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A PRELIMINARY REVIEW OF POST-RELEASE LIVE-DISCARD MORTALITY RATE ESTIMATES IN SHARKS FOR USE IN SEDAR 34

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Abstract

This working paper reviewed post-release live-discard mortality rate estimates for sharks from the primary scientific literature for use in SEDAR 34. However, the review was not exhaustive and therefore should be considered preliminary. Discard mortality rates appear to vary among species and by gear type. As a result, this review identified estimates of post-release live-discard mortality rate by species and by gear type (longline, hook and line, gillnet, and trawl) where available. Post-release live-discard mortality rate estimates were available in the literature for the Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) captured with recreational hook and line (10%), and for bonnethead shark (*Sphyrna tiburo*) captured with research gillnets (40%). Post-release live-discard mortality rate estimates were also available in the literature for juvenile and small adult sharks, including Atlantic sharpnose, captured with research gillnets (35%). As a result, these values are recommended for consideration in SEDAR 34. In other cases, at-vessel mortality rates and blood physiology may provide useful indications of the relative condition of sharks at release and subsequent post-release live-discard mortality rates, but the specific relationships are uncertain. Previously, the SEDAR 29 Assessment Process (AP) panel applied a post-release live-discard mortality rate estimated for research gillnets to commercial bottom longline for the base model with a range for the low and high sensitivity scenarios. The SEDAR 29 AP panel also applied a 10% post-release live-discard mortality rate to the live-discards (B2) from MRIP/MRFSS, and included a range of 5-15% for the low and high scenario sensitivity runs. Applying the SEDAR 29 AP panel rational for bottom longline here for Atlantic sharpnose sharks would result in a post-release live-discard mortality rate of 35% for commercial bottom longline for the base model, with a range of 19 – 82% for the low and high sensitivity scenarios. Applying the SEDAR 29 AP panel rational for bottom longline here for bonnethead sharks would result in a post-release live-discard mortality rate of 40% for commercial bottom longline for the base model, with a range of 19 – 91% for the low and high sensitivