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Dean Courtney

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A Preliminary Review of Post-release Live-discard Mortality Rate Estimates in Sharks for use in SEDAR 39

Dean Courtney

NOAA Fisheries
Southeast Fisheries Science Center
Panama City Laboratory
3500 Delwood Beach Drive,
Panama City, FL 32408, USA
E-mail: dean.courtney@noaa.gov

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SUMMARY

This working paper reviewed the primary scientific literature for estimates of delayed discard-mortality rates (M_D) in sharks (Tables 1 and 2). However, the review was not exhaustive and therefore should be considered preliminary. Delayed discard-mortality rate estimates, M_D, obtained from the literature (Tables 1 and 2) were summarized for smooth dogfish (*Mustelus spp*.) from many geographic regions and for spiny dogfish (*Squalus acanthias*) from the northwest Atlantic (Table 3). Estimates of immediate (i.e. at-vessel or acute) discard-mortality rates (M_A) were also identified for *Mustelus spp.* and *S. acanthias* from the literature and for *Mustelus canis* from northwest Atlantic commercial gillnet observer program data (Table 3). A range of post-release live-discard mortality (PRLDM) rates (Low, Base, and High) were developed by gear type based on the estimates obtained for M_D and M_A following methods analogous to those adopted by previous SEDAR Assessment Process (AP) panels (equations 3–10 and Table 3), and summarized in the following table.

PRLDM rates	Longline[1]	Hook and line[1]	Gillnet[1]	Trawl[1]
Low-PRLDM	8%	5%	27%	19%
Base-PRLDM	27%	10%	31%	27%
High-PRLDM	36%	15%	36%	36%

[1] Post-release live-discard mortality (PRLDM) rates calculated from M_D and M_A by gear type following methods analogous to those adopted by previous SEDAR Assessment Process (AP) panels (equations 3–10) as described in the text.

For comparison, alternative PRLDM rates were developed for gillnet and trawl fisheries from the average delayed mortality rates obtained from the literature for *Mustelus spp.* from any region and for *Squalus acanthias* from the northwest Atlantic (mean $M_D \pm 1.98$*S.E.; Table 3), and summarized in the following table. Alternative PRLDM rates were also developed for longline and recreational hook and line fisheries based on an ad hoc approach described in the text (Table 3), and summarized in the following table.

Alternative PRLDM rates	Longline[2]	Hook and line[2]	Gillnet[1]	Trawl[1]
Low-PRLDM	8%	10%	13%	0%
Base-PRLDM	13.5%	17%	27%	19%
High-PRLDM	19%	24%	40%	37%

[1] Alternative PRLDM rates based on the average delayed discard-mortality rates, M_D, by gear type (Mean ± 1.98*S.E.) as described in the text.
[2] Alternative PRLDM rates based on an ad hoc approach as described in the text.

1. INTRODUCTION

Sharks react to the stress of capture and handling with more exaggerated disruptions to their physiology and biochemistry than higher vertebrates (Skomal 2007). Anaerobic white muscle is dominant in most sharks, which allows high work output in short bursts (Skomal 2007). Many fishing techniques cause high anaerobic activity, muscular fatigue, and time out of water, which results in physiological disruptions in sharks (Skomal 2007). However, forecasting the survival rates of sharks based on their physiological response to the stress of capture is complicated (Skomal 2007; Renshaw et al. 2012; Skomal and Mandelman 2012). There are species-specific differences in the physiological response to capture stress (Manire et al. 2001; Skomal 2007). Consequently, discard mortality rates are variable among species, even those that are closely related (Mandelman and Skomal 2009; Morgan and Carlson 2010; Braccini et al. 2012). The physiological response to capture stress may also depend on other factors such as season, water temperature, and body size (Cicia et al. 2012; Hoffmayer et al. 2012; Braccini et al. 2012).

2. METHODS

This report reviewed the same literature as previously reviewed within the SEDAR process for PRLDM rates in sharks (Tables 1 and 2) (NMFS 2011a, 2011b, 2011c, 2011d, 2012, 2013a, 2013b), plus some additional recent publications.

For the purposes of this report, the primary scientific literature (Tables 1 and 2) was reviewed to identify papers which included reference to *Mustelus spp*. Papers which included reference to *Mustelus spp.* were then reviewed in more detail to determine if they contained estimates of delayed discard-mortality, M_D, which could be used to provide estimates of PRLDM for use in SEDAR 39, as described in more detail below. Several estimates of M_D for *Mustelus spp.* resulted from this process, and are provided for consideration in SEDAR 39 (Table 3).

In addition, Mandelman and Skomal (2009 their p 270) noted that blood biochemistry values were not significantly different for captive spiny dogfish, *S. acanthias*, n = 10 and captive smooth dogfish, *Mustelus canis*, n = 10 from the northwest Atlantic held in tanks under similar—assumed minimally stressed—conditions. This result suggests that *S. acanthias* and *M. canis* from the northwest Atlantic may have similar responses to capture stress. As a result, papers which included reference to *S. acanthias* from the northwest Atlantic were also reviewed in more detail to determine if they contained estimates of delayed discard-mortality, M_D, which could be used to provide estimates of PRLDM for use in SEDAR 39, as described in more detail below. Several estimates of M_D for *S. acanthias* from the northwest Atlantic resulted from this process, and are provided for consideration in SEDAR 39 (Table 3).

In addition, several estimates of immediate (i.e., at-vessel or acute) mortality, M_A, for *Mustelus spp.* and *S. acanthias* from both research and commercial fisheries were also identified from both the primary scientific literature and from observer program data in the northwest Atlantic (Table 3).

A range of PRLDM rate values (Low, Base, and High) were then developed by gear type from estimates of delayed discard-mortality, M_D, and immediate discard-mortality, M_A, following approaches analogous to those adopted by previous SEDAR AP panels (Table 3).

For comparison, alternative PRLDM rates were developed for gillnet and trawl fisheries from the average delayed mortality rates obtained from the literature for *Mustelus spp.* from any region and for *Squalus acanthias* from the northwest Atlantic (mean $M_D \pm 1.98*S.E.$; Table 3).

For these gear types, the average delayed mortality rate (Mean M_D± 1.98*S.E.) obtained from the literature provided a wider range of uncertainty than the range of PRLDM rate values developed following approaches analogous to those adopted by previous SEDAR AP panels (Table 3). Alternative PRLDM rates were also developed for longline and hook and line fisheries based on an ad hoc approach described below (Table 3).

Previous discard mortality rate decisions were summarized from recent SEDAR shark stock assessments (NMFS 2011a, 2011b, 2011c, 2011d, 2012, 2013a, 2013b) and from a recent Northeast Fisheries Science Center (NEFSC) spiny dogfish stock assessment (NEFSC 2006) (Table 4).

2.1. Analytical approach adopted by previous SEDAR AP panels

Because mortality rates likely vary among gear types as well as among species, previous SEDAR AP panels developed estimates of discard mortality separately by species and gear type (Tables 1 and 2) (NMFS 2011a, 2011b, 2011c, 2011d, 2012, 2013a, 2013b). This review followed the same convention, and attempted to identify and evaluate estimates of post-release live-discard mortality rate by species and gear type (longline, hook and line, gillnet, and trawl), where available (Tables 1 and 2).

Previous SEDAR AP panels (NMFS 2012, 2013a, 2013b) 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): $M_T = M_A + M_D * S_A$, where M_T = Total discard-mortality rate, defined as the immediate plus delayed discard-mortality rate resulting from the fishing event; M_A = Immediate (i.e., at-vessel or acute) discard-mortality rate resulting from the fishing event; M_D = 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 S_A = Acute survival rate (i.e., the proportion released alive).

Previous SEDAR AP panels (NMFS 2012, 2013a, 2013b) developed a range of PRLDM rate values (Low, Base, and High) by gear type from estimates of delayed discard-mortality, M_D, and immediate (i.e., at-vessel or acute) mortality, M_A, obtained from a literature search, as summarized below.

PRLDM rates for gillnet fisheries—For gillnet fisheries, previous SEDAR AP panels (NMFS 2013a, 2013b) developed a low PRLDM rate for commercial gillnet fisheries as:

(2) $\text{Low-PRLDM}_{\text{gillnet}} = M_{D,\ \text{research-gillnets}}$,

where

$M_{D,\ \text{research-gillnets}}$ = an estimate of the delayed discard-mortality rate obtained from the scientific literature for sharks captured with gillnets fished under research conditions.

