An Updated Literature Review of Post-Release Live-Discard Mortality Rate Estimates in Sharks for use in SEDAR 77

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An Updated Literature Review of Post-Release Live-Discard Mortality Rate Estimates in Sharks for use in SEDAR 77

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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 hammerhead sharks (Sphyrnidae). 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 and Mathers 2019; 91 existing records and 20 new records) was searched for hammerhead sharks (Sphyrnidae): Scalloped Hammerhead (*Sphyrna lewini*), Great Hammerhead (*Sphyrna mokarran*), Smooth Hammerhead (*Sphyrna zygaena*), and Carolina Hammerhead (*Sphyrna gilberti*). Some PRLDM rates identified for Bonnethead (*Sphyrna tiburo*) were also identified and summarized.

There were few direct estimates of delayed discard-mortality rates (M_D) available for hammerhead sharks. Consequently, indirect estimates of M_D obtained from meta-analysis were also reviewed and summarized for comparison with direct M_D estimates available for hammerhead sharks.

Hammerheads appear to be vulnerable to the effects of capture in commercial gears (e.g., Gallagher et al 2014a; Ellis et al 2017). Consequently, selected immediate (i.e. at-vessel or acute) discard-mortality rates (M_A) were also reviewed and summarized for comparison direct M_D estimates available for hammerhead sharks.

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

(1) Total discard mortality rate = (Dead-discard rate) + (PRLDM) * (Live-discard rate).

The same approach was used here. However, in order to be consistent with more recent literature, as described below, the following definitions were also used interchangeably with equation (1): MT = MA + MD *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 hammerhead 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, 2014, and 2018).

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Table 1. Delayed discard-mortality rate, M_D, estimates obtained for hammerhead sharks from the literature review.

Gear/Source	Hammer-head(s)	Scientific name	Delayed discard mortality rate (M_D)	Notes
Longline (pelagic)				
NA (see Meta-analysis)				
Longline (demersal)				
Drymon and Wells (2017)	Great hammerhead	*Sphyrna mokarran*	0% (Satellite tag; n = 3) 187-250 cm STL	The percentage of double tagged sharks reporting. Mean number of days at liberty measured by the sPAT tags was 24 days (ranging from 20 to 30 days). 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 tag failure from animal mortality. Tagged great hammerheads were deemed to be in good condition (i.e., active and responsive, little or no visible external damage).
Gallagher et al. (2014b)	Great hammerhead	*Sphyrna mokarran*	46.4% (Satellite tag; n = 28) 101-345 cm TL; 289.8 ± 30.6 (mean ± SD)	Percentage of satellite tagged sharks reporting after four weeks (53.6%, n = 28). Fishery independent baited drumline (n = 10) soaked for at least one hour. All satellite-tagged animals swam away in good condition (strong tail beat and swimming behavior).
Hook and line				
NA (see Meta-analysis)				
Gillnet				
Braccini et al. (2012)	Smooth hammerhead	*Sphyrna zygaena*	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 *S. zygaena*, 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%.
Hueter et al. (2006)	Bonnethead	*Sphyrna tiburo*	40% (30%LCI, 55% UCI) Estimate based on relative numerical tag and recapture events assuming that sharks in the best condition survived to the same degree as sharks that were not captured	Juvenile and small adult sharks captured with research gillnets in Florida estuaries. For S. tiburo, delayed survival (M_D = 40%) from the stress of gill-net capture, tagging, and release was obtained from Hueter et al. (2006; n tagged = 4,352, n recovered = 155). The 95% LCI and UCI were calculated in MS Excel following Hueter et al 2006, their equations 10 and 11, with data provided in their tables 3 and 4.

Trawl				
NA				
Purse seine				
Eddy et al. (2016)	Scalloped hammerhead	*Sphyrna lewini*	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) Three scalloped hammerhead (100%) showed evidence of post-release mortality.
Reviews				
NA				
Meta-analyses				
Dapp et al. (2016c)	Elasmobranchs	(Obligate ram-ventilators)	Gillnet (35.9%) Longline (19.51%) Trawl – Scenario 1 (22.12 %) Trawl – Scenario 2 (54.42%) Trawl – Scenario 3 (58.02%)	Predicted mean total discard mortality (TDM) obtained from immediate mortality (IM; 83 species) and post-release mortality (PM; 40 species) of obligate ram-ventilating elasmobranchs caught in longline, gillnet and trawl gear types using Bayesian models (immediate mortality), non-parametric tests (gillnet post-release mortality), arithmetic average (longline post-release mortality) and three approximation scenarios (trawl post-release mortality). Studies limited to N ≥ 15.
Musyl and Gilman (2019)	Scalloped hammerhead Pelagic sharks	*Sphyrna lewini*	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). See Table X for breakdown by species

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)×(1-PM/100)]×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
*Final decisions adopted for stock assessment.				

Table 4. Continued.
Footnotes:
[1]SEDAR 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); [2]SEDAR 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); [3]SEDAR 34 assessment process (AP) decisions adopted by NMFS (2013a, 2013b their sections 2.2.2.3 and 2.2.2.4); [4]SEDAR 29 update assessment process (AP) decisions adopted by NMFS (2018); [5]SEDAR 65 data workshop (DW) decisions adopted by NMFS (2020)

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

Table A.1. Summary of literature reviewed for post-release live-discard mortality (PRLDM) rate estimates in sharks.

Primary Literature	Species		Gear type					Study type				Notes
	Hammer-head(s)	Other	Pelagic longline	Demersal longline	Hook and Line	Gillnet	Trawl	Physi-ological or behavioral	Electronic tagging	Lab.	Other	
<u>Longline (pelagic)</u>												
Afonso et al. (2011)	X	Pelagic sharks	X								Experimental pelagic longline sets	At-vessel mortality
Afonso et al. (2012)	X	Pelagic sharks	X								Experimental pelagic longline sets	At-vessel mortality
Beerkircher et al. (2004)	X	Pelagic sharks	X								Commercial fisheries	Catch disposition
Bromhead et al. (2012)	X	Pelagic sharks - Tropical Pacific	X								Commercial fisheries research	At-vessel mortality
Campana et al. (2016)		Blue, porbeagle, shortfin mako	X						X		Observer data	At-vessel mortality and PRLDM
Campana et al. (2009a, 2009b)		Blue	X						X			PRLDM
Coelho et al. (2011)	X	Pelagic sharks - Atlantic and Indian Ocean	X								Observer data	At-vessel mortality
Coelho et al. (2012)	X	Pelagic sharks - Atlantic	X								Observer data	At-vessel mortality
Coelho et al. (2013)		Blue	X								Observer data	At-vessel mortality rate models GLM and GEE
Dapp et al. (2016a)		Bonze whaler	X	X				X			Research longline	At-vessel mortality
Dapp et al. (2016b)		Blue, tiger, oceanic whitetip, and porbeagle	X								Commercial logbook	At-vessel mortality
Diaz (2011)		Many	X								Observer data	At-vessel mortality
Fernandez-	X	Many	X								Experimental	At-vessel

Carvalho, J., et al. (2015)							pelagic longline sets	mortality
Gallagher et al. (2014a)		Pelagic sharks - Atlantic	X				Observer data	At-vessel mortality - logistic regression integrated with reproductive potential
Moyes et al. (2006)	X	Blue	X		X	X		PRLDM
Musyl et al. (2009)		Blue	X		X	X		PRLDM
Musyl et al. (2011)		Blue, mako, others	X			X	Meta-analysis	PRLDM
Serafy et al. (2012)		Blue, silky	X				Observer data	At-vessel mortality - logistic regression, comparing circle and j-hook
<u>Longline (demersal)</u>								
Afonso and Hazin (2014)		Tiger		X		X		PRLDM
Brooks et al. (2015)		Deep-water elasmobranch assemblage - Bahamas		X		X	Research longline	At-vessel mortality and PRLDM
Butcher et al. (2015)	X	Coastal sharks		X	X		Commercial fisheries research	At-vessel mortality, stress response
Drymon and Wells (2017)	X			X		X	Research longline	PRLDM
Gallagher et al. (2014b)	X	Coastal sharks		X	X	X	Drum-line	PRLDM, stress response
Gallagher et al. (2017)	X	Blacktip, nurse, tiger, and great hammerhead		X	X	X	Drum-line	Behavioral response to capture measured with accelerometers attached to the fishing gear
Gulak et al. (2015)	X	Coastal sharks		X			Commercial fisheries research	At-vessel mortality
Marshall et al.		Dusky,		X		X	Commercial	At-vessel

