtained from the literature search.

Table A.3 provides a summary of immediate (i.e. at-vessel or acute) discard-mortality rates, M_A , in sharks by gear type obtained from the literature search.

Table A.4 provides a summary of at vessel mortality (AVM %) and post-release mortality (PRM %) in sharks from a recent literature review (Ellis et al. 2017).

Table B.1 provides a summary of post-release live-discard mortality, PRLDM, rate decisions from the recent SEDAR 65 Atlantic blacktip domestic shark stock assessment.

Discussion

For comparison, a summary of post-release live-discard mortality, PRLDM, rate decisions from the recent SEDAR 65 Atlantic blacktip domestic shark stock assessment is provided in Appendix B (Courtney and Mathers 2019). Previous PRLDM reviews available for use in previous SEDAR domestic shark assessments are provided in Courtney (2012, 2013, 2014, and 2018), Courtney and Mathers (2019), and Courtney et al. (2021).

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Table 1. Delayed discard-mortality rate, M_D , estimates obtained for sandbar sharks (*Carcharhinus plumbeus*) and dusky sharks (*Carcharhinus obscurus*) from the literature review.

Gear/Source	Sandbar sharks (<i>Carcharhinus plumbeus</i>)	Dusky sharks (<i>Carcharhinus obscurus</i>)	Delayed discard mortality rate (M_D)	Notes
Longline (pelagic)				
Barnes et al. (2016)	X	X	Sandbar shark (25.0%) dusky shark (12.5%)	Tagged sharks were released alive and in good condition. There was no apparent correlation between mortality and longer hook times (1:33-18:12 h:min).
Grosse et al. (2023)	X		Sandbar shark (0%)	Of 57 individuals tagged with PSAT tags, scientific demersal longline surveys, there was a post-release survival rate of 100% after a maximum of 4 h on the hook
Sulikowski et al. (2020)		X	Dusky shark (5%)	PRLDM rates are lower than in previous studies By (Marshall et al. 2015)
Longline (demersal)				
Marshall et al. (2015)	X	X	Sandbar shark (20%) Dusky shark (29%)	Dusky sharks exhibited 29% (n = 6) post-release mortality, with 11% of sharks dying after time-on-the-line ≤ 3 -hours and 42% >3 -hours; Sandbar sharks exhibited 20% (n = 2) post-release mortality, with 100% survival if captured up to 3 h on the longline, but showing mortalities at ~ 7 -8 h.
Whitney et al.(2021)	X		Sandbar shark (3.1%) se = 2.5%	Soak times ranged from 2–18 h \pm 95% confidence intervals, calculated using equations outlined by Goodyear (2002). M_D was consistently higher than M_A .
Hook and line				
Kneebone et al. (2024)	X		Sandbar shark (0%)	While no PRM was observed in the present study the authors provide a PRM rate of 5.6% which is the upper limit of the 95% CI.
Gillnet				
Hueter and Manire (1994)	X	X	Coastal sharks (34.8%)	Tag return data was used to estimate delayed mortality for all juvenile and small adult sharks, combined, captured with research gillnets in Florida Gulf Coast estuaries.
Trawl				
NA				
Purse seine				
NA				
Reviews				
Ellis et al. (2017)	X	X	E.g., Sandbar shark longline PRLDM 20% Adapted from Marshall et al. (2015)	Review published results of PRLDM and at-vessel mortality.
Meta-analyses				
NA				

Table 2. Delayed discard-mortality rates, M_D , obtained for pelagic sharks from meta-analyses (Musyl and Gilman 2019, their Figures 3 and 6).

Species	Gear or disposition	Estimate	LCI	UCI	Mortality	N
Blue (9 studies)		0.17	0.107	0.259	28	158
Silky (8 studies)	Purse-seine	0.475	0.31	0.645	29	63
Silky (3 studies)	Longline	0.164	0.008	0.819	7	45
Common Thresher (3 studies)		0.353	0.072	0.793	12	35
Shortfin Mako (5 studies)		0.254	0.137	0.42	15	67
Oceanic White-tip (2 studies)		0.163	0.008	0.831	1	15
Bigeye Thresher (2 studies)		0.225	0.081	0.49	3	15
Scalloped Hammerhead (1 study) ¹		0.875	0.266	0.993	3	3
Overall		0.268	0.193	0.36	95	401
Pelagic sharks	Healthy (27 studies) ²	0.199	0.148	0.263	59	346
Pelagic sharks	Unhealthy (6 studies)	0.647	0.507	0.763	36	55

¹ Scalloped Hammerhead sharks were captured in tuna purse seine sets around FADs (Eddy et. al 2016).

² Scalloped Hammerhead sharks were included in the healthy pelagic shark grouping.

Table 3. Predicted mean total discard mortality (TDM) obtained from meta-analysis of immediate mortality (IM; 83 species) and post-release mortality (PM; 40 species) obligate ram-ventilating (Panel A) and stationary respiring (Panel B) elasmobranchs (adapted from Dapp et al. 2016c, their Table 2).

A

Gear type	Respiratory mode	IM (%)	PM (%)	TDM (%)
Gillnet	Obligate ram-ventilating	67.3	35.9	79
Longline	Obligate ram-ventilating	37.6	19.51	49.8
Trawl – Scenario 1	Obligate ram-ventilating	62.5	22.12	70.8
Trawl – Scenario 2	Obligate ram-ventilating	62.5	54.42	82.9
Trawl – Scenario 3	Obligate ram-ventilating	62.5	58.02	84.2

$$TDM = [1-(1-IM/100) \times (1-PM/100)] \times 100.$$

Sample size n ≥ 15 in each study.

Immediate mortality studies comprised primarily pelagic longline (83% of studies), benthic gillnet (64%), and benthic trawls (100%).

Post-release mortality studies comprised a greater proportion of species capable of stationary respiration 76% (24 of 33 data points) compared to the immediate mortality analysis 55% (61 of 111 data points).

Post-release mortality of obligate ram ventilating species was under-represented in trawls and, consequently, was estimated from other sources based on three scenarios:

Trawl – Scenario 1 “[A]ssumed that respiratory mode did not affect post-release mortality and we used the mean post-release mortality percentage of stationary-respiring species to model the post-release mortality percentage of obligate ram ventilating species.”

Trawl – Scenario 2 “[A]ssumed that changes in immediate mortality percentages caused by respiratory mode would be similar to changes in post-release mortality percentages caused by respiratory mode in trawl-caught species.”

Trawl – Scenario 3 “[A]ssumed that the impact of respiratory mode on post-release mortality percentages of trawl-caught species was similar to the impact of respiratory mode on post-release mortality percentages of gillnet-caught elasmobranchs.”

B

Gear type	Respiratory mode	IM (%)	PM (%)	TDM (%)
Gillnet	Stationary respiring	13.4	13.7	25.3
Longline	Stationary respiring	4.6	2.71	7.2
Trawl	Stationary respiring	25.4	22.1	41.9

Table 4. Previous SEDAR domestic shark post-release live-discard mortality (PRLDM) rate decisions from recent stock assessments.