A high PRLDM rate for commercial gillnet fisheries was developed as:

(3) $\text{High-PRLDM}_{gillnet} = M_{D,\ research\text{-}gillnets}\ (M_{A,\ commercial\text{-}gillnets})/(M_{A,\ research\text{-}gillnets})$,

where
$M_{A,\ commercial\text{-}gillnets}$ = an estimate of immediate (i.e., at-vessel or acute) discard-mortality obtained from the scientific literature for sharks captured with gillnets fished under commercial conditions, and
$M_{A,\ research\text{-}gillnets}$ = an estimate of immediate (i.e., at-vessel or acute) discard-mortality obtained from the scientific literature for sharks captured with gillnets fished under research conditions.

A base PRLDM rate for commercial gillnet fisheries was developed as:

(4) $\text{Base-PRLDM}_{gillnet} = (\text{Low-PRLDM}_{gillnet} + \text{High-PRLDM}_{gillnet})/2$.

An assumption was that the delayed discard-mortality rate for sharks captured in commercial gillnets was proportional to that in research gillnets, and that the proportionality constant could be approximated from the ratio of at-vessel mortality rates for sharks captured with gillnets fished under commercial versus research conditions.

PRLDM rates for longline fisheries—For longline fisheries, previous SEDAR AP panels (2012, 2013a, 2013b) developed a low PRLDM rate for commercial longline fisheries based on estimates of delayed discard-mortality obtained from the scientific literature for tagged and released blue sharks captured with pelagic longlines fished under research conditions ($M_{D,\ research\text{-}longlines}$ = 19%; Campana et al. 2009b) as:

(5) $\text{Low-PRLDM}_{longline} = M_{D,\ research\text{-}longlines}$

A base PRLDM rate for commercial longline fisheries was developed based on estimates of delayed discard-mortality obtained from the scientific literature for sharks captured with gillnets fished under research conditions as:

(6) $\text{Base-PRLDM}_{longline} = \text{Low-PRLDM}_{gillnet.}$

A high PRLDM rate for commercial longline fisheries was developed as:

(7) $\text{High-PRLDM}_{longline} = \text{High-PRLDM}_{gillnet}$

Previous SEDAR AP panels (NMFS 2012, 2013a, 2013b) considered the delayed discard mortality rate estimate, $M_{D,\ research\text{-}longlines}$ = 19%, provided by Campana et al. (2009b) for blue sharks to be the best available estimate of PRLDM in pelagic longlines because the study included both injured and healthy animals. An assumption was that the minimum estimate of delayed discard-mortality rate for coastal sharks captured in commercial longlines (Low-PRLDM) was similar to that of the best available estimate of PRLDM in pelagic longlines. Another assumption was that the Base-PRLDM and High-PRLDM rates of coastal sharks captured in commercial longlines were similar to those of the same species captured in commercial gillnets.

PRLDM rates for hook and line fisheries—For recreational hook and line fisheries, previous SEDAR AP panels (2012, 2013a, 2013b) developed a base PRLDM rate based on estimates of delayed discard-mortality obtained from the scientific literature for tagged and released Atlantic sharpnose sharks captured with recreational hook and line gear ($M_{D,research\text{-}hook\ and\ line}$ = 10%; Gurshin and Szedlmayer 2004) as:

(8) $\text{Base-PRLDM}_{hook\ and\ line} = M_{D,research\text{-}hook\ and\ line.}$

A low and high PRLDM rate were developed for hook and line fisheries based 50% and 150%, respectively, of the base PRLDM rate as:

(9) $\text{Low-PRLDM}_{hook\ and\ line} = 50\%\ \text{Base-PRLDM}_{hook\ and\ line}$, and

(10) $\text{High-PRLDM}_{hook\ and\ line} = 150\%\ \text{Base-PRLDM}_{hook\ and\ line}$.

Previous SEDAR AP panels (NMFS 2012, 2013a, 2013b) considered the delayed discard mortality rate estimate, $M_{D,research\text{-}hook\ and\ line}$ = 10%, provided by Gurshin and Szedlmayer (2004) for Atlantic sharpnose sharks to be the best available estimate of PRLDM in recreational hook and line gear because the study included both injured and healthy animals. An assumption was that the delayed discard-mortality rate of coastal sharks captured in hook and line gear was similar to that of the best available estimate of PRLDM in hook and line gear.

PRLDM rates for trawl fisheries— Previous SEDAR AP panels (NMFS 2012, 2013a, 2013b) did not provide PRLDM rates for coastal shark species in commercial trawls.

2.2. PRLDM rates developed here for consideration in SEDAR 39

PRLDM rates for gillnet fisheries— A range of PRLDM rates for commercial gillnet fisheries was developed for consideration in SEDAR 39 as follows. A low PRLDM rate for commercial gillnet fisheries ($\text{Low-PRLDM}_{gillnet}$ = 27%; Table 3) was developed with equation (2) from the average of four delayed discard-mortality rates obtained from the scientific literature for *Mustelus spp.*—31.0% (Frick et al. 2010a), 6.5% (Frick et al., 2012), and 36.2% (Braccini et al., 2012)—and for *S. acanthias* from the northwest Atlantic—33.2% (Rulifson 2007)—. Delayed discard-mortality rates were estimated for sharks captured with gillnets fished under research conditions (Rulifson 2007), in captivity (Frick et al. 2010a, 2012), and from risk analysis of commercial gillnet fisheries (Braccini et al. 2012).

A high PRLDM rate for commercial gillnet fisheries was developed with equation (3) ($\text{High-PRLDM}_{gillnet}$ = 36%; Table 3) from estimates of immediate and delayed discard-mortality. An estimate of the average immediate discard-mortality for sharks captured with gillnets fished under research conditions (Average $M_{A,\ research\text{-}gillnets}$ = 13.5%; Table 3) was developed from three immediate discard-mortality rates obtained from the scientific literature for *Mustelus spp.*—20.0% (Frick et al. 2010a), 3.0% (Frick et al. 2012),—and for *S. acanthias* from the northwest Atlantic—17.5% (Rulifson 2007)—. An estimate of the average immediate discard-mortality for sharks captured with commercial gillnets (Average $M_{A,\ commercial\text{-}gillnets}$ = 18.2%; Table 3) was developed from at-vessel mortality rates for *Mustelus canis* in northwest Atlantic commercial gillnet fisheries obtained from observer program data during the years 2010, 2011, and 2012 (E. Cortes, NMFS, personal communication). Consequently, an assumption of this approach is that the delayed discard-mortality rate for *Mustelus spp.* captured in commercial gillnets was proportional to that in research gillnets, and that the proportionality constant could be approximated by the ratio (Average $M_{A,\ commercial\text{-}gillnets}$)/ (Average $M_{A,\ research\text{-}gillnets}$) = 1.35 (Table 3).

However, this approach is sensitive to the estimate of immediate discard-mortality obtained for commercial conditions. For example immediate discard-mortality for *Mustelus spp.* captured with commercial gillnets in Australian commercial fisheries may be much higher (Average $M_{A,\ commercial\text{-}gillnets\text{-}literature}$ = 56.7%)— 60% (Walker et al. 2005), 53% (Walker et al. 2005), and 57% (Braccini et al. 2012)—. In this case, the resulting ratio of (Average $M_{A,\ commercial\text{-}gillnets}$)/(Average $M_{A,\ research\text{-}gillnets}$) would also be much larger (c. 4.2).

A base PRLDM rate for commercial gillnet fisheries (Base-$PRLDM_{gillnet}$ = 31%, Table 3) was developed with equation (4) as the average of the low and high PRLDM rates for gillnets developed above.