(2015)		sandbar						fisheries research	mortality, PRLDM
Morgan and Burges (2007)	X	Coastal sharks	X					Observer data	At-vessel mortality
Morgan and Carlson (2010)		Many	X					Research/ commercial longline	At-vessel mortality
Morgan et al. (2009)	X	Many	X					Observer data	At-vessel mortality
Morgan et al. (2010)		Many	X					Observer data	Spatial and temporal bycatch distribution
Rogers et al. (2017)		School shark	X				X	PAT	PRLDM
Scott-Denton et al. (2011)	X	Many	X					Observer data	Bycatch disposition
Whitney et al. (2021)		Large coastal sharks	X			X	X	Research/ commercial longline	PRLDM and At-vessel mortality
<u>Hook and line</u>									
Bullock et al. (2015)		Lemon		X			X	Net pen	Post-release behavior of tagged sharks in net pens and in situ
Danylchuk et al. (2014)		Lemon (majority neonate)		X		X	X	Reflex indices	PRLDM - 15 min. Not clear how sharks were tracked
French et al. (2015)		Shortfin mako		X		X	X	sPAT	PRLDM
Gurshin and Szedlmayer (2004)		Atlantic sharpnose		X			X		PRLDM
Heberer et al. (2010)		Common thresher		X		X	X	PSAT	PRLDM
Heupel and Simpfendorfer (2002)		Blacktip		X			X		PRLDM
Holland et al. (1999)		Tiger		X			X		Movement rates
Holts and Bedford (1993)		Shortfin mako		X			X		Movement rates
Mandelman and Farrington (2007a)		Spiny dogfish		X	X			Captured and held in net-pen (72 hrs)	PRLDM
Sepulveda et al. (2015)		Common thresher		X				PSAT	PRLDM

Whitney et al. (2016)		Blacktip	X				X		PRLDM
Whitney et al. (2017)		Blacktip	X				X		PRLDM
Gillnet									
Bell and Lyle (2016)		Australian swellshark		X				Tank trials	PRLDM
Braccini et al. (2012)	X	Many species		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)		Many		X			X	Tagging study	PRLDM
Hueter et al. (2006)	X	Bonnethead and Blacktip		X					PRLDM
Reid and Krogh (1992)	X	Many		X				Protective shark meshing	At-net mortality
Rulifson (2007)		Spiny dogfish		X	X			Captured and held in net-pen (48 hrs)	PRLDM
Thorpe and Frierson (2009)	X	Many species		X				Bycatch mitigation	At-vessel mortality
Trawl									
Fennessy (1994)	X	Many species			X			Commercial prawn trawl fisheries	Bycatch disposition
Stobutzki et al. (2002)		Many species			X				At-vessel mortality
Purse seine									
Eddy et al. (2016)	X	Silky shark					X	Tuna purse seine around FAD	At-vessel mortality, PRLDM
Hutchinson et al. (2015)		Silky				X	X	Tuna purse seine	At-vessel mortality, PRLDM
Poisson et al.		Silky					X	Tuna purse	At-vessel