Discard mortality rates by gear type				
Working group	Longline	Hook and line	Gillnet	Trawl
A. SEDAR 21 ¹				
Sandbar shark				
LH WG	38.24%	3.25%	NA	NA
Catch WG	2% (Pelagic longline); 5% (Bottom longline)	NA	5%	NA
DW*	28.5% (Pelagic longline); 28.5 – 38.0% (Bottom longline)	3.2%	5 – 10%	NA
Blacknose shark				
LH WG	71.18%	6.6%	NA	67.0%
Catch WG	50% (Bottom longline)	NA	50% (Drift gillnet); 5% (Strike gillnet); 25% (Sink gillnet)	NA
DW*	50 – 71% (Bottom longline)	6.6%	Same as Catch WG	67.0%
Dusky shark				
LH WG	65.17%	6.0%	NA	NA
Catch WG	5% (Pelagic longline); 35% (Bottom longline)	NA	50%	NA
DW*	44.2% (Pelagic longline); 44.2 – 65% (Bottom longline)	6.0%	50%	NA
B. SEDAR 29 ²				
Gulf of Mexico blacktip shark				
AP *	31% (Base) 19 – 73% (Range)	10% (Base) 5 – 15% (Range)	31% (Base)	NA
C. SEDAR 34 ³				
Atlantic sharpnose shark				
AP *	35% (Base) 19 – 82% (Range)	10% (Base) 5 – 15% (Range)	58.5% (Base) 35 – 82% (Range)	NA
Bonnethead shark				
AP *	40% (Base) 19 – 91% (Range)	10% (Base) 5 – 15% (Range)	65.5% (Base) 40 – 91% (Range)	NA
D. SEDAR 29 Update ⁴				
Gulf of Mexico blacktip shark				
AP *	31% (Base)	9.7% (Base)	31% (Base)	NA
AP *	NA	10 – 19% (Range)	NA	NA
E. SEDAR 65 ⁵				
(See Appendix B for a summary decisions from the recent SEDAR 65 Atlantic blacktip domestic shark stock assessment)				
Atlantic blacktip shark				
DW*	44.2% (Base, Bottom longline)	18.5% (Base)	31% (Base)	NA
	34.0–54.8% (Range)	10.8–28.7% (Range)	8.7–44.4% (Range)	NA

Table 4. Continued.

Discard mortality rates by gear type				
Working group	Longline	Hook and line	Gillnet	Trawl
F. SEDAR 54 ⁶				
Sandbar Shark				
No changes were introduced to the methods to develop the catch series used in SEDAR 21.				
G. SEDAR 77 ⁷				
Great Hammerhead				
DW*	81.41% (Base, Bottom longline)	26.8% (Base)	81.41% (Base)	NA
	(77.005 - 85.93%, Range)	(11.8 - 36.0 %, Range)	(77.005 - 85.93%, Range)	NA
Scalloped Hammerhead				
DW*	69.15 % (Base, Bottom longline)	26.8% (Base)	81.41% (Base)	NA
	(66.79 - 75.19%, Range)	(11.8 - 36.0 %, Range)	(77.005 - 85.93%, Range)	NA
Smooth Hammerhead				
DW*	69.15 % (Base, Bottom longline)	26.8% (Base)	69.15 % (Base, Bottom longline)	NA
	(66.79 - 75.19%, Range)	(11.8 - 36.0 %, Range)	(66.79 - 75.19%, Range)	NA
*Final decisions adopted for stock assessment.				

Footnotes:

¹SEDAR 21 life history (LH) working group (WG) decisions adopted by NMFS (2011a, 2011b, 2011c, 2011d their sections II Data Workshop Report, sub-section 2.5 Discard Mortality); SEDAR 21 catch WG and final data workshop (DW) panel decisions adopted by NMFS (2011a, 2011b, 2011c, 2011d their sections II Data Workshop Report, sub-section 3.4.2. Post Release Mortality).

²SEDAR 29 assessment process (AP) decisions adopted by NMFS (2012 their sections 2.2.2.3—Commercial Discards Datasets—and 2.2.2.5—Recreational Discards Datasets and Decisions);

³SEDAR 34 assessment process (AP) decisions adopted by NMFS (2013a, 2013b their sections 2.2.2.3 and 2.2.2.4).

⁴SEDAR 29 update assessment process (AP) decisions adopted by NMFS (2018).

⁵SEDAR 65 data workshop (DW) decisions adopted by NMFS (2020).

⁶SEDAR 54 did not make any new decisions regarding Post Release Live Discard Mortality.

⁷SEDAR 77 data workshop (DW) decisions adopted by NMFS (2022 their section III Data Workshop Report, subsection 3.1.2—Commercial Post-Release Live Discard Mortality—and 3.1.3 Recreational Post-Release Live Discard Mortality).

Appendix A. Literature database search for post-release live-discard mortality (PRLDM) rates in sharks.

Table A.1. Summary of literature reviewed for shark post-release live-discard mortality (PRLDM), post-capture physiological stress, at-vessel mortality rate estimates, and catch disposition (e.g., % discard dead (DD) and % discard alive (DA)).

Primary Literature	Species		Gear type					Study type				Notes
	Sandbar sharks (<i>Carcharhinus plumbeus</i>)	Dusky Shark (<i>Carcharhinus obscurus</i>)	Pelagic longline	Demersal longline	Hook and Line	Gillnet	Trawl	Physiological or behavioral	Electronic tagging	Lab.	Other	
Longline (pelagic)												
Afonso et al. (2011)			X								Experimental pelagic longline sets	At-vessel mortality
Afonso et al. (2012)			X								Experimental pelagic longline sets	At-vessel mortality
Barnes et al. (2016) ¹	X	X	X						X		Chartered commercial fishing vessels	PRLDM
Beerkircher et al. (2002)	X	X	X								Commercial fisheries	Catch disposition
Bromhead et al. (2012)	X		X								Commercial fisheries research	At-vessel mortality
Campana et al. (2016)			X						X		Observer data	At-vessel mortality and PRLDM
Campana et al. (2009a, 2009b)			X						X			PRLDM
Coelho et al. (2011)			X								Observer data	At-vessel mortality
Coelho et al. (2012)			X								Observer data	At-vessel mortality
Coelho et al. (2013)			X								Observer data	At-vessel mortality rate models GLM and GEE
Dapp et al. (2016a)			X	X				X			Research longline	At-vessel mortality
Dapp et al. (2016b)			X								Commercial logbook	At-vessel mortality Estimate
Diaz (2011)	X	X	X								Observer data	coefficient of variation for at-vessel mortality

Fernandez-Carvalho, J., et al. (2015)			X				Experimental pelagic longline sets	(dead discards). At-vessel mortality
Gallagher et al. (2014a)			X				Observer data	At-vessel mortality - logistic regression integrated with reproductive potential
Gilman et al. (2016) ¹	X		X				Observer data	Bycatch at-vessel fishing mortality
Grosse et al. (2023) ¹	X		X		X			Stress physiology and post release survival
Megalofonou et al. (2005) ¹	X		X				Observer data	At-vessel mortality
Moyes et al. (2006)			X		X	X		PRLDM Factors
Musyl et al. (2009)			X		X	X		Influencing PRLDM
Musyl et al. (2011)			X			X	Meta-analysis	PRLDM At-vessel mortality -
Serafy et al. (2012)			X				Observer data	logistic regression, comparing circle and j-hook
Sulikowski et al. (2020) ¹		X	X			X		At-vessel mortality and PRLDM
<u>Longline (demersal)</u>								
Afonso and Hazin (2014)				X		X		PRLDM
Braccini and Waltrick (2019) ¹	X	X		X			Research longline	At-vessel mortality
Brooks et al. (2015)				X		X	Research longline	At-vessel mortality and PRLDM

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Butcher et al. (2015)	X	X	X	X	Commercial fisheries research	At-vessel mortality, stress response
Drymon and Wells (2017)			X		Research longline	PRLDM
Gallagher et al. (2014b)			X	X	Drum-line	PRLDM, stress response Behavioral response to capture
Gallagher et al. (2017)			X	X	Drum-line	measured with accelerometers attached to the fishing gear
Gulak et al. (2015)	X	X	X		Commercial fisheries research	At-vessel mortality Catch disposition of the shark bottom longline fishery
Hale et al. (2010) ¹	X	X	X		Observer data	At-vessel mortality, PRLDM
Marshall et al. (2015)	X	X	X		Commercial fisheries research	At-vessel mortality, PRLDM
Morgan and Burges (2007)	X	X	X		Observer data	At-vessel mortality
Morgan and Carlson (2010)	X		X		Research/commercial longline	At-vessel mortality
Morgan et al. (2009)	X	X	X		Observer data	At-vessel mortality Spatial and temporal bycatch distribution
Morgan et al. (2010)			X		Observer data	Bycatch disposition
Rogers et al. (2017)			X		PAT	PRLDM
Scott-Denton et al. (2011)	X	X	X		Observer data	Bycatch disposition
Whitney et al. (2021)	X		X	X	Research/commercial longline	PRLDM and At-vessel mortality
<u>Hook and line</u>						
Bullock et al. (2015)			X		Net pen	Post-release behavior of tagged sharks