PRLDM rates for longline fisheries— A range of PRLDM rates for commercial longline fisheries was developed for consideration in SEDAR 39 as follows. A low PRLDM rate for commercial longline fisheries (Low-$PRLDM_{longline}$ = $M_{D,\ research\text{-}longlines}$ = 8%; Table 3) was developed analogously to equation (5) from the delayed discard-mortality rate obtained from the scientific literature for *Mustelus spp.*—8.3% (Frick et al 2010a)—. The delayed discard-mortality rate was estimated for sharks captured with longlines fished under research conditions in captivity (Frick et al. 2010a). A base PRLDM rate for commercial longline fisheries was developed based on estimates of delayed discard-mortality in gillnets obtained with equation (6) (Base-$PRLDM_{longline}$ = Low-$PRLDM_{gillnet}$ = 27%; Table 3). A high PRLDM rate for commercial longline fisheries was developed based on estimates of delayed discard-mortality in gillnets obtained with equation (7) (High-$PRLDM_{longline}$ = High-$PRLDM_{gillnet}$ = 36%; Table 3).

PRLDM rates for trawl fisheries—A range of PRLDM rates for commercial trawl fisheries was developed for consideration in SEDAR 39 as follows. Skomal (2007, citing Francis 1989) noted that tag return rates for rig, *Mustelus lenticulatus,* were lower for sharks captured with trawls and subsequently tagged and released than for sharks captured with set nets and subsequently tagged and released, suggesting that delayed discard mortality rates of *M. lenticulatus* in trawls may be relatively higher than that in set nets (gillnets). Consequently, an assumption made here was that delayed discard mortality rates of *Mustelus spp.* in trawls were at least as large as those in gillnets.

A range of PRLDM rates for commercial trawl fisheries was then developed here analogously to those developed above for longline fisheries. A low PRLDM rate for commercial trawl fisheries was developed analogously equation (5) (Low-$PRLDM_{trawl}$ = $M_{D,\ research\text{-}trawl}$ = 19%; Table 3) from the average of three delayed discard-mortality rates obtained from the scientific literature for *Mustelus spp.*—26.9% (Frick et al. 2010b)—and for *S. acanthias* from the northwest Atlantic—29% (Mandelman and Farringdon 2007a), and 0.0% (Rulifson 2007) —. Delayed discard-mortality rates were estimated for sharks captured with trawls fished under research conditions (Mandelman and Farringdon 2007a; Rulifson 2007) and in captivity (Frick et al 2010b). A base PRLDM rate for commercial trawl fisheries was developed based on estimates of delayed discard-mortality in gillnets analogously to equation (6) (Base-$PRLDM_{trawl}$ = Low-$PRLDM_{gillnet}$ = 27%; Table 3). A high PRLDM rate for commercial longline fisheries was developed based on estimates of delayed discard-mortality in gillnets analogously to equation (7) (High-$PRLDM_{trawl}$ = High-$PRLDM_{gillnet}$ = 36%; Table 3).

PRLDM rates for hook and line fisheries—A range of PRLDM rates for hook and line (i.e., recreational) fisheries was developed for consideration in SEDAR 39 based on the approach adopted by previous SEDAR AP panels (2012, 2013a, 2013b) following equations (8)–(10), as described above.

2.3. Alternative PRLDM rates developed here for consideration in SEDAR 39

Alternative PRLDM rates for gillnet and trawl fisheries— Alternative PRLDM rates for gillnet and trawl fisheries were developed for consideration in SEDAR 39 from the average delayed mortality rates obtained from the literature for *Mustelus spp.* from any region and for *Squalus acanthias* from the northwest Atlantic by gear type (mean M_D ± 1.98*S.E.; Table 3).

Alternative PRLDM rates for longline fisheries.—Alternative PRLDM rates for longline fisheries were developed for consideration in SEDAR 39 based on the following ad hoc approach. Previous SEDAR AP panels (NMFS 2012, 2013a, 2013b) considered the delayed discard mortality rate estimate, $M_{D,\text{ research-longlines}}$ = 19%, provided by Campana et al. (2009b) for blue sharks to be the best available estimate of PRLDM in pelagic longlines because the study included both injured and healthy animals. However, the average delayed mortality rate for *M. antarcticus* captured with demersal longlines under laboratory conditions (M_D = 8.3%; *n* = 24, adapted from Frick et al. 2010a their Figure 1 as described below) is somewhat lower. Consequently, an alternative low PRLDM rate for longline fisheries ($\text{Low-PRLDM}_{\text{longline}}$ = 8%; Table 3) was developed based on Frick et al. (2010a adapted from their Figure 1). An alternative high PRLDM rate for longline fisheries ($\text{High-PRLDM}_{\text{longline}}$ = 19%; Table 3) was developed based on Campana et al. (2009b) for blue sharks. An alternative base PRLDM rate for longline fisheries ($\text{Base-PRLDM}_{\text{longline}}$ = 13.5%; Table 3) was developed as the average of 8% and 19%.

Alternative PRLDM rates for hook and line fisheries— Alternative PRLDM rates for hook and line fisheries were developed for consideration in SEDAR 39 based on the following ad hoc approach. Previous SEDAR AP panels (NMFS 2012, 2013a, 2013b) considered the delayed discard mortality rate estimate, $M_{D,\text{research-hook and line}}$ = 10%, provided by Gurshin and Szedlmayer (2004) for Atlantic sharpnose sharks to be the best available estimate of PRLDM in hook and line (recreational) gear because the study included both injured and healthy animals. However, the average delayed mortality for *S. acanthias* captured with hook and line (i.e., M_D = 24 ± 6% (mean ± S.D.); *n* = 55, Mandelman and Farrington 2007a) is somewhat higher. Mandelman and Farrington (2007a) attributed the delayed mortality of hook and line captured *S. acanthias* in their study (c. 24%) to the stress of being held in a net-pen after capture. Consequently, an alternative high PRLDM rate for hook and line fisheries ($\text{High-PRLDM}_{\text{hook and line}}$ = 24%; Table 3) was developed based on Mandelman and Farrington (2007a). An alternative low PRLDM rate for hook and line fisheries ($\text{Low-PRLDM}_{\text{hook and line}}$ = 10%; Table 3) was developed based on Gurshin and Szedlmayer (2004). An alternative base PRLDM rate for hook and line fisheries ($\text{Base-PRLDM}_{\text{hook and line}}$ = 17%; Table 3) was developed as the average of 10% and 24%.

3. LITERATURE REVIEW

3.1. Literature reviewed for delayed discard-mortality rates in *Mustelus spp*.

Review of Frick et al. (2010a)—Frick et al. (2010a) conducted laboratory experiments to evaluate stress related physiological changes and post-release survival of Port Jackson sharks (*Heterodontus portusjacksoni*), and gummy sharks (*Mustelus antarcticus*) following simulated gillnet and longline capture in captivity. For example, Frick et al (2010a their Figure 1) calculated the acute survival rate (S_A, calculated as the proportion alive at the end of the experimental fishing treatment) and the total survival rate (S_T, calculated as the proportion alive 72 hr after the experimental fishing treatment) for *M. antarcticus* following varying durations of simulated gillnet fishing (30 min, 120 min, and 180 min) and simulated longline fishing (30 min, 120 min, and 360 min) under laboratory conditions. For the purposes of this report, the acute survival rates, S_A, and total survival rates, S_T, provided in (Frick et al. 2010a their Figure 1) were adapted from their figure to provide estimates of delayed mortality, M_D, for *M. antarcticus* captured in gillnets and longlines under laboratory conditions. The calculation of M_D from S_A and S_T was based on the following assumed relationships:

(11) $S_T = S_A * S_D$

⇨ $S_D = S_T / S_A$

⇨ $M_D = (1- S_D)$,

where

S_T = Total survival rate (Proportion alive 72 hr after the experimental fishing treatment) (Adapted from Frick et al. 2010a their Figure 1),

S_A = Acute survival rate (Proportion alive at the end of the experimental fishing treatment) (Adapted from Frick et al. 2010a their Figure 1),

S_D = Delayed survival rate (Proportion of acute survivors alive 72 hr after treatment) (from equation 11), and

$M_D = (1- S_D)$ = Delayed mortality rate (Proportion of acute survivors that die up to 72 hr after treatment) (from equation 11).