(2014)											seine	mortality, PRLDM
Physiology												
Barham and Schwartz (1992)										X		
Brooks et al. (2011)		Lemon						X		X		
Brooks et al. (2012)		Caribbean reef		mid-water longlines				X				
Cain et al. (2004)		Southern stingray					X	X				
Cicia et al. (2012)		Skates						X		X		Aerial exposure and acute thermal stress
Cliff and Thurman (1984)		Dusky			X			X				
Frick et al. (2009)		Benthic sharks				X		X		X		
Frick et al. (2010a)		Benthic sharks		X		X		X		X		
Frick et al. (2010b)		Benthic sharks					X	X		X		
Frick et al. (2012)		Benthic sharks				X		X		X		
Gallagher et al. (2014b)	X	Five species of coastal sharks						X	X		Drum-line	PRLDM, stress response
Gallagher et al. (2017)	X	Blacktip, nurse, tiger, great hammerhead		X				X	X		Drum-line	Behavioral response to capture measured with accelerometers attached to the fishing gear
Hight et al. (2007)		Pelagic sharks	X		X			X				
Hoffmayer and Parsons (2001)		Atlantic sharpnose			X			X				
Hoffmayer et al. (2012)		Atlantic sharpnose			X			X				
Hyatt et al. (2016)	X	Bonnethead, bull				X		X				Seasonal component behavioral release condition score (BRCS)
Hyatt et al. (2012)	X	Bonnethead, bull, lemon				X		X				Stress response
Jerome et al.	X	Coastal		X				X				Stress

(2018)		sharks										response
Lowe 2001	X	Juv. scalloped hammerhead						X		X		Metabolic rate
Mandelman and Farrington (2007b)		Spiny dogfish					X	X				
Mandelman and Skomal (2009)		Carcharhinid sharks		X				X				Stress response
Manire et al. (2001)	X	Bonnethead, blacktip, bull				X		X				Behavioral and serological response
Marshall et al. (2012)		Eleven pelagic and coastal species	X	X				X				Stress response
Scarponi et al (2021)		African catsharks			X			X				Stress response
Skomal (2007)		pelagic species						X	X		Review article	
Skomal and Mandelman (2012)		Many species						X			Review article	
<u>General review</u>												
Dapp et al. (2016c)	X	Many	X	X		X	X				Meta-analysis	Review of PRLDM and at-vessel-mortality
Ellis et al. (2017)	X	Many	X	X		X	X				Review article	Review of PRLDM and at-vessel-mortality
Godin et al. (2012)	X	Pelagic and coastal sharks	X	X							Review	meta-analysis and analysis of covariance to test the effects of circle hooks on catchability and at-vessel mortality rates
Hammerschlag (2011)	X	Many							X		Review - tag failure	A review of shark satellite tagging studies
Musyl and Gilman (2019)	X	Pelagic sharks	X		X						Meta-analysis	PRLDM
Oliver et al.		Many									Review	Reviews

(2015)						article	published results of PRLDM and at-vessel-mortality bycatch-mitigation
Poisson et al. (2016)	X	Many	X			Review article	
Raby et al. (2013)						Review	
Renshaw et al. (2012)	X	Many species			X	Review article	Biochemistry
Worm et al. (2013)			X			Review	PRLDM pelagic longline
<u>Government report</u>							
Campana et al. (2011)		Blue, porbeagle, shortfin mako	X			Review	Estimation of bycatch mortality in Canadian pelagic longline
Clarke (2011)	X	Pelagic sharks				Review report	Status of sharks WCPFC
McLoughlin and Eliason (2008)		Many species		X		Review report	
<u>Non-governmental agency(NGO) report</u>							
Clarke et al. (2013)	X	Many species				Review report	Studies of mortality to Sharks
Cosandey-Godin and Morgan (2011)		Many species				Review report	Fisheries bycatch of sharks

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

Gear/Source	Hammer-head(s)	Scientific name	Other species	Delayed discard mortality rate (M_D)	Notes
Longline (pelagic)					
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.
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).
Longline (demersal)					
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.

Afonso and Hazin (2014)			Tiger shark	0%	Tiger sharks (19) captured with demersal longline, tagged with PSAT, and tracked for up to 30 days
Drymon and Wells (2017)	Great hammerhead	*Sphyrna mokarran*		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 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 M. antarcticus 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)	Great hammerhead	*Sphyrna mokarran*	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)			Dusky, 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)			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.
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).
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 (*Cephaloscyllium laticeps*)	0%	Tank trial mortality up to 3 days post capture (n = 39 condition 1 and n = 32 condition 2)
Braccini et al. (2012)	Smooth hammerhead	*Sphyrna zygaena*	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 *S. zygaena*, 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)			*Mustelus antarcticus*	Average within captive lab study of 31%	The average delayed mortality (MD, up to 72 hr. after treatment) for M. antarcticus 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)			*Mustelus antarcticus*	Average within captive lab study of 6.5% (2/31 = 0.065)	The average delayed mortality (MD, up to 72 hr. after treatment) for M. antarcticus captured in gillnets under laboratory conditions was calculated here from simulated gillnet fishing under laboratory conditions for 60 min; May not reflect

					commercial fishery.
Hueter and Manire (1994)			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)
<u>Trawl</u>					
Francis (1989)			*Mustelus lenticulatus*	NA	Francis (1989) noted that reported recapture rates of trawl-tagged rig, M. lenticulatus, were lower than those of set-net tagged M. lenticulatus, suggesting that delayed mortality of M. lenticulatus was higher in trawls than set-nets.
Frick et al. (2010b)			*Mustelus antarcticus*	Average within captive lab study of 27%	The average delayed mortality (MD, up to 72 hr. after treatment) for M. antarcticus 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	*Sphyrna lewini*	Scalloped hammerhead Silky shark	100% (PSAT, n = 3) 62% (PSAT, n = 13)	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) Three scalloped hammerhead (100%) showed evidence of post-release mortality. Eight silky sharks (62%) showed evidence of post-release mortality.
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)	Percentage of satellite

				0% (entangled)	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)			Many	e.g., Blacktip Gillnet PRLDM 31% Hueter et al. (2006)	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)	Scalloped hammerhead	*Sphyrna lewini*	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):	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

				Dead=95, Tagged = 401	gears (longline, purse-seine, rod & reel).

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	Hammer-head(s)	Scientific name	Immediate (i.e. at-vessel or acute) discard-mortality rates (M_A)	Notes
Longline (pelagic)				
Afonso et al. (2011)	Scalloped hammerhead	*S. lewini*	33.3 - 87.5% (N=11)	Fishing mortality at haulback (33.3 and 87.5%) by hook type (circle and "J", respectively; N = 11 total catch). Experimental pelagic longline fisheries with circle and "J" hooks off Northeast Brazil.
Afonso et al. (2012)	Hammerheads	*Sphyrna spp.*	100.00%	Fishing mortality at haulback (100%; dead individuals/N; N = 3, absolute frequency). Experimental pelagic longline fisheries with circle and "J" hooks in the southwestern equatorial Atlantic.
Beerkircher et al. (2004)	Scalloped hammerhead	*S. lewini*	NA	Catch disposition of elasmobranchs observed in the pelagic longline fishery off the southeastern U.S. 1992-2000. 51.8% Dead discard, 34.2% released alive, and 14.1% retained.
Bromhead et al. (2012)	Scalloped hammerhead Great hammerhead	*S. lewini* *S. mokarran*	60% (n = 5) 100% (n = 3)	Descriptive statistics of elasmobranchs caught and analyzed for this study. The percent of sharks caught which were judged to be dead (at haulback) or unlikely to survive after release. Marshall Islands tuna longline fishery.
Coelho et al. (2011)	Smooth hammerhead	*S. zygaena*	84% (n = 25, IO) 70.1% (n = 338, AO)	At-haulback mortality of elasmobranchs caught by commercial longline vessels in the Indian Ocean (IO) and Atlantic Ocean (AO).
Coelho et al. (2012)	Scalloped hammerhead Great hammerhead Smooth hammerhead	*S. lewini* *S. mokarran* *S. zygaena*	57.1% (n = 21) 0.0% (n = 3) 71.0% (n = 372)	Descriptive statistics of elasmobranchs caught and analyzed for this study. Data were collected by fishery observers onboard commercial longline vessels in the Atlantic Ocean and used for GAM and GLM analyses of at-vessel mortality rates.
Fernandez-Carvalho, J., et al. (2015)	Smooth hammerhead	*S. Zygaena*	62.03 % (N=79, J-hook) 62.86 % (N=70, Circle hook - no offset) 62.96 % (N=54, Circle hook - offset)	202 experimental pelagic longline sets carried out in the Tropical Northeast Atlantic Ocean.