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Danylchuk et al. (2014)		X		X	X	Reflex indices	in net pens and in situ PRLDM - 15 min. Not clear how sharks were tracked
French et al. (2015)		X		X	X	sPAT	PRLDM
Gurshin and Szedlmayer (2004)		X			X		PRLDM
Heberer et al. (2010)		X		X	X	PSAT	PRLDM
Heupel and Simpfendorfer (2002)		X			X		PRLDM
Holland et al. (1999)		X			X		Movement rates
Holts and Bedford (1993)		X			X		Movement rates
Kneebone et al. (2013) ¹		X		X	X	X	Post-release monitoring of 65 sharks surgically implanted with acoustic tags demonstrated high degrees of immediate (99%), short-term (82%), and long-term post-release survivorship (75%).
Kneebone et al. (2024) ¹	X	X			X	Observer data from recreational land-based fishing	PRLDM
Mandelman and Farrington (2007a)		X	X			Captured and held in net-pen (72 hrs.)	PRLDM
Sepulveda et al. (2015)		X				PSAT	PRLDM
Whitney et al. (2016)		X			X		PRLDM
Whitney et al. (2017)		X			X		PRLDM
Gillnet							

Bell and Lyle (2016)				X				Tank trials	PRLDM
Braccini et al. (2012)				X				Risk assessment	At-vessel mortality and post capture survival based on an assessment of at-vessel condition
Francis (1989)				X	X			Large scale tagging study	Noted that recapture rates were lower for trawl than set-net
Hueter and Manire (1994)	X		X	X				Tagging study	PRLDM
Hueter et al. (2006)		X		X					PRLDM
Reid and Krogh (1992)				X				Protective shark meshing	At-net mortality
Rulifson (2007)				X	X			Captured and held in net-pen (48 hrs.)	PRLDM
Thorpe and Frierson (2009)				X				Bycatch mitigation	At-vessel mortality
<u>Trawl</u>									
Fennessy (1994)	X							Commercial prawn trawl fisheries	Bycatch disposition
Stobutzki et al. (2002)									At-vessel mortality
<u>Purse seine</u>									
Eddy et al. (2016)								Tuna purse seine around FAD	At-vessel mortality, PRLDM
Hutchinson et al. (2015)						X		Tuna purse seine	At-vessel mortality, PRLDM
Poisson et al. (2014)								Tuna purse seine	At-vessel mortality, PRLDM
<u>Physiology</u>									
Barham and Schwartz (1992)									Physiological response in dogfish
Brill et al. (2008) ¹	X			X					Investigates the

Brooks et al. (2011)					X	X	consequences of anaerobic exercise accompanying catch and release fishing. Behavioral and physiological effects of tonic immobility for extended durations
Brooks et al. (2012)			mid-water longlines		X		Stress response in longline capture
Cain et al. (2004)				X	X		Blood chemistry of southern stingrays
Cicia et al. (2012)					X	X	Aerial exposure and acute thermal stress
Cliff and Thurman (1984)	X			X	X		Physiological effects of capture and transport
Frick et al. (2009)	X				X	X	Measure immediate and short term effects of capture stress.
Frick et al. (2010a)			X	X	X	X	Measure immediate and delayed effects of capture stress associated with gear type
Frick et al. (2010b)					X	X	Effects of trawl capture
Frick et al. (2012)				X	X	X	Effects of gillnet capture
Hight et al. (2007)		X		X	X		Stress response to

Hoffmayer and Parsons (2001)												longline capture
Hoffmayer et al. (2012)												Baseline estimates for hematological parameters
Hyatt et al. (2016)												Seasonal component behavioral release condition score (BRCS)
Hyatt et al. (2012)												Stress response
Jerome et al. (2018)	X											Stress response
Lowe 2001												Metabolic rate
Mandelman and Farrington (2007b)											X	Physiological threshold for dogfish
Mandelman and Skomal (2009)												Stress response Behavioral and serological response
Manire et al. (2001)												Stress response
Marshall et al. (2012)	X	X										Stress response
Scarponi et al (2021)												Stress response
Skomal (2007)												Evaluates current methods for assessing post capture stress.
Skomal and Bernal (2010)	X	X										Physiological responses to stress in sharks
Skomal and Mandelman (2012)	X	X										Current understanding of physiological stress in elasmobranchs
<u>General review</u>												
Dapp et al. (2016c)												Review of PRLDM and at-vessel-mortality
												Meta-analysis

Ellis et al. (2017)	X	X	X	X	X	X	X	Review article	Review of PRLDM and at-vessel-mortality meta-analysis and analysis of covariance
Godin et al. (2012)			X	X				Review	to test the effects of circle hooks on catchability and at-vessel mortality rates
Hammerschlag (2011)								X	Review - tag failure
Musyl and Gilman (2019)			X		X			Meta-analysis	A review of shark satellite tagging studies
Oliver et al. (2015)								Review article	PRLDM
Poisson et al. (2016)			X					Review article	Reviews published results of PRLDM and at-vessel-mortality bycatch-mitigation
Raby et al. (2013)								Review article	Predation
Renshaw et al. (2012)							X	Review article	Biochemistry
Worm et al. (2013)			X					Review	PRLDM pelagic longline
<u>Government report</u>									
Campana et al. (2011)			X					Review	Estimation of bycatch mortality in Canadian pelagic longline
Clarke (2011)								Review report	Status of sharks
McLoughlin and Eliason (2008)						X		Review report	WCPFC Cryptic mortality
<u>Non-governmental agency(NGO) report</u>									
Clarke et al. (2013)								Review	Studies of

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Cosandey-Godin and Morgan (2011)			report Review report	mortality to Sharks Fisheries bycatch of sharks
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¹ New records added to the literature database.

Table A.2. Summary of delayed discard-mortality rates, M_D , in sharks by gear type obtained from the literature search (Table A.1).

Gear/Source	Sandbar sharks (<i>Carcharhinus plumbeus</i>)	Dusky Sharks (<i>Carcharhinus obscurus</i>)	Other species	Delayed discard mortality rate (M_D)	Notes
Longline (pelagic)					
Barnes et al. (2016)	X	X	Sandbar shark dusky shark	25.0% 12.5%	Estimation of sandbar shark and dusky shark PRLDM affiliated with capture by targeted commercial demersal longlines. Tagged sharks were released alive and in good condition. Authors found no clear correlation between mortality and longer hook times.
Campana et al. (2016)			Blue, porbeagle, shortfin mako sharks	9.8% (s.e. = 4.7%); 27.2% (s.e. = 12%); 31.3% (s.e. = 18%)	Tagged injured and healthy animals with PRLDM expanded by the proportion of each category observed in the fishery. Authors indicate that the blue shark estimate is likely a minimum estimate.
Campana et al. (2011)			Blue shark	19%	Estimation of blue shark total bycatch mortality in pelagic longline fisheries based on PRLDM of 19% citing Campana et al. (2009b)
Campana et al. (2009b)*			Blue shark	19%* (10 – 29%)	Tagged both injured and healthy animals; Range is 95% confidence interval.
Grosse et al. (2023)	X		Sandbar Shark	0%	Of 57 individuals tagged with PSAT tags on scientific demersal longline surveys, there was a post-release survival rate of 100% after a maximum of 4 h on the hook
Moyes et al. (2006)			Blue shark	10 %	Authors utilized PSAT tagging and biochemical analysis to assess the survival of blue sharks in the longline fishery.
Musyl et al. (2011)			Blue shark	15% (8.5 – 25.1%)	Meta-analysis; Range is 95% confidence interval.
Worm et al. (2013)			All sharks	15%	Assumed 15% post-release mortality of all sharks released alive based on PRLDM of pelagic sharks from Campana et al. (2011) and Musyl et al. (2011).
Sulikowski et al. (2020)		X	Dusky shark	5%	30 day attachment period. Forty-three of the 50 deployed tags reported data with deployment times ranging from 1 to 28 days (11.2 ± 9.8 days). Four dusky sharks were in poor condition at release and two individuals suffered PRM. The authors found lower rates of PRLDM than in previous studies by Marshall et al. (2015).
Longline (demersal)					
Afonso and Hazin (2014)			Tiger shark	0%	Tiger sharks (19) captured with demersal longline, tagged with PSAT, and tracked for up to 30 days
Brooks et al. (2015)			Deep-water elasmobranch assemblage - Bahamas	NA	16 PSATs deployed, only two reported via the Argos system. Consequently, the exact proportion of PRLDM by species is unknown.
Drymon and Wells (2017)				0%	Fishery-independent bottom longline sampling in the northern Gulf of Mexico set for 1 h. Double tagging [n = 3; with electronic tags] to distinguish satellite