An average delayed mortality rate for *M. antarcticus* captured in gillnets in captivity (M_D = 31%; n = 24) was calculated here (from equation 11) from the delayed mortality (M_D, up to 72 hr after treatment) resulting from simulated gillnet fishing under laboratory conditions for 30 min (M_D = 70%), 120 min (M_D = 0%), and 180 min (M_D = 22%), based on the acute survival rates, S_A, and total survival rates, S_T, (Adapted from Frick et al. 2010a their Figure 1) as:

Gillnet treatment conditions and initial sample size (n)	Acute survival rate (S_A, n; adapted from Frick et al. 2010a their Figure 1)	Acute mortality rate ($M_A = 1 – S_A$; adapted from Frick et al. 2010a their Figure 1)	Total survival rate (S_T, n; adapted from Frick et al. 2010a their Figure 1)	Delayed survival rate (S_D; from equation 11)	Delayed mortality rate ($M_D = 1 – S_D$; from equation 11)
30 min, n = 10	100%, n = 10	0.0%	30%, n = 3	30%	70%
120 min, n = 10	50%, n = 5	50%	50%, n = 5	100%	0%
180 min, n = 10	90%, n = 9	10%	70%, n = 7	78%	22%
Average acute mortality rate gillnet (In captivity, n =30)		20%	Average M_D gillnet (In captivity, n = 24)		**31%**

An average delayed mortality rate for *M. antarcticus* captured with longlines under laboratory conditions (M_D = 8.3%; n = 24) was calculated here (from equation 11) from the delayed mortality (M_D, up to 72 hr after treatment) resulting from simulated longline fishing under laboratory conditions for 30 min (M_D = 12.5%), 120 min (M_D = 12.5%), and 180 min (M_D = 0.0%), based on the acute survival rates, S_A, and total survival rates, S_T, (Adapted from Frick et al. 2010a their Figure 1) as:

Longline treatment conditions and initial sample size (*n*)	Acute survival rate (S_A, *n*; adapted from Frick et al. 2010a their Figure 1)	Acute mortality rate ($M_A = 1 - S_A$; adapted from Frick et al. 2010a their Figure 1)	Total survival rate (S_T, *n*; adapted from Frick et al. 2010a their Figure 1)	Delayed survival rate (S_D; from equation 11)	Delayed mortality rate ($M_D = 1 - S_D$; from equation 11)
30 min, *n* = 8	100%, *n* = 8	0.0%	87.5%, *n* = 7	87.5%	12.5%
120 min, *n* = 8	100%, *n* = 8	0.0%	87.5%, *n* = 7	87.5%	12.5%
360 min, *n* = 8	100%, *n* = 8	0.0%	100%, *n* = 8	100%	0.0%
Average acute mortality rate longline (In captivity, n = 24)		0.0%	Average M_D longline (In captivity, n = 24)		**8.3%**

Review of Frick et al. (2010b)— Frick et al. (2010b) conducted laboratory experiments to evaluate stress related physiological changes and post-release survival of Port Jackson sharks, *H. portusjacksoni*, and gummy sharks, *M. antarcticus*, following simulated trawl-net capture in captivity. For example, Frick et al (2010b their Figure 2) provide the acute survival rate (S_A, calculated as the proportion alive at the end of the experimental fishing treatment) and the total survival rate (S_T, calculated as the proportion alive 72 hr after the experimental fishing treatment) for *M. antarcticus* following varying durations of simulated trawl-net fishing (30 min, 60 min, 120 min), simulated trawl-net fishing followed by air exposure (60 min + air), and simulated trawl-net fishing with crowding—three sharks in a trawl-net at a time (60 min + crowding) under laboratory conditions. For the purposes of this report, the acute survival rates, S_A, and total survival rates, S_T, provided in (Frick et al. 2010b their Figure 2) were adapted from their figure to provide estimates of M_D for *M. antarcticus* captured in trawl-nets under laboratory conditions based on the assumed relationships described above (from equation 11).

An average delayed mortality rate for *M. antarcticus* captured in trawls in captivity (M_D = 27%; *n* = 38) was calculated here (from equation 11) from the delayed mortality (M_D, up to 72 hr after treatment) resulting from simulated trawl-net fishing under laboratory conditions for 30 min (M_D = 37.5%), 60 min (M_D = 0.0%), 120 min (M_D = 85.7%), 60 min + air (M_D = 0.0%), and 60 min + crowding (M_D = 11.1%), as described above, based on the acute survival rates, S_A, and total survival rates, S_T, (Adapted from Frick et al. 2010b their Figure 2) as:

Trawl-net treatment conditions and initial sample size (*n*)	Acute survival rate (S_A, *n*; adapted from Frick et al. 2010b their Figure 2)	Acute mortality rate ($M_A = 1 - S_A$; adapted from Frick et al. 2010b their Figure 2)	Total survival rate (S_T, *n*; adapted from Frick et al. 2010b their Figure 2)	Delayed survival rate (S_D; from equation 11)	Delayed mortality rate ($M_D = 1 - S_D$; from equation 11)
30 min, *n* = 8	100%, *n* = 8	0.0%	62.5%, *n* = 5	62.5%	37.5%
60 min, *n* = 8	100%, *n* = 8	0.0%	100%, *n* = 8	100%	0.0%
120 min, *n* = 8	87.5%, *n* = 7	12.5%	12.5%, *n* = 1	14.2%	85.7%
60 min + air, *n* = 8	75%, *n* = 6	25%	75%, *n* = 6	100%	0.0%
60 min + crowding, *n* = 9	100%, *n* = 9	0.0%	88.9%, *n* = 8	88.9%	11.1%
Average acute mortality rate trawl (In captivity, n = 41)		7.5%	Average M_D trawl (In captivity, n = 38)		**26.9%**

Review of Frick et al. (2012)— Frick et al. (2012) conducted laboratory experiments to evaluate the immediate and delayed effects of gill-net capture on acid–base balance and intramuscular lactate concentration of gummy sharks, *M. antarcticus*, in captivity. Frick et al (2012) provide the acute survival rate (S_A, calculated as the proportion alive at the end of the experimental fishing treatment) and the total survival rate (S_T, calculated as the proportion alive 72 hr after the experimental fishing treatment) for *M. antarcticus* following simulated gillnet fishing (60 min) under laboratory conditions. For the purposes of this report, the acute survival rates, S_A, and total survival rates, S_T, provided in Frick et al. (2012) were adapted to provide estimates of M_D for *M. antarcticus* captured in gillnets under laboratory conditions based on the assumed relationship described above (from equation 11).

A delayed mortality rate for *M. antarcticus* captured in gillnets in captivity (M_D = 6.5%; *n* = 31) was calculated here (from equation 11) from the delayed mortality (M_D, up to 72 hr after treatment) resulting from simulated gillnet fishing under laboratory conditions for 60 min (M_D = 6.5%), based on the acute survival rates, S_A, and total survival rates, S_T, (Adapted from Frick et al. 2012) as:

Gillnet treatment conditions and initial sample size (*n*)	Acute survival rate (S_A, *n*; adapted from Frick et al. 2012)	Acute mortality rate ($M_A = 1 - S_A$; adapted from Frick et al. 2012)	Total survival rate (S_T, *n*; adapted from Frick et al. 2012)	Delayed survival rate (S_D; from equation 11)	Delayed mortality rate ($M_D = 1 - S_D$; from equation 11)
60 min, *n* = 32	97%, *n* = 31	3%	91%, *n* = 25	93.5%	6.5%
Acute mortality rate gillnet (In captivity, n = 32)		3%	M_D gillnet (In captivity, n = 31)		**6.5%**

Review of Braccini et al. (2012)—Braccini et al. (2012) conducted risk analysis and laboratory experiments to estimate post-capture survival (PCS) of sharks captured in a southern Australia commercial gillnet shark fishery. Risk analysis was based on data collected by onboard observers during fishery dependent surveys conducted with commercial fishing vessels and designed to be representative of common fishing practices in the region.

For risk analysis, Braccini et al. (2012) partitioned total PCS (e.g., from equation 11) into an immediate and a delayed component. Immediate PCS was defined as the probability of surviving the capture process prior to being discarded (i.e. defined here as acute survival, S_A). Delayed PCS was defined as the probability of surviving after discarding (i.e. defined here as delayed survival, S_D). Braccini et al. (2012) then assumed that the risk of delayed PCS was proportional to four arbitrary survival scores: High (1.0), Moderate (0.66), Low (0.33), and Nil (0.0). Survival scores were then recorded by onboard observes at the time of capture based on physical injury and behavioral responses: 1) Activity and stimuli; 2) Wounds and bleeding; 3) Sea lice; and 4) Skin damage and bruising. The total risk of delayed PCS, i.e. S_D, was then calculated, for each shark, from the survival score assigned to each physical injury and behavioral response as:

(12) S_D = (Activity and stimuli survival score)*(Wounds and bleeding survival score)*(Sea lice survival score)*(Skin damage survival score).