			61.54% (N=117, Squid) 64.95% (N=86, Mackerel)	
Gallagher et al. (2014a)	Scalloped hammerhead	*S. lewini*	54.1% (Model based mean survival rate)	Least square mean survival (45.9%) obtained from logistic regression of at-vessel survival rates recorded by observers averaged over variables, which would likely affect catch/survival. U.S. pelagic longline fishery 1995 to 2012 omitting sets made prior to 2005 that used J hooks.
Gear/Source	Hammer-head(s)	Scientific name	Immediate (i.e. at-vessel or acute) discard-mortality rates (M_A)	Notes
Longline (demersal)				
Butcher et al. (2015)	Scalloped hammerhead Great hammerhead Smooth hammerhead	*S. lewini* *S. mokarran* *S. zygaena*	88.8% (Captured, n = 52) 100% (Captured, n = 11) 100% (Captured, n = 2)	Experimental fishing with hook-timers in a southern Australia commercial demersal longline fishery. Average percent survival for S. lewini (S_A = 11.2%, n = 52) was obtained as the average of 7 hr and 14 hr deployments obtained from Butcher et al. (2015 their Table 2); M_A = (1 - S_A) = 88.8%. Percent survival at haulback was 0% for S. mokarran and S. zygaena. The model based probability of mortality obtained with GLMM in all hammerhead sharks combined at the genus level (Sphyrna spp) was estimated at close to 100% across all capture depths.
Gulak et al. (2015)	Scalloped hammerhead Great hammerhead	*S. lewini* *S. mokarran*	62.9% (Captured on hook timers, n = 164) 56% (Captured on hook timers, n = 71)	Experimental fishing with hook timers and temperature–depth recorders deployed on bottom-longline gear to assess factors related to at-vessel mortality. Contracted commercial vessels in the US Highly Migratory Species Shark Research Fishery fishing.
Morgan and Burges (2007)	Scalloped hammerhead Great hammerhead	*S. lewini* *S. mokarran*	91.4% (Observed, n =455) 93.8% (Observed, n = 178)	At-vessel fishing mortality rates recorded by fishery observers in the U.S. East Coast and Gulf of Mexico bottom longline commercial shark fishery, 1994–2005.
Morgan et al. (2009)	Scalloped hammerhead	*S. lewini*	92.0%	At-vessel fishing mortality rates

	Great hammerhead	*S. mokarran*	95.8%	recorded by fishery observers in the U.S. East Coast and Gulf of Mexico bottom longline commercial shark fishery, 1994–2003. Also quantified the percentage of dead sharks observed after soak times broken down into 4 h bins, ranging from 0 to >24 h. Scalloped hammerhead 60.0% (0-4h) to 100% (>24 h). Great hammerhead 90.9% (4-8 h) to 100% (0.4h, 20-24h, and >24h).
Scott-Denton et al. (2011)	Scalloped hammerhead	S. lewini	NA	Catch disposition of the U.S. Gulf of Mexico reef fish bottom longline and vertical line fisheries based on observer data 2006-2009. Number, condition, and fate of fish (including scalloped hammerhead) species with n>25 caught. Most hammerheads captured with longline. Descriptive statistics of at-vessel mortality for species caught and analyzed for this study were not provided.
Hook and line				
NA				
Gillnet				
Braccini et al. (2012)	Smooth hammerhead	*S. zygaena*	89.3% (n =122)	Assessment of at-vessel mortality (and condition) in a southern Australia commercial gillnet shark fishery. E.g., for S. zygaena (SA = 10.7%, n = 122) was obtained from Braccini et al. (2012 their Table 2); M_a was then calculated as M_A = (1 - S_A) = 89.3%.
Reid and Krogh (1992)	Hammerheads	*Sphyrna spp.*	98.3% (n = 2031)	Protective mesh netting of beaches along the more populous sections of the NSW coast Australia for the protection of swimmers and surfers against shark attack
Thorpe and Frierson (2009)	Bonnethead shark	*S. tiburo*	71.5%	Experimental fishing with modified gillnets in coastal waters (0–5 km) off North Carolina, USA. Mean capture mortality rate for Atlantic sharpnose sharks (80.4%), bonnethead sharks (71.5%), blacknose sharks (81.3%) and