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					tag failure from animal mortality
Frick et al. (2010a)			Mustelus sp.	Average within captive lab study of 8%	The average delayed mortality (MD, up to 72 hr. after treatment) for <i>M. antarcticus</i> captured in longlines under laboratory conditions (8.3%) was calculated here from simulated longline fishing under laboratory conditions for 30 min (MD = 12.5%), 120 min (MD = 12.5%), and 360 min (MD = 0.0%); May not reflect commercial fishery.
Gallagher et al. (2014b)			Five species of coastal sharks	Tiger (3.6%), bull (25.9%), and great hammerhead (46.4%)	Percentage of satellite tagged sharks reporting after four weeks. Gallagher et al. (2014b) noted that the use of research drum-lines with long gangions (23m) may have allowed for a higher potential for ram-ventilating than in other studies (citing Brooks et al. 2012).
Marshall et al. (2015)	X	X	Dusky and sandbar sharks	29% (Dusky) 20% (Sandbar)	Dusky sharks exhibited 29% (n = 6) post-release mortality, with 11% of sharks dying after time-on-the-line ≤3-hours and 42% >3-hours; Sandbar sharks exhibited 20% (n = 2) post-release mortality, with 100% survival if captured up to 3 h on the longline, but showing mortalities at ~7–8 h.
Rogers et al. (2017)			School shark	0%	All (10) satellite tags released prematurely and tag retention periods ranged between 5 and 44 days (average = 24 ± 13.7 d). Tags were deployed on uninjured sharks.
Whitney et al. (2021)	X		Large coastal sharks	Sandbar 3.1% ± 2.5, n = 130 Blacktip 41.9% ± 7.9, n = 105 Tiger 1.9% ± 3.1, n = 52 Spinner 71.4% ± 19.9, n = 14 Bull 7.1% ± 11.3, n = 14 Blacknose 100%, n = 1	Experimental bottom longline; Sharks were caught on standard bottom longline gear; Soak times ranged from 2–18 h ± 95% confidence intervals, calculated using equations outlined by Goodyear (2002). M_D was consistently higher than M_A.
Hook and line					
Bullock et al. (2015)			Lemon shark	0%	Post-release behavior of tagged sharks in net pens and in situ.
Danylchuk et al. (2014)			Lemon shark (majority neonate)	12.5%	Four sharks (12.5%) died following release during the 15 min tracking period following catch-and-release angling. Not clear how sharks were tracked.
French et al. (2015)			Shortfin mako shark	10% (3 – 20%)	Three mortalities (10%) were observed after 30 days at liberty. All mortalities occurred within 24 h of release. Range is 95% confidence interval obtained from the program Release Mortality version 1.1.0 developed by Goodyear (2002) as described by Kerstetter and Graves (2006).
Gurshin and Szedlmayer (2004)*			Atlantic sharpnose shark	10%*	Tagged both injured and healthy animals (n = 10).
Heberer et al. (2010)			Common thresher shark	26%	Five mortalities (26%) were observed over 10 day PSAT deployment.

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Heupel and Simpfendorfer (2002)			Blacktip shark (juvenile)	About 5%	Five of 92 sharks died within 24 hrs. of release; May reflect stress from anesthetic, tagging and resuscitation, as well as hook and line capture.
Holts and Bedford (1993)			Shortfin mako shark	0%	Tagged large healthy sharks (n = 3).
Kneebone et al. (2013)			juvenile sand tigers	Immediate (1%, 5 days), short- (18%, 50 days), and long-term post-release survivorship (25% 100 days)	Post-release monitoring of 65 sharks surgically implanted with acoustic tags demonstrated high degrees of immediate (99%, 5 days), short- (82%, 50 days), and long-term post-release survivorship (75%, 100 days).
Kneebone et al. (2024)	X		Sandbar shark	0.0%	While no PRM was observed in the present study, the authors provide a PRM rate of 5.6% which is the upper limit of the 95% CI.
Mandelman and Farrington (2007a)			Spiny dogfish shark	24 ± 6% (mean ± S.D.)	Five squid-baited standard circle hooks hung in the water-column and retrieved in 3 min; Mandelman and Farrington (2007a) concluded that the MD estimate reflected both the stress of hook and line capture plus the additional stress of being held in a net-pen after capture (72 hrs.).
Sepulveda et al. (2015)			Common thresher shark	78% (with trailing tail hook gear) 0% (with mouth hook and release)	Six mortalities within 5 days and one mortality after 81 days (78%) with trailing tail hook gear. No mouth-hooked mortalities (n=7) within 10 days.
Whitney et al. (2016 and 2017)			Blacktip shark	9.7%	Acceleration data loggers (ADLs, n=31) attached to blacktip sharks captured on rod and reel by recreational fishermen. Mortalities (n=3; 9.7%) all occurred within 2 h after release.
Gillnet					
Bell and Lyle (2016)			Australian swellshark (<i>Cephaloscyllium laticeps</i>)	0%	Tank trial mortality up to 3 days post capture (n = 39 condition 1 and n = 32 condition 2)
Braccini et al. (2012)			Many	43.2% (Based on an assessment of at-vessel condition; n = 122)	The average risk of delayed post-capture survival (PCS) in a southern Australia commercial gillnet shark fishery was estimated based on an assessment of at-vessel condition. For <i>S. zygaena</i> , delayed survival (S_D = 56.8%, n = 122; 89% at-vessel mortality rate) was obtained from Braccini et al. (2012 their Table 2); PRLDM was then calculated as M_D = (1 - S_D) = 43.2%.
Frick et al. (2010a)			<i>Mustelus antarcticus</i>	Average within captive lab study of 31%	The average delayed mortality (MD, up to 72 hr. after treatment) for <i>M. antarcticus</i> captured in gillnets under laboratory conditions (30.7%) was calculated here from gillnet fishing under laboratory conditions for 30 min (MD = 70%), 120 min (MD = 0%), and 180 min (MD = 22%); May not reflect commercial fishery.
Frick (2012)			<i>Mustelus antarcticus</i>	Average within captive lab study of 6.5% (2/31 = 0.065)	The average delayed mortality (MD, up to 72 hr. after treatment) for <i>M. antarcticus</i> captured in gillnets under laboratory conditions was calculated