Braccini et al. (2012) also applied their risk assessment method in a controlled laboratory experiment with captive Port Jackson sharks, *H. portusjacksoni*, and gummy sharks, *M. antarcticus*, and found a strong correlation between total PCS from the risk assessment method and the actual survival rate observed after ten days of monitoring (r = 1.00 and 0.89, for *H. portusjacksoni* and *M. antarcticus*, respectively).

For the purposes of this report, an average risk of delayed PCS for *M. antarcticus* in a gillnet fishery (63.8%, n = 3,726) was obtained from Braccini et al. (2012 their Table 2) as:

	Numbers captured		Delayed survival risk score				Post capture survival risk		
Species	Alive	Dead	Activity and Stimuli	Wounds and bleeding	Sea lice	Skin damage and bruising	Immediate (S_A)	Delayed (S_D)	Total (S_T)
M. antarcticus	1606	2120	0.784	0.983	0.985	0.877	0.431	**0.638**	0.257

The corresponding average risk of delayed mortality, M_D, in the southern Australia commercial gillnet shark fishery was calculated here (from equation 11) as $M_D = (1- S_D) = 36.2\%$.

3.2. Literature reviewed for delayed discard-mortality rates in spiny dogfish

Review of Rulifson (2007)— Rulifson (2007) estimated the short-term delayed discard-mortality rates, M_D, of spiny dogfish, *S. acanthias*, induced by gillnet and trawl capture and tag and release. Fishing was conducted off the coast of North Carolina south of Oregon Inlet and north of Cape Hatteras, during March 2004 in depths of 8.5–18.1 m and water temperatures of 5.3–7.0 °C. Gillnets of various mesh sizes were set for 19 to 24 hr periods. Trawls (c. 18 m headrope) were fished for 30 to 90 min periods. Gillnet and trawl captured *S. acanthias* were subsequently held in net pens attached to the seafloor for 48 hrs in order to determine the delayed mortality rate.

Gillnet captured *S. acanthias* (*n* = 2,284) experienced a 17.5% at-vessel-mortality rate. Untagged gillnet captured *S. acanthias* (*n* = c. 240) subsequently held for 48 hrs experienced a 33.2% delayed mortality rate (i.e., $M_D = 33.2\%$).

Trawl captured *S. acanthias* (*n* = 635) experienced 0.0% at-vessel-mortality rate. Untagged trawl captured *S. acanthias* (*n* = c. 240) subsequently held for 48 hrs experienced 0.0% delayed mortality rate (i.e., $M_D = 0.0\%$).

Rulifson (2007) emphasized that his study was not designed to examine trawling mortality of *S. acanthias* as bycatch in a non-directed fishery; rather, it focused on determining the mortality of *S. acanthias* targeted and captured by trawl, tagged, and released in mark-and-release studies conducted earlier. Rulifson (2007) also cited a previous study (Chisholm 2003 [Not available for review in this report]) in which [total] discard mortality of *S. acanthias* captured in a Massachusetts trawl fishery was estimated at 25%. Rulifson (2007) noted that one reason for the observed difference in mortality rates between the two studies may the difference in on-deck temperatures experienced by *S. acanthias* between the two studies. For example, Rulifson (2007) noted that Chisholm (2003) conducted trawling during the New England summer, which resulted in taking *S. acanthias* from chilled waters to a boat deck heated by the summer sun to an unknown temperature. In contrast Rulifson (2007) conducted trawling off of North Carolina in the spring, which resulted in taking *S. acanthias* from chilled waters to a boat deck of approximately the same or lower temperature compared with the water. Rulifson (2007) also noted that ocean trawlers off of New England typically catch thousands of *S. acanthias* in one haul, and the crushing weight and pressure probably result in mortality rates higher than those observed in his study.

Review of Mandelman and Farringdon (2007a)— Mandelman and Farringdon (2007a) estimated the short-term delayed discard-mortality rates, M_D, of spiny dogfish, *S. acanthias*, induced by trawls and hook and line (short vertical longlines hauled by hand). Fishing was conducted off the coast of Cape Cod, Massachusetts, during June and September 2004 in depths of 66.0–73.0 m with bottom temperatures of 6–11 °C, surface temperatures of 13–16 °C and air temperatures of 20–29 °C. The size and capacity of the fishing vessel, as well as the catch potential of the trawl gear, was intended to be representative of the Northwest Atlantic bottom trawl fleet. Trawl captured *S. acanthias* were subsequently held in net pens attached to the seafloor for 72 hrs in order to determine the delayed mortality rate.

Hook and line capture was conducted opportunistically from the fishing vessel with five squid-baited standard circle hooks hung in the water-column (not directly on the substrate) from a short makeshift longline. This method enabled the landing of individuals within 3 min of hook deployment. Each set was rapidly retrieved by hand and dogfish were immediately de-hooked. Hook and line capture was intended to serve as a control because it was presumed that it would result in a relatively low delayed mortality rate. Hook and line captured *S. acanthias* were also subsequently held in net pens attached to the seafloor for 72 hrs to determine the delayed mortality rate.

Trawl captured *S. acanthias* (n = 185) subsequently held for 72 hrs experienced a delayed discard-mortality rate, M_D, of 29 ± 12% (mean ± S.D.).

Hook and line captured *S. acanthias* (n = 55) subsequently held for 72 hrs experienced a delayed mortality rate, M_D, of 24 ± 6% (mean ± S.D.).

However, Mandelman and Farrington (2007a) concluded that the post-release mortality estimates of trawl captured *S. acanthias* in their study (c. 29%) included both the stress of trawl capture plus the additional stress of being held in a net-pen after capture as estimated from their presumed low stress hook and line control group (c. 24%). Mandelman and Farrington (2007a) also concluded that delayed mortality of trawled *S. acanthias* was significantly affected by the weight of the catch, which explained 67% of the variation.

3.3. Literature reviewed for immediate discard-mortality rates, M_A, under research conditions

Review of Frick et al. (2010a)— An average acute mortality rate for *M. antarcticus* captured by gill-nets in captive conditions (M_A = 20%; n = 30) was obtained from Frick et al. (2010a), as described above. An average acute mortality rate for *M. antarcticus* captured by longlines in captive conditions (M_A = 0.0%; n = 24) was obtained from Frick et al. (2010a), as described above.

Review of Frick et al. (2010b)— An average acute mortality rate for *M. antarcticus* captured by trawls in captive conditions (M_A = 7.5%; n = 41) was obtained from Frick et al. (2010a), as described above.

Review of Frick et al. (2012)— An average acute mortality rate for *M. antarcticus* captured by gill-nets in captive conditions (M_A = 3%; n = 32) was obtained from Frick et al. (2012), as described above.

Review of Rulifson (2007)— Gillnet captured spiny dogfish, *S. acanthias*, (n = 2,284) experienced a 17.5% at-vessel-mortality rate (acute mortality) (Rulifson 2007), as described above.

3.4. Literature reviewed for immediate discard-mortality rates, M_A, in commercial fisheries

Review of Walker et al. (2005)—Walker et al. (2005, their Tables 8A and 8B) reported the at-vessel disposition (live or dead) of total gill-net catch in south-eastern Australia shark fisheries for many shark species. For example, Walker et al. (2005, their Table 8A) reported an at-vessel mortality rate (i.e., acute mortality, M_A) for *M. antarcticus* captured by commercial gill-nets in Bass Strait of 60% (n = 3,697) (Table 3). Similarly, Walker et al. (2005, their Table 8B) reported an at-vessel mortality rate for *M. antarcticus* captured by commercial gill-nets in South Australia of 53% (n = 928) (Table 3).