				blacktip sharks (90.5%)
Trawl				
Fennessy (1994)	Scalloped hammerhead	*S. lewini*	NA	Catch disposition (numbers of mortalities and survivors of elasmobranchs recorded) from South Africa commercial prawn trawl fisheries Number dead = 165 Number alive = 4 Percent mortality 97.6%
Purse seine				
Eddy et al. (2016)	Scalloped hammerhead	*S. lewini*	0% (n=6)	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)
Reviews				
NA				
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 SPHYRNIDAE Hammerhead sharks *Sphyrna* spp. appear to be particularly vulnerable to the effects of capture in commercial gears. High AVM for *Sphyrna* spp. has been reported in trawls (97·6%; Fennessy, 1994), protective nets (98·3%; Reid & Krogh, 1992) and commercial gillnets (71·5–89·3%; Thorpe & Frierson, 2009; Braccini *et al.*, 2012). Even capture in gillnets set for short periods (≤1 h) during scientific studies can result in an AVM of 31–37% (Manire *et al.*, 2001; Hueter *et al.*, 2006). Furthermore, estimates of overall mortality in the latter study, using mark–recapture data from fishes at different categories of vitality, suggested mortality of 62%. Within commercial longline fisheries, although some studies have indicated AVM of 54–71% (Beerkircher *et al.*, 2004; Coelho *et al.*, 2012; Gallagher *et al.*, 2014*a*; Fernandez-Carvalho *et al.*, 2015), higher estimates (AVM=70–90% or more) have also been reported widely (Morgan & Burgess, 2007; Coelho *et al.*, 2011; Bromhead *et al.*, 2012; Butcher *et al.*, 2015). Afonso *et al.* (2011) noted a higher mortality when *Sphyrna* spp. were caught by J-hooks in comparison with circle hooks, but this was based on a low sample size. There have been fewer studies on PRM of *Sphyrna* spp. Gallagher *et al.* (2014*b*) noted that 43% of *S. mokarran* tagged were thought to have died within 2weeks of release, despite the comparatively benign capture technique (baited drum lines, 17–131 min fight times). Eddy *et al.* (2016) reported full PRM of *S. lewini* released after capture in tuna purse seine, but this was only based on tagging three specimens."

A.

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
Trawl						
Trawl (excluding beam 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		Sphyrnidae	*Sphyrna lewini* (n=169)	97.6	
Gillnet						
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	Sphyrnidae	*Sphyrna spp.* (n=2031)	98.3	Values relate to the percentage recovered dead from protective shark nets, which is analogous to AVM
South Australia (Walker et al., 2005); Commercial gillnets 6–6.5″ (150–160 mm) mesh; mean soak time of 8.2 h; Fishing depths of 17–130m (mostly <80 m)	AVM	AVM recorded for two fishing grounds (Bass Strait and South Australia)	Sphyrnidae	*Sphyrna zygaena* (n=77)	3	
SE Australia (Braccini et al., 2012); Gillnet fishery (2.4–20.6 h soak times)	AVM		Sphyrnidae	*Sphyrna zygaena* (n=122)	89.3	