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					here from simulated gillnet fishing under laboratory conditions for 60 min; May not reflect commercial fishery.
Hueter and Manire (1994)	X	X	Coastal sharks	34.8%	Tag return data was used to estimate delayed mortality for all juvenile and small adult sharks, combined, captured with research gillnets in Florida Gulf Coast estuaries.
Hueter et al. (2006)			Blacktip and bonnethead sharks	31% (blacktip); 40% (bonnethead)	Juvenile and small adult sharks captured with research gillnets in Florida estuaries.
Rulifson (2007)			Spiny dogfish shark	33%	Held in net-pen after capture (48 hrs., North Carolina)
Trawl					
Francis (1989)			<i>Mustelus lenticulatus</i>	NA	Francis (1989) noted that reported recapture rates of trawl-tagged rig, <i>M. lenticulatus</i> , were lower than those of set-net tagged <i>M. lenticulatus</i> , suggesting that delayed mortality of <i>M. lenticulatus</i> was higher in trawls than set-nets.
Frick et al. (2010b)			<i>Mustelus antarcticus</i>	Average within captive lab study of 27%	The average delayed mortality (MD, up to 72 hr. after treatment) for <i>M. antarcticus</i> captured in trawl-nets under laboratory conditions (26.9%) was calculated here from simulated trawl-net fishing under laboratory conditions for 30 min (MD = 37.5%), 60 min (MD = 0.0%), 120 min (MD = 85.7%), 60 min + air (MD = 0.0%), and 60 min + crowding (MD = 11.1%); May not reflect commercial fishery.
Mandelman and Farrington (2007a)			Spiny dogfish shark	29 ± 12% (mean ± SD)	Mandelman and Farrington (2007a) concluded that post-release mortality was significantly affected by the weight of the trawl catch and also likely reflected both the stress of trawl capture plus the additional stress of being held in a net-pen after capture (72 hrs.).
Rulifson (2007)			Spiny dogfish shark	0%	Held in net-pen after capture (48 hrs.); Rulifson (2007) noted that the research trawl used in this study were probably not comparable to commercial trawls – especially large New England trawl gear.
Purse seine					
Eddy et al. (2016)			Scalloped hammerhead	100% (PSAT, n = 3)	At-vessel mortality and post-release survival of pelagic sharks captured with tuna purse seines in the equatorial Eastern Pacific Ocean associated drifting fish aggregating devices (FADs)
			Silky shark	62% (PSAT, n = 13)	Three scalloped hammerhead (100%) showed evidence of post-release mortality. Eight silky sharks (62%) showed evidence of post-release mortality.

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Hutchinson et al. (2015)			Silky shark	36%	Percentage of satellite tagged sharks that died after being released alive (tag deployment ≥ 10 d, n = 9) and those that died post release (0–9 d, n = 5). However, total mortality (at-vessel plus live post release) was much higher (84.2%).
Poisson et al. (2014)			Silky shark	48% (brailed) 0% (entangled)	Percentage of satellite tagged sharks that died after being released alive. However, total mortality (at-vessel plus live post release) was much higher (81%).
Reviews					
Dapp et al. (2016c)			Many	Table S2. Contains published results of at-vessel capture mortality studies on elasmobranchs. Table S3. Contains published results of post-release and total discard mortality studies on elasmobranchs.	Model predicted mean total discard mortality as combined immediate and post-release mortality to obtain percentages of obligate ram-ventilating elasmobranchs caught in longline, gillnet and trawl gear types as 49.8, 79.0 and 84.2%, respectively, and total discard mortality percentages of stationary-respiring species as 7.2, 25.3, and 41.9%, respectively.
Ellis et al. (2017)	X	X	Many	e.g., Sandbar Longline PRLDM 20% Marshall et al. (2015)	Review published results of PRLDM and at-vessel-mortality
Oliver et al. (2015)			Many		Develop global shark bycatch estimates from a literature review of shark bycatch and estimates of post-release mortality
Poisson et al. (2016)			Many		Review shark bycatch mitigation measures in pelagic tuna fisheries
Meta-analyses					
Musyl and Gilman (2019)			Pelagic sharks	87.5% (26.6% LCI, 99.3% UCI) One study (Eddy et al (2016, Purse-seine): Dead=3, Tagged = 3. 26.8% (19.3% LCI, 36.0% UCI) 33 studies (longline, purse-seine, rod & reel): Dead=95, Tagged = 401	Random-effects meta-analysis synthesized M_D in seven pelagic shark species captured, tagged and released with 401 pop-up satellite archival tags compiled from 33 studies and three gears (longline, purse-seine, rod & reel).

* Previous SEDAR AP panels considered the delayed discard mortality rate estimates, M_D , provided by Campana et al. (2009b) and by Gurshin and Szedlmayer (2004) to be the best available estimates for post-release live-discard mortality, PRLDM, in pelagic longlines and hook and line, respectively, because both studies included injured as well as healthy animals (NMFS 2012, 2013a, 2013b).

Table A.3. Summary of immediate (i.e. at-vessel or acute) discard-mortality rates (M_A) by gear type obtained from the literature search (Table A.1).

Gear/Source	Sandbar sharks (<i>Carcharhinus plumbeus</i>)	Dusky sharks (<i>Carcharhinus obscurus</i>)	Immediate (i.e. at-vessel or acute) discard-mortality rates (M_A)	Notes
Longline (pelagic)				
Beerkircher et al. (2002)	X	X	Sandbar shark 26.8 % dusky shark 48.7%	Catch status (condition of animal when brought alongside the vessel) was used for at-vessel mortality estimates.
Bromhead et al. (2012)	X		Sandbar shark 0%	Identified environmental and fishing method factors that influence shark catch rates. Sharks judged as dead or unlikely to survive after release were grouped as Per cent dead (AVM).
Dapp et al. (2016b)	X	X	Sandbar shark 2% dusky shark 12%	Summarized the number of sharks discarded dead by the U.S pelagic longline fleet from 1992-2008.
Gallagher et al. (2014a)	X	X	Sandbar shark 26.7% dusky shark 27.9%	Investigates the effects on shark bycatch survival in the pelagic longline fishery.
Gilman et al. (2016)	X		Sandbar shark 50%	Authors recognize that the 2003 ban on shark retention influenced the decline in shark fishing mortality in this study conducted from 1999-2011.
Grosse et al. (2023)	X		Sandbar Shark 0%	Of 57 individuals tagged with PSAT tags, scientific demersal longline surveys, there was a post-release survival rate of 100% after a maximum of 4 h on the hook
Megalofonou et al. (2005)	X		Sandbar Shark 0%	Documented bycatch from 1998-2000 in the swordfish and tuna fisheries. Only 2 sandbar sharks were observed, both in fair condition.
Sulikowski et al. (2020)		X	dusky shark 0%	Utilize PSAT tags to estimate AVM. AVM was defined as a shark dead upon capture. The current study presents the lowest rates of AVM to date.
Longline (demersal)				
Braccini and Waltrick et al. (2019)	X	X	Sandbar shark 5% dusky shark 1.3%	The present study found that species was the most reliable predictor of at-vessel mortality.
Butcher et al. (2015)	X	X	Sandbar shark 43% (7hr) 62.7% (14hr) dusky shark 53.3% (7hr) 79.5% (14hr)	Experimental fishing with hook tiers (7hr and 14hr). Morality rate was adapted from described survival rate. Morality rate was higher for animals caught during the 14hr deployment than the 7hr deployment.