Review of Braccini et al. (2012)—Braccini et al. (2012 their Table 2) also reported the at-vessel disposition (live or dead) of total gill-net catch in south-eastern Australia shark fisheries for many shark species. For example, Braccini et al. (2012 their Table 2) reported the at-vessel survival (i.e., acute survival, S_A) for *M. antarcticus* captured by commercial gill-nets in south-eastern Australia shark fisheries as 43% (*n* = 3,726). The corresponding at-vessel mortality rate was obtained here as: $M_A = 1 – S_A = 57\%$ (Table 3).

3.5. Immediate discard-mortality rates, M_A, for *M. canis* in northwest Atlantic commercial gillnet fisheries

An average at-vessel mortality rate for *M. canis* in northwest Atlantic commercial gillnet fisheries, $M_A = 18.2\%$ (*n* = 1,541; Table 3), was obtained from observer program data during the years 2010, 2011, and 2012 (E. Cortes, NMFS, personal communication).

4. REVIEW of PREVIOUS SEDAR SHARK PRLDM DECISIONS

4.1. SEDAR gillnet

SEDAR 21—The SEDAR 21 DW panel adopted post-release discard mortality rates for sandbar sharks caught in commercial gillnets (5–10%), for dusky sharks caught in commercial gillnets (50%), and for blacknose sharks caught in commercial drift gillnets (50%), strike gillnets (5%), and sink gillnets (25%) (Based on industry input and the SEDAR 21 Catch WG recommendations; NMFS 2011a, 2011b, 2011c, and 2011d; their Section II Data Workshop Report, sub-section 2.5 Discard Mortality).

SEDAR 29—The SEDAR 29 AP panel did not record a decision for post-release live-discard mortality rate estimates for blacktip sharks captured in commercial gillnets (NMFS 2012). However, the stock assessment applied a post-release live-discard mortality rate of 31% for blacktip sharks captured in commercial gillnets (Pers. Comm. Enric Cortes 6/5/2013) based on the estimate provided in Hueter et al. (2006) and reviewed by the SEDAR 29 AP panel.

SEDAR 34—For Atlantic sharpnose sharks, the SEDAR 34 AP panel adopted a PRLDM rate of 58.5% for commercial gillnet for the base model, with a range of 35–82% for the low and high sensitivity scenarios (Table 4; NMFS 2013a their sections 2.2.2.3 and 2.2.2.4). The value of 58.5% was the average of the low and high sensitivity scenarios (35% and 82%). The value of 35% was the PRLDM rate estimate for all sharks, including Atlantic sharpnose, captured in research gillnets (Hueter and Manire, 1994), used as a “minimum” estimate for commercial gillnet mortality. The value of 82% was obtained from the ratio of 80.4% (at-vessel mortality rate for Atlantic sharpnose captured in commercial gillnets; Thorpe and Frierson, 2009) to 34.2% (at-vessel mortality rate for Atlantic sharpnose captured in research gillnets; Hueter and Manire, 1994) multiplied by 34.8% (the post-release live-discard mortality rate estimate for all sharks, including Atlantic sharpnose, captured in research gillnets; Hueter and Manire, 1994), as:

$$82\% = 34.8\% *(80.4\%/34.2\%) = 34.8\%*2.35$$

These calculations assumed that the PRLDM rate for Atlantic sharpnose sharks captured in commercial gillnets (82%) was proportional to (~2.3 times higher than) that in research gillnets (34.8%).

For bonnethead sharks, the SEDAR 34 AP panel adopted a PRLDM rate of 65.5% for commercial gillnet for the base model, with a range of 40-91% for the low and high sensitivity scenarios (Table 4; NMFS 2013a their sections 2.2.2.3 and 2.2.2.4). The value of 65.5% was the average of the low and high sensitivity scenarios (40% and 91%). The value of 40% was the bonnethead shark PRLDM rate estimate from research gillnets (Hueter et al. 2006), used as a “minimum” estimate of commercial gillnet mortality. The value of 91% was obtained from the ratio of 71.5% (at-vessel mortality rate for bonnethead sharks captured in commercial gillnets; Thorpe and

Frierson, 2009) to 31.4% (at-vessel mortality rate for bonnethead sharks captured in research gillnets; Hueter and Manire, 1994) multiplied by 40% (the bonnethead shark PRLDM rate estimate from research gillnets; Hueter et al. 2006) as:

$$91\% = 40\% *(71.5\%/31.4\%) = 40\%*2.28$$

These calculations assumed that the PRLDM rate for bonnethead sharks captured in commercial gillnets (91%) was proportional to (~2.3 times higher than) that in research gillnets (40%).

4.2. SEDAR longline (pelagic and demersal)

SEDAR 21—Campana *et al*. (2009b) analyzed pelagic longline fishery mortality of blue sharks and estimated both at-vessel (~13%) and post-release (19%) mortality. The SEDAR 21 LH WG concluded that this represented a 6% difference in mortality. Assuming the relationship between the two mortality rates is applicable to other species, the SEDAR 21 LH WG applied this 6% increase in mortality to the at-vessel mortality estimates [post release mortality = (% at-vessel mortality + 6%)] for sandbar and blacknose sharks obtained from observer data collected in the longline fishery during the years 1994-2009 and to the at-vessel mortality estimates for dusky sharks from observer data collected in the longline fishery during the years 2005-2009. This resulted in post-release mortality estimates for longline caught sharks of 38.24% (sandbar), 71.18% (blacknose), and 65.17% (dusky) (Table 3).

SEDAR 29—For blacktip sharks, the SEDAR 29 AP panel adopted a PRLDM rate of 31% for commercial bottom longline for the base model, with a range of 19–73% for the low and high sensitivity scenarios (NMFS 2012; their section 2.2.2.3 Commercial Discards Datasets and Decisions) (Table 4).The value of 31% was the post-release live-discard mortality rate estimate for juvenile blacktip sharks captured in research gillnets (Hueter et al. 2006). The value of 19% was the post-release live-discard mortality rate estimated for blue sharks captured with pelagic longlines (Campana et al., 2009). The value of 73% was obtained from the ratio of 90% (at-vessel mortality rate for sub adult blacktip sharks captured in commercial gillnets; Thorpe and Frierson, 2009) to 38% (at-vessel mortality rate for juvenile blacktip sharks captured in research gillnets; Hueter and Manire, 1994) multiplied by 31% (the research gillnet post-release live-discard mortality rate of juvenile blacktip sharks captured in research gillnets; Hueter et al. 2006) as:

$$73\% = 31\% *(90\%/38\%) = 31\%*2.4$$

These calculations assumed that the PRLDM rate for blacktip sharks captured in commercial gillnets (73%) was proportional to (2.4 times higher than) that in research gillnets (31%).

SEDAR 34—For Atlantic sharpnose sharks, the SEDAR 34 AP panel applied a PRLDM rate of 35% for commercial bottom longline for the base model, with a range of 19-82% for the low and high sensitivity scenarios (Table 4; NMFS 2013a their sections 2.2.2.3 and 2.2.2.4). The value of 35% was the post-release live-discard mortality rate estimate for all sharks, including Atlantic sharpnose, captured in research gillnets (Hueter and Manire, 1994), used as a “central” estimate of longline mortality. The value of 19% was the PRLDM rate estimated for blue sharks captured with pelagic longlines (Campana et al., 2009). The value of 82% was obtained from the SEDAR 34 Atlantic sharpnose shark gillnet PRLDM estimates as described above.

For bonnethead sharks, the SEDAR 34 AP panel applied a PRLDM rate of 40% for commercial bottom longline for the base model, with a range of 19–91% for the low and high sensitivity scenarios (Table 4; adapted from NMFS 2013b their sections 2.2.2.3 and 2.2.2.4). The value of 40% was the bonnethead shark post-release live-discard mortality rate estimate from research gillnets (Hueter et al. 2006), used as a "central" estimate of longline mortality. The value of 19% was the PRLDM rate estimated for blue sharks captured with pelagic longlines (Campana et al., 2009). The value of 91% was obtained from the SEDAR 34 bonnethead shark gillnet PRLDM estimates as described above.