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; south-eastern coast of the U.S.A. (Beerkircher et al., 2004); Pelagic longline fishery (hooks of 7/0 to 11/0; Hook depths usually 35–60m)	AVM	Condition of captured sharks recorded by observers	Sphyrnidae	*Sphyrna lewini* (n=199)	61	
NW Atlantic Ocean; Gulf of Mexico (Morgan & Burgess, 2007); Commercial longline fisheries with observer coverage	AVM	AVM assessed visually (alive–dead)	Sphyrnidae	*Sphyrna lewini* (n=455)	91.4	
	AVM	AVM assessed visually (alive–dead)	Sphyrnidae	*Sphyrna mokarran* (n=178)	93.8	
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	Sphyrnidae	*Sphyrna lewini* (n=11)	33.3-87.5	Lower AVM reported for circle hooks (33.3%) than J-hooks (87.5%)
Atlantic & Indian Oceans (Coelho et al., 2011); Commercial longliners targeting swordfish	AVM	AVM recorded	Sphyrnidae	*Sphyrna zygaena*	70.1–84.0	AVM ranged from 70.1% (n=338; Atlantic) to 84.0% (n=25; Indian Ocean)
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)	Sphyrnidae	*Sphyrna lewini* (n=73)	19.2	

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

A. Continued.

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
SW Atlantic Ocean; Brazil (Afonso et al., 2012); Research fishing from a commercial longline vessel (pelagic), with combinations of wire and monofilament leaders, and circle and J-hooks	AVM	AVM recorded; catch rates and bite-offs recorded	Sphyrnidae	*Sphyrna spp.* (n=3)	100	
Pacific Ocean (Bromhead et al., 2012) Commercial longline fishery	AVM	AVM recorded from observer coverage	Sphyrnidae	*Sphyrna lewini* (n=5) and *S. mokarran* (n=3)	75	Although data were limited, AVM was 75% for this genus
Atlantic Ocean (Coelho et al., 2012) Pelagic longline	AVM	AVM recorded by observers on commercial vessels	Sphyrnidae	*Sphyrna lewini* (n=21) *Sphyrna mokarran* (n=3) *Sphyrna zygaena* (n=372)	57.1 (0) 71	Whilst no AVM was observed for *S. mokarran*, this was based on a small sample size
Tropical NE Atlantic Ocean (Fernandez-Carvalho et al., 2015) Pelagic longline	AVM	Fate recorded for sharks taken on different hook types (J, circle and offset circle hooks) and baits (squid and mackerel)	Sphyrnidae	*Sphyrna zygaena* (n=203)	62.0–62.9	AVM was higher for this species (62.0–62.9% for the three hook types)

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

A. Continued.

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
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	Sphyrnidae	*Sphyrna lewini* (n=727)	54.1	
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	Sphyrnidae	*Sphyrna lewini* (n=52) *Sphyrna zygaena* (n=2) (100) *Sphyrna mokarran* (n=11) 100	87.5–90.1 100 100	Higher AVM with longer soak time (lewini)
Pacific Ocean; Palau (Gilman et al., 2015) Pelagic longline fishery for tuna	AVM	AVM data collected by observers	Sphyrnidae	*Sphyrna mokarran* (n=1) and *S. lewini* (n=1)	100	Data limited, but AVM=100%
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	Sphyrnidae	*Sphyrna lewini* (n=175) 62.9 *Sphyrna mokarran* (n=75) 56	62.9 56.0	

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

B.

Fishery	Approach	Details	Family	Species	PRM (%)	Key findings
NW Atlantic Ocean; Florida (Gallagher et al., 2014b); Experimental drumline, (soak time of 1 h, circle hooks)	PRM and blood sampling	Satellite tags used to examine PRM Blood chemistry examined	Sphyrnidae	*Sphyrna mokarran* (n=28)	43	Based on data from satellite tags, 43% were thought to have died within 2 weeks of release
Eastern Pacific Ocean (Eddy et al., 2016) Tuna purse seine fishery. Work undertaken on commercial fishing vessel, fishing operations of 1–2 h and catch brailed on board	AVM and PRM	Vitality (1–5 scale) and AVM data recorded; PRM assessed with PSATs	Sphyrnidae	*Sphyrna spp.* (n=3)	100	Three specimens were tagged with PSATs, showing 100% post-release mortality

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 (Beta^) 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):

	Beta^	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% ±8.3% (±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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