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Gulak et al. (2015)	X	X	Sandbar shark 16.9% Dusky shark 70.2%	Experimental fishing employing hook-timers and temperature-depth recorders to assess the influence of environmental factors on at vessel mortality.
Hale et al. (2010)	X	X	Sandbar shark (0%), (5.8%), (14.3%) , (0%) dusky shark (0%), (54.3%), (100%)	At-vessel mortality rates for sandbar sharks were 0%, 5.8%, 14.3%, and 0% in the observed hauls targeting reef fish, sandbar sharks, large coastal sharks, and mixed species in the Gulf of Mexico respectively. At-vessel mortality rates for dusky sharks were 0%, 54.3%, and 100% for the observed hauls targeting reef fish, sandbar sharks, and mixed species in the Gulf of Mexico respectively.
Marshall et al. (2015)	X	X	Sandbar shark 5% dusky shark 22%	Shorter soak times may have contributed to smaller rates of at-vessel mortality than previously published. Mortality for Dusky sharks increased after 3hr hook time, while sandbar sharks had good survival up until 11hr soak time.
Morgan and Burgess (2007)	X	X	Sandbar shark 36.1% dusky shark 81.1%	It was found that soak time and age group explained 44% of variation in mortality for sandbar sharks. Soak time was found to have a positive relationship with mortality.
Morgan and Carlson (2010)	X		Sandbar shark 21%	Mortality rates increased after 10 hour soak time.
Morgan et al. (2009)	X	X	Sandbar shark 33% dusky shark 60.8%	Mortality rates increased with soak time. AVM rates for sandbar sharks increased from 6.5% with 0-4hr soak time to 51.3% with 20-24hr soak time. There was no explicit at-vessel mortality or at-vessel survival rate for sharks so the percentage presented herein is adapted from table 9.
Scott-Denton et al. (2011)	X		Sandbar shark 3.4%	The study estimated mortality levels from observer logbook data.
Whitney et al. (2021)	X		Sandbar shark 0.5%	The single at-vessel mortality rate for sandbar sharks occurred after 12 hours on the hook. Though it is to mention that other sandbar sharks with similar hook times were landed alive.
Hook and line				
NA				
Gillnet				
NA				
Trawl				
Fennessy (2994)	X	X	Sandbar shark 33.3% dusky shark 12.5%	Mortality data was only collected in August of 1990 for a total of 100 trawls. Mortality rates were determined from the catches of 6 sandbar sharks and 8 dusky sharks.
Purse seine				
N/A				
Reviews				
Ellis et al. (2017)	X	X	E.g., Sandbar longline AVM 16.9% adapted from Gulak et al. (2015)	Review published results of PRLDM and at-vessel-mortality
Meta-analyses				
NA				

Table A.4. Ellis et al. (2017)* at vessel mortality (AVM %; Panel A) and post-release mortality (PRM%; Panel B) fishery and species (adapted from Ellis et al. 2017, their Table 2).

*Ellis et al. (2017): “CARCHARHINIFORMES: FAMILY CARCHARHINIDAE Those members of this family that occur in northern European seas are generally pelagic, although there are several more demersal species in sub-tropical and tropical waters. Overall, survival appears to be highly variable across this family (Table II). On one extreme, tiger shark *Galeocerdo cuvier* (Péron & LeSueur 1822) is one of the more robust carcharhinid sharks and multiple studies have indicated AVM of <10% following capture by longline (Beerkircher *et al.*, 2004; Morgan & Burgess, 2007; Coelho *et al.*, 2012; Gallagher *et al.*, 2014a; Butcher *et al.*, 2015; Gulak *et al.*, 2015), with high post-release survival also reported (Afonso & Hazin, 2014; Gallagher *et al.*, 2014b). Similarly, *P. glauca*, which is a frequent by-catch of pelagic longline fisheries and one of the most studied pelagic sharks, typically exhibits an AVM of <25% (Boggs, 1992; Beerkircher *et al.*, 2004; Megalofonou *et al.*, 2005; Moyes *et al.*, 2006; Campana *et al.*, 2009a, b, 2011, 2016; Coelho *et al.*, 2011, 2012; Musyl *et al.*, 2011; Bromhead *et al.*, 2012; Epperly *et al.*, 2012; Serafy *et al.*, 2012; Gallagher *et al.*, 2014a; Gilman *et al.*, 2015). There is, however, some post-release mortality (Campana *et al.*, 2016) and some other field studies (Poisson *et al.*, 2010; Afonso *et al.*, 2012) have reported a higher AVM (30–50%). Several studies have reported AVM of 15–35% AVM for *C. longimanus* taken in longline fisheries (Boggs, 1992; Beerkircher *et al.*, 2004; Bromhead *et al.*, 2012; Coelho *et al.*, 2012; Gallagher *et al.*, 2014a; Fernandez-Carvalho *et al.*, 2015), with those studies reporting either a higher or lower AVM (Poisson *et al.*, 2010; Musyl *et al.*, 2011; Afonso *et al.*, 2012) being based on more limited sample sizes. In contrast to the above, other carcharhinids may be more prone to die during capture. Several studies have reported that night shark *Carcharhinus signatus* (Poey 1868) and *C. falciformis* exhibit higher AVM in relation to other members of the family taken in the same studies, ranging from 67 to 81% in the former and typically 42 to 75% in the latter (Beerkircher *et al.*, 2004; Coelho *et al.*, 2011, 2012; Serafy *et al.*, 2012; Gallagher *et al.*, 2014a). Interestingly, two studies have reported AVM of *C. falciformis* when caught by longline to be <30% (Musyl *et al.*, 2011; Gilman *et al.*, 2015). *Carcharhinus falciformis* is also by-catch in purse-seine fisheries, where AVM and PRM can result in >80% total mortality (Poisson *et al.*, 2014a; Hutchinson *et al.*, 2015; Eddy *et al.*, 2016). Most studies on members of this family have explored survival following capture by longline fisheries, with far fewer studies examining the effects of other gears. Fennessy (1994) examined the survival of several species caught in a prawn trawl fishery and, of those species taken in meaningful numbers, AVM ranged from 29% [*Rhizoprionodon acutus* (Rüppell 1837)] to 56% [*Carcharhinus brevipinna* (Müller & Henle 1839)]. The various carcharhinids taken in a prawn trawl fishery in Australian waters exhibited 52–82% AVM (Stobutzki *et al.*, 2002). Capture in scientific gillnets (soak times ≤1 h) can result in AVM of 18–40% (Manire *et al.*, 2001; Hueter *et al.*, 2006). In relation to commercial gillnet fisheries, whilst some carcharhinids may be more robust [e.g. 36% AVM was reported for copper shark *Carcharhinus brachyurus* (Günther 1870) by Braccini *et al.* (2012)], higher AVM has been reported in other studies: 80·4–90·5% for three carcharhinid species (Thorpe & Frierson, 2009), with 61–77% of two species of carcharhinid recovered dead from protective nets (Reid & Krogh, 1992).”

A.

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
Trawl						
Indian Ocean; Natal (Fennessy, 1994) Commercial prawn trawl (otter trawl, 38mm stretched mesh codend, 3·7–5·6 kmh–1 trawl speed; fishing depths of 20–45m)	AVM		Carcharhinidae	<i>Carcharhinus obscurus</i> (n=8) <i>Carcharhinus plumbeus</i> (n=6)	(12.5) (33.3)	
Longline						
Mediterranean Sea (Megalofonou <i>et al.</i> , 2005) Commercial longlines targeting swordfish, albacore or blue-fin tuna. Limited data for commercial driftnet	AVM	Vitality and AVM recorded (1=good; 2=fair; 3=poor; 4=dead or no response to stimuli)	Carcharhinidae	<i>Carcharhinus plumbeus</i> (n=2)	(0)	
NW Atlantic Ocean; south-eastern coast of the U.S.A. (Beerkircher <i>et al.</i> , 2004) Pelagic longline fishery (hooks of 7/0 to 11/0; hook depths usually 35–60m)	AVM	Condition of captured sharks recorded by observers	Carcharhinidae	<i>Carcharhinus obscurus</i> (n=679) <i>Carcharhinus plumbeus</i> (n=112)	48.7 26.8	
NW Atlantic Ocean; Gulf of Mexico (Morgan & Burgess, 2007) Commercial longline fisheries with observer coverage	AVM	AVM assessed visually (alive–dead)	Carcharhinidae	<i>Carcharhinus obscurus</i> (n=662) <i>Carcharhinus plumbeus</i> (n=8583)	81 36	
NW Atlantic Ocean; Gulf of Mexico (Morgan & Carlson, 2010) Research longline fishing from commercial vessels, soak times ranging from 4 to 6 h (day) and 6 to 10 h (night), 18/0 circle hooks	AVM	AVM assessed visually (alive–dead). Hook timers used to assess the time each shark had been hooked	Carcharhinidae	<i>Carcharhinus plumbeus</i>	21	Mortality generally increased with time the shark was hooked. In the case of <i>C. plumbeus</i> , larger individuals typically had a higher mortality case of <i>C. plumbeus</i> , larger individuals typically had a higher mortality