4.3. SEDAR trawl

SEDAR 21—The SEDAR 21 DW panel adopted a post-release discard mortality rate for blacknose sharks of 67% (NMFS 2011c; their Section II: Data Workshop Report, sub-section 2.5 Discard Mortality). A single document was reviewed (Stobutzki *et al*., 2002) indicating a 61% at-vessel mortality rate for all sharks in the Australian northern prawn trawl fishery. Sharks included three species of the genus *Carcharhinus* and one species of the genus *Rhizoprionodon*. The SEDAR 21 Data Workshop used the 6% difference between at-vessel and post-release mortality reported by Campana *et al*. (2009b) to convert the at-vessel mortality indicated above to a discard mortality. This conversion resulted in an estimate of 67% (61% + 6%) discard mortality for trawl fisheries.

SEDAR 29 and 34—The SEDAR 29 and 34 AP panels determined that there was not sufficient literature to guide the Panel to decide on post release live discard mortality rate estimates for either Atlantic sharpnose or bonnethead sharks caught in commercial trawls.

4.4. SEDAR recreational hook and line

SEDAR 21—The SEDAR 21 DW panel adopted a 6.0% post-release mortality rate for dusky sharks, 3.2% for sandbar sharks, and 6.6% for blacknose sharks (NMFS 2011a, 2011b, 2011c, 2011d; their Section II: Data Workshop Report, sub-section 2.5 Discard Mortality). The SEDAR 21 DW panel used a 6.0% post-release mortality rate for dusky sharks and at-vessel hooking mortality form Observer Program data sets (CSFOP and SBLOP) to estimate that sandbar sharks exhibited 54% less at-vessel mortality than dusky sharks. Using these relationships, The SEDAR 21 Data Workshop calculated that sandbar sharks have hook and line post-release mortality of 3.25% (6%×54%). Similarly, the SEDAR 21 Data Workshop concluded that blacknose sharks exhibited 10% greater at-vessel mortality than dusky sharks and calculated a hook and line post-release mortality rate of 6.6% (6% + 6%×10%) for blacknose sharks.

SEDAR 29 and SEDAR 34—The SEDAR 29 and 34 AP panels recommended applying a 10% discard mortality rate (Gurshin and Szedlmayer, 2004) to the live discards (B2) from MRIP/MRFSS, and included a range of 5-15% for the low and high scenario sensitivity runs. (NMFS, 2012 their section 2.2.2.5. Recreational Discards Datasets and Decisions, p.18; NMFS 2013a, 2013b their sections 2.2.2.3 and 2.2.2.4). The recreational hook and line post-release discard mortality comes from (Gurshin and Szedlmayer, 2004), who estimated a 10% rate based on tagged Atlantic sharpnose sharks captured with hook and line. The SEDAR 34 AP panel noted that this rate was obtained using only ten tagged sharpnose sharks being monitored for six hours and that it might not be appropriate to use, especially for bonnethead sharks. The Panel discussed and decided that if the methodology was externally reviewed and accepted in SEDAR 29 than it should be acceptable for use in SEDAR 34 as well. The Panel also decided that in the absence of information specific to bonnethead sharks, it was appropriate to use the data for Atlantic sharpnose sharks.

4.5. NEFSC spiny dogfish

A Northeast Fisheries Science Center (NEFSC) stock assessment workshop (43rd SAW) developed total discard mortality rate estimates for spiny dogfish (NEFSC 2006 their sections 4.2—Recreational landings and 4.4—Discards). A total discard mortality rate of 20% was applied for spiny dogfish captured and released from recreational landings (MRFSS B2) (Table 4). A total discard mortality rate of 30% was applied for spiny dogfish captured and released from gillnets (Table 4). A total discard mortality rate of 50% was applied for spiny dogfish captured and released from otter trawls (Table 4).

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Table 1. Literature reviewed in this report for post-release live-discard mortality (PRLDM) rate estimates.

	Species/genus			Gear type					Study type				
Primary Literature	Mustelus sp.	genus	Other species	Pelagic longline	Demersal longline	Hook and Line	Gillnet	Trawl	Physi-ological	Electronic tagging	Lab.	Other	Notes
Longline (pelagic)													
Campana et al. (2009a, 2009b)			Blue	X						X			PRLDM
Diaz (2011)			Many	X								Observer data	At-vessel mortality
Moyes et al. (2006)			Blue	X					X	X			PRLDM
Musyl et al. (2009)			Blue	X					X	X			PRLDM
Musyl et al. (2011)			Blue	X						X		Meta-analysis	PRLDM
Longline (demersal)													
Afonso and Hazin (2014)			Tiger		X					X			PRLDM
Gallagher et al. (2014)			Tiger, bull, and great hammerhead		X							Drum-line	Inferred post-release survival from electronic tag reporting rates
Morgan and Burges (2007)			Many		X							Observer data	At-vessel mortality
Morgan and Carlson (2010)	X	canis (n=1)	Many		X							Research/ commercial longline	At-vessel mortality
Morgan et al. (2010)	X	canis	Many		X							Observer data	Bycatch composition
Hook and line													
Gurshin and Szedlmayer (2004)			Atlantic sharpnose			X				X			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

Table 1. Continued.

Primary Literature	Species/genus: Mustelus sp.	genus	Other species	Gear type: Pelagic longline	Demersal longline	Hook and Line	Gillnet	Trawl	Study type: Physi-ological	Electronic tagging	Lab.	Other	Notes
Gillnet													
Braccini et al. (2012)	X	antarcticus	Many species				X					Risk assessment	Post Capture Survival (PCS)
Francis (1989)	X	lenticulatus					X	X				Large scale tagging study	Noted that recapture rates were lower for trawl than set-net
Hueter and Manire (1994)	X	norrisi	Many				X			X		Tagging study	PRLDM
Hueter et al. (2006)			Bonnethead and Blacktip				X						PRLDM
Rulifson (2007)			Spiny dogfish				X	X				Captured and held in net-pen (48 hrs)	PRLDM
Thorpe and Frierson (2009)			Many species				X					Bycatch mitigation	At-vessel mortality
Trawl													
Stobutzki et al. (2002)			Many species					X					At-vessel mortality

Table 1. Continued.

Primary Literature	Species/genus: Mustelus sp.	Species/genus: genus	Species/genus: Other species	Gear type: Pelagic longline	Gear type: Demersal longline	Gear type: Hook and Line	Gear type: Gillnet	Gear type: Trawl	Study type: Physiological	Study type: Electronic tagging	Study type: Lab.	Study type: Other	Notes
Physiology													
Barham and Schwartz (1992)	X	canis									X		Not useful
Brooks et al. (2011)			Lemon						X		X		Tonic immobility
Brooks et al. (2012)			Caribbean reef		mid-water longlines				X				Cites Whitman et al. (1986) tonic immobility of *M. canis*
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				Cites Scott (1921) *M. canis* blood sugar
Frick et al. (2009)			Benthic sharks				X		X		X		
Frick et al. (2010a)	X	antarcticus	Benthic sharks		X		X		X		X		Lab study includes gummy sharks (*M. antarcticus*)
Frick et al. (2010b)	X	antarcticus	Benthic sharks					X	X		X		Lab study includes gummy sharks (*M. antarcticus*)
Frick et al. (2012)	X	antarcticus	Benthic sharks				X		X		X		Lab study includes gummy sharks (*M. antarcticus*)
Hight et al. (2007)			Pelagic sharks	X		X			X				
Hoffmayer and Parsons (2001)			Atlantic sharpnose			X			X				Cites Scott (1921) *M. canis* blood sugar
Hoffmayer et al. (2012)			Atlantic sharpnose			X			X				Seasonal component
Mandelman and Farrington (2007b)			Spiny dogfish					X	X				Capture, transport, and captivity
Mandelman and Skomal (2009)	X	canis	Carcharhinid sharks		X				X				Captive *S. acanthias* and *M. canis* used as controls

Table 1. Continued.

Primary Literature	Species/genus			Gear type					Study type				Notes
	Mustelus sp.	genus	Other species	Pelagic longline	Demersal longline	Hook and Line	Gillnet	Trawl	Physi-ological	Electronic tagging	Lab.	Other	
Physiology continued													
Manire et al. (2001)			Bonnethead, blacktip, bull				X		X				
Renshaw et al. (2012)			Many species						X			Review article	
Skomal (2007)			pelagic species						X	X		Review article	
Skomal and Mandelman (2012)			Many species						X			Review article	
General review													
Raby et al. (2013)												Review	
Worm et al. (2013)												Review	PRLDM pelagic longline
Government report													
Campana et al. (2011)			Blue, porbeagle, shortfin mako	X								Review	Estimation of bycatch mortality in Canadian pelagic longline
McLoughlin and Eliason (2008)			Many species			X						Review report	
Non-governmental agency(NGO) report													
Cosandey-Godin and Morgan ()			Many species									Review report	Fisheries bycatch of sharks

Table 2. Delayed discard-mortality rates, M_D, by gear type obtained from a review of the primary scientific literature (Table 1).

	Species				
Gear/Source	Mustelus sp.	genus	Other species	Delayed discard mortality rate (M_D)	Notes
Longline (pelagic)					
Campana et al. (2009b)			Blue shark	19%* (10 – 29%)	Tagged both injured and healthy animals; Range is 95% confidence interval.
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)
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)					
Frick et al. (2010a)	X	antarcticus		Average within captive lab study of 8%	The average delayed mortality (M_D, 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 (M_D = 12.5%), 120 min (M_D = 12.5%), and 360 min (M_D = 0.0%); May not reflect commercial fishery.
Gallagher et al. (2014)			Tiger, bull, and great hammerhead	Tiger (0%), bull (25.9%, and great hammerhead (42.9%)	Gallagher et al. (2014) 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).
Hook and line					
Gurshin and Szedlmayer (2004)			Atlantic sharpnose	10%*	Tagged both injured and healthy animals (*n* = 10).
Heupel and Simpfendorfer (2002)			Blacktip	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	0%	Tagged large healthy sharks (*n* = 3).
Mandelman and Farrington (2007a)			Spiny dogfish	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 M_D 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).

* 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 2. Continued.

	Species				
Gear/Source	Mustelus sp.	genus	Other species	Delayed discard mortality rate (M_D)	Notes
Gillnet					
Braccini et al. (2012)	X	antarcticus		Average risk analysis result of 36.2%	The average risk of delayed PCS of *M. antarcticus* in a southern Australia commercial gillnet shark fishery (S_D = 63.8%, n = 3,726) was obtained from Braccini et al. (2012 their Table 2); PRLDM was then calculated as M_D = (1- S_D) = 36.2%.
Frick et al. (2010a)	X	antarcticus		Average within captive lab study of 31%	The average delayed mortality (M_D, 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 (M_D = 70%), 120 min (M_D = 0%), and 180 min (M_D = 22%); May not reflect commercial fishery.
Frick (2012)	X	antarcticus		Average within captive lab study of 6.5% (2/31 = 0.065)	The average delayed mortality (M_D, 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)	X	norrisi	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	31% (blacktip); 40% (bonnethead)	Juvenile and small adult sharks captured with research gillnets in Florida estuaries.
Rulifson (2007)			Spiny dogfish	33%	Held in net-pen after capture (48 hrs, North Carolina).
Trawl					
Francis (1989)	X	*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)	X	*antarcticus*		Average within captive lab study of 27%	The average delayed mortality (M_D, 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 (M_D = 37.5%), 60 min (M_D = 0.0%), 120 min (M_D = 85.7%), 60 min + air (M_D = 0.0%), and 60 min + crowding (M_D = 11.1%); May not reflect commercial fishery.
Mandelman and Farrington (2007a)			Spiny dogfish	29 ± 12% (mean ± S.D.)	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	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.

Table 3. A range of post-release live-discard mortality (PRLDM) rates (Low, Base, and High) was developed for each gear type (longline, hook and line, gillnet, and trawl) from estimates of delayed mortality (M_D) and acute mortality (M_A) following methods analogous to those adopted by previous SEDAR Assessment Process (AP) panels (Panels A–F; equations 3–10); Alternative PRLDM rates were developed for gillnet and trawl from the average delayed mortality rates obtained from the literature for *Mustelus spp.* from any region and for *Squalus acanthias* from the northwest Atlantic (Panel G, mean M_D ± 1.98*S.E.), and for longline and hook and line using an ad hoc approach described in the text (Panel H).

Species	Longline	Hook and line	Gillnet	Trawl
A. Delayed discard-mortality rates, M_D, obtained from the literature (Tables 1 and 2) for *Mustelus spp.* and *S. acanthias*.				
			31.0% (*n* = 24)[1]	
			6.5% (*n* = 31)[2]	26.9% (*n* = 38)[4]
Mustelus spp.	8.3% (*n* = 24)[1]		36.2% (*n* = 3,726)[3]	
				29% (*n* = 185)[5]
S. acanthias		24% (*n* = 55)[5]	33.2% (*n* = c. 240)[6]	0.0% (*n* = c. 240)[6]
B. Immediate (i.e. at-vessel or acute) mortality rates, M_A, under research conditions obtained from the literature (Tables 1 and 2).				
			20% (*n* = 30)[1]	
Mustelus spp.	0.0% (n = 24)[1]		3% (*n* = 32)[2]	7.5% (*n* = 41)[4]
S. acanthias			17.5% (*n* = 2,284)[6]	
C. Immediate (i.e. at-vessel or acute) mortality rates, M_A, for commercial fisheries obtained from the literature (Tables 1 and 2).				
			60% (n = 3,697)[7]	
			53% (n = 928)[7]	
Mustelus spp.			57% (n = 3,726)[3]	
D. Immediate (i.e. at-vessel or acute) mortality rates, M_A, from Atlantic commercial fisheries obtained from observer program data[8].				
Mustelus canis			18.2% (n = 1,541)[8]	
E. Average M_D and M_A rates obtained from the literature and from Atlantic commercial fisheries observer program data.				
Rate	Longline	Hook and line	Gillnet	Trawl
Average $M_{D,\ research}$	8.3%	24%	26.7%	18.6%
Average $M_{A,\ research}$	0%	NA	13.5%	7.5%
Average $M_{A,\ commercial}$	NA	NA	18.2%[8]	NA
(Average $M_{A,\ commercial}$)/(Average $M_{A,\ research\text{-}literature}$)	NA	NA	1.35	NA
F. Post-release live-discard mortality (PRLDM) rates calculated from M_D and M_A by gear type (equations. 3–10).				
Rate	Longline	Hook and line	Gillnet	Trawl
Low-PRLDM	8%	5%	27%	19%
Base-PRLDM	27%	10%	31%	27%
High-PRLDM	36%	15%	36%	36%
G. Alternative PRLDM rates based on the average delayed discard-mortality rates, M_D, by gear type (Mean ± 1.98*S.E.).				
Rate	Longline	Hook and line	Gillnet	Trawl
n (number of M_D estimates, by gear type)	1	1	4	3
Mean (of M_D estimates, by gear type)	8.3%	24%	26.7%	18.6%
S.E. (of the mean)	NA	NA	6.8%	9.3%
Low- M_D = mean - 1.98*S.E.	NA	NA	13%	0%
Base- M_D = mean	8.3%	24%	27%	19%
High- M_D = mean+1.98*S.E.	NA	NA	40%	37%
H. Alternative PRLDM rates based on an ad hoc approach as described in the text				
Rate	Longline	Hook and line	Gillnet	Trawl
Low-PRLDM	8%	10%	NA	NA
Base-PRLDM	13.5%	17%	NA	NA
High-PRLDM	19%	24%	NA	NA

[1] Frick et al. (2010a); [2] Frick et al. (2012); [3] Braccini et al. (2012); [4] Frick et al. (2010b); [5] Mandelman and Farringdon (2007a); [6] Rulifson (2007); [7] Walker et al. (2005); [8] Average at-vessel mortality rate for *Mustelus canis* in northwest Atlantic commercial gillnet fisheries obtained from observer program data during the years 2010, 2011, and 2012 (E. Cortes, NMFS, personal communication).

Table 4. Previous SEDAR shark post-release live-discard mortality (PRLDM) rate decisions along with Northeast Fisheries Science Center (NEFSC) spiny dogfish total discard mortality 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%	50% (Drift gillnet); 5% (Strike gillnet); 25% (Sink gillnet)	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. NEFSC[4]			
	Spiny dogfish			
AP *		20%	30%	50%

*Final decisions adopted for stock assessment.

[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] NEFSC decisions adopted for a recent spiny dogfish stock assessment (NEFSC 2006 their sections 4.2—Recreational landings and 4.4—Discards).