Table A.4. Continued (adapted from Ellis et al. 2017, their Table 2).
A. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
Gillnet and Tangle net						
Australia; New South Wales (Reid & Krogh, 1992) Protective nets set off beaches. Soak times generally 12–48 h	AVM	Information on the percentage alive recorded, but no specific information in relation to soak time	Carcharhinidae	<i>Carcharhinus</i> spp. (n=724)	61	
Longline						
SW Atlantic Ocean; Brazil (Afonso et al., 2011) Research longline (pelagic) with 18/0 circle hooks and 9/0 J-hooks	AVM	Catch rates and AVM compared between hook types	Carcharhinidae	<i>Carcharhinus obscurus</i> (n=10)	(28.5)–(100)	Lower AVM reported for circle hooks (28.5%) than J-hooks (100%)
Gulf of Mexico (Scott-Denton et al., 2011) Bottom longline fishery for reef fish. Average fishing depth=94 m. Most hooks were 13/0 but ranged from 12/0 to 15/0. Mean soak time was 5.1 h (range=0.9–32.2h)	AVM	Condition and fate recorded by observers, (but data lacking for some specimens and estimates of AVM are given here)	Carcharhinidae	<i>Carcharhinus plumbeus</i> (n=59)	3.4	
Pacific Ocean (Bromhead et al., 2012) Commercial longline fishery	AVM	VM recorded from observer coverage	Carcharhinidae	<i>Carcharhinus plumbeus</i> (n=1)	(0)	
NW Atlantic Ocean (Gallagher et al., 2014a) Pelagic longline (targeting tuna or swordfish)	AVM	AVM data collected by observers (1995–2012). Data used for fish classed as alive and dead (those reported as damaged were excluded from analysis). Mean survival given for tuna and swordfish longline fisheries	Carcharhinidae	<i>Carcharhinus obscurus</i> (n=274) <i>Carcharhinus plumbeus</i> (n=189)	27.9 26.7	
Australia; New South Wales (Butcher et al., 2015) Demersal longline with nylon trace and 16/0 non-offset circle hook (water depths 50–100 m; 7–14 h soak times; hook timers used)	AVM and blood sampling	Survival and condition examined in relation to hooking time. Blood samples also collected	Carcharhinidae	<i>Carcharhinus obscurus</i> (n=74) <i>Carcharhinus plumbeus</i> (n=160)	53.3–79.5 43–62.7	
Pacific Ocean; Palau (Gilman et al., 2015) Pelagic longline fishery for tuna	AVM	AVM data collected by observers	Carcharhinidae	<i>Carcharhinus plumbeus</i> (n=6)	(50)	
NE Atlantic Ocean and Gulf of Mexico; North Carolina to Louisiana (Gulak et al., 2015) Bottom longlines deployed from chartered fishing vessels (soak times of 1.5–22.6 h; 16/0, 18/0, 20/0 circle hooks and 12/0 J hooks)	AVM	AVM data recorded; hook timers deployed	Carcharhinidae	<i>Carcharhinus obscurus</i> (n=104) <i>Carcharhinus plumbeus</i> (n=933)	70.2 16.9	

Table A.4. Continued (adapted from Ellis et al. 2017, their Table 2).

A. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
Longline						
NW Atlantic Ocean (Marshall <i>et al.</i> , 2015) Demersal longline deployed from research vessel (18/0 circle hooks with 10° offset; soak times of 0.5–12.5 h)	AVM	AVM data recorded (alive, dead, moribund). PSATs deployed to estimate PRM	Carcharhinidae	<i>Carcharhinus obscurus</i> (n=50) <i>Carcharhinus plumbeus</i> (n=119)	22 5	A further 18% of specimens were moribund. PRM estimated at 28.6% from PSAT data (n=21) A further 2% of specimens were moribund. PRM estimated at 20% from PSAT data (n=10)
Purse seine fisheries						
NW Atlantic Ocean: Gulf of Mexico (De Silva <i>et al.</i> , 2001) Commercial purse seine targeting gulf menhaden <i>Brevoortia patronus</i>	Vitality	Observers recorded fate of sharks (caught and released; caught and retained; gilled; kept by crew; released but disorientated; released in a healthy state; discarded dead)	Carcharhinidae	Not all identified to species level. Main species encountered were <i>Carcharhinus limbatus</i> , <i>C. brevipinna</i> , <i>C. obscurus</i> , <i>C. leucas</i> , <i>C. falciformis</i> , <i>C. plumbeus</i> , <i>C. isodon</i> , <i>C. acronotus</i> and <i>Rhizoprionodon terraenovae</i> (Carcharhinidae)	-	Most fish were dead and either discarded (n=50) or retained on board (n=24). Some live fish were released in either a disorientated (n=12) or healthy (n=8) condition. Fate of six unknown

Table A.4. Continued (adapted from Ellis et al. 2017, their Table 2).

B.

Fishery	Approach	Details	Family	Species	PRM (%)	Key findings
Longline						
NW Atlantic Ocean (Marshall <i>et al.</i> , 2015) Demersal longline deployed from research vessel (18/0 circle hooks with 10° offset; soak times of 0.5–12.5 h)	PRM	AVM data recorded (alive, dead, moribund). PSATs deployed to estimate PRM	Carcharhinidae	<i>Carcharhinus obscurus</i> (n=21) <i>Carcharhinus plumbeus</i> (n=10)	28.6 20	A further 18% of specimens were moribund. PRM estimated at 28.6% from PSAT data (n=21) A further 2% of specimens were moribund. PRM estimated at 20% from PSAT data (n=10)

Appendix B. Post-release live-discard mortality (PRLDM) rate decisions from the recent SEDAR 65 Atlantic blacktip domestic shark stock assessment.

Table B.1. SEDAR 65 Atlantic blacktip shark post-release live-discard mortality (PRLDM) rate decisions.

SEDAR 65 ¹				
Atlantic blacktip shark				
Working group	Longline	Hook and line	Gillnet	Trawl
DW*	44.2% (Base, Bottom longline)	18.5%(Base)	31% (Base)	NA
	34.0–54.8%(Range)	10.8–28.7%(Range)	8.7–44.4% (Range)	NA

*Final decisions adopted for stock assessment.

¹ SEDAR 65 data workshop (DW) decisions adopted by NMFS (2020)

Gillnet post-release live discard mortality (NMFS 2020, their Section II pp 24-26):

“Previous SEDAR panels (SEDAR29) adopted 31% as the best estimate of the post-release live-discard mortality rate for Gulf of Mexico blacktip sharks captured in gillnet fisheries (SEDAR65-DW20, their Table 4) obtained from juvenile blacktip sharks captured with research gillnets (Hueter *et al.* 2006). The same approach was adopted by the Panel here. In addition, 95% CIs for gillnet fisheries were calculated by the Panel using methods and data available in Hueter *et al.* (2006). Release and recapture data for blacktip sharks captured in research gillnets and summarized by their condition at release was obtained from Hueter *et al.* (2006, their Table 3):

Condition	Tagged	Recaptured	Ratio
1	928	58	0.0625
2	939	39	0.0415
3	666	24	0.0360
4	365	4	0.0110

The relative survival (β) of tagged blacktip sharks released in conditions 2–4 was estimated relative to that of blacktip sharks released in condition 1 as the ratio of recapture rates using equation (10) in Hueter *et al.* (2006); lower and upper 95% CIs were obtained using equation (11) in Hueter *et al.* (2006) adapted from Hueter *et al.* (2006, their Table 4):

	β	LCI	UCI
Ratio of ratios (condition 2: condition 1)	0.6645	0.4474	0.9870
Ratio of ratios (condition 3: condition 1)	0.5766	0.3621	0.9181
Ratio of ratios (condition 4: condition 1)	0.1753	0.0641	0.4795

Hueter *et al.* (2006) obtained estimates of absolute post-release mortality by assuming all sharks in condition 1 survived the catch–tag–release event. Using this approach 31% (898 of 2,898) of blacktip sharks released from gillnets are estimated to have died (adapted from Hueter *et al.* (2006, their Table 5):

Condition	Number tagged	Survival rate	Death rate	Number dying	Percent dying (PRLDM)
1	928	1	0	0	
2	939	0.66	0.34	319.26	
3	666	0.58	0.42	279.72	
4	365	0.18	0.82	299.30	
Total	2898			898.28	31%

Lower and upper 95% CIs (alpha = 0.05) for cryptic post-release mortality of blacktip sharks released from gill nets were calculated by the Panel using the same approach (Adapted from Hueter *et al.* 2006, their Tables 4, and 5):

Condition	Number tagged	Survival rate LCI	Death rate UCI	Number dying UCI	Percent dying UCI (PRLDM)
1	928	1	0	0	
2	939	0.45	0.55	516.45	
3	666	0.36	0.64	426.24	
4	365	0.06	0.94	343.1	
Total	2898			1285.79	44.4%

Condition	Number tagged	Survival rate UCI	Death rate LCI	Number dying LCI	Percent dying LCI (PRLDM)
1	928	1	0	0	
2	939	0.99	0.01	9.39	
3	666	0.92	0.08	53.28	
4	365	0.48	0.52	189.80	
Total	2898			252.47	8.7%

Because all sharks in condition 1 are assumed to survive (death rate =0), this approach may underestimate the total post-release mortality. Similarly, a previous literature review developed for Gulf of Mexico blacktip sharks during SEDAR 29 (Courtney 2012) suggested that the best estimate of the post-release live-discard mortality rate of blacktip sharks captured in gillnets, 31%, obtained from juvenile blacktip sharks captured with research gillnets Hueter *et al.* (2006), may need to be adjusted upward to reflect the relative difference in the at-vessel gillnet mortality rate observed for juvenile blacktips captured with research gillnets (38%) (Hueter and Manire, 1994) relative to that of sub-adult blacktips captured in scientifically monitored commercial gillnets (90%) (Thorpe and Frierson, 2009). However, the Panel discussed that the new approach developed here to calculate 95% CIs was the preferred approach for developing the range of uncertainty for blacktip shark post-release mortality in gillnet fisheries because it was based on data available from the original publication, which resulted in a relatively wide range of uncertainty.”

Bottom longline post-release live discard mortality (NMFS 2020, their Section II pp 26-27):

“A new estimate of acute post-release mortality rates for coastal sharks caught in the Florida commercial shark demersal longline fishery, $44.2\% \pm 8.3\%$ ($\pm 95\%$ CI), was presented and discussed by the Panel for use in SEDAR 65 demersal longline fisheries (SEDAR65-RD06). The estimate was based on a large sample size ($N = 95$) of physically recovered acceleration data loggers (ADLs) released on blacktip sharks captured near Madeira Beach, FL, and Key West, FL. At both study sites, specific fishing locations and practices were directed by commercial longline captains to ensure methods were consistent with typical commercial fishing practices. Post-release mortality rates were calculated as the percentage of blacktip sharks that died post-release out of the number of tags recovered. Mortality was identified from recovered tag data as a lack of movement and a constant depth, assumed to be associated with a negatively buoyant shark on the bottom. Accelerometer deployments, all shark species tagged in the study, lasted between 0.7 and 205 h (mean 20.9 ± 18.7 h). Ninety one % of mortalities, all tagged sharks in the study, occurred within 5 h of release, and all mortalities occurred within 12 h of release.

The 95% confidence interval obtained for post-release mortality estimates in demersal longlines (SEDAR65-RD06) was based on methods in Goodyear (2002) which was not available for the Panel to review. Consequently, the Panel re-calculated 95% CIs for demersal longlines during the meeting using a binomial distribution with 95 releases and 42 mortalities, and obtained a slightly wider range of uncertainty (34.0 % to 54.8%). The binomial 95% CI calculations were later verified in R version 3.3.2 (R Development Core Team, 2016) using the library “binom” (Dorai-Raj 2014): `binom.confint(x = 42, n = 95, method = "exact").`”

Recreational post-release live discard mortality (NMFS 2020, their Section II pp 29-30):

“Based on document SEDAR65-DW-18, a post-release mortality rate of 18.5% was proposed (average of 17.1% for shore-based fishing and 20.0% for charter boats). This more recent rate was considered to have improved previous research and was therefore adopted. The need to provide estimates of uncertainty for these estimates was also noted and a proposal to use a binomial distribution to generate them presented and approved.

Post release mortality (PRM) rates were estimated for blacktip sharks captured and released alive on rod-and-reel by shore-based ($n = 41$) and charter boat-based ($n=40$) fishermen using acoustic transmitters (total $n = 81$). Blacktip sharks were caught with rod-and-reel by participating recreational anglers from the shore (i.e. beach) and onboard charter fishing boats in the coastal waters of South Carolina and Florida. All fishing from charter boats was conducted by the clients who hired the charter, and thus a wide range of angler experience was sampled. Anglers used their personal fishing equipment, which varied in size and strength, and no input was provided by the authors on the fishing equipment (e.g. rod and reel type/size, hook type/size) or capture techniques. Survivorship was assessed by passively monitoring sharks following release and examining movements of sharks among fixed acoustic receivers deployed along the eastern coast of the U.S. as part of both the Atlantic Cooperative Telemetry (ACT) and the Florida Atlantic Coast Telemetry (FACT) Networks. Sharks that were detected multiple times by an acoustic receiver more than 10 days post-release were considered to have survived the capture event (and any associated tag ingestion during predation events, typically regurgitated within around 5 days of ingestion). Additionally, a subset of acoustically tagged individuals from shore-based ($n = 12$) and charter boat-based ($n = 12$) fishing were double-tagged with pop-off satellite archival tags (PSATs, total $n = 24$) to validate the survivorship results obtained from the acoustic transmitters. The survivorship results inferred from acoustic transmitters were consistent with results inferred from PSATs, Fifteen sharks ($n = 7$ shore-based; $n = 8$ charter boat-based) died within 10 days of being released by recreational anglers, resulting in post-release mortality rates of 17.1% (shore-based) and 20.0% (charter boat-based).

The Panel calculated 95% CIs for the recreational fishery during the meeting using a binomial distribution with 81 releases and 15 mortalities, and obtained a PRM rate for recreational fisheries of 18.5 and a range of uncertainty

from 10.8 % to 28.7%. The binomial 95% CI calculations were later verified in R version 3.3.2 (R Development Core Team, 2016) using the library “binom” (Dorai-Raj 2014): `binom.confint(x = 15, n = 81, method = "exact")`.

The new estimate of post-release mortality obtained for blacktip sharks captured in recreational fisheries in the coastal waters of South Carolina and Florida is consistent with an updated estimate from the Gulf of Mexico recreational fisheries where 22 tags with conclusive data resulted in 5 mortalities and a PRM estimate of 22.7% with a 95% binomial CI of 7.8-45.4% (pers. comm. John Mohan; also see SEDAR65-RD04, their Appendix B).

...

Using the new estimate of post-release mortality of 18.5% resulted in almost a doubling (90% increase) of animals released alive assumed to have died compared to the numbers obtained using the previous estimate of 9.7%. In absolute terms, this translated to an increase from 991,810 mortalities to 1,891,596 mortalities during the entire time series (1981-2018).”

References

- Dorai-Raj, S. 2014. binom: Binomial confidence intervals for several parameterizations. R package version 1.1-1. <https://CRAN.R-project.org/package=binom>.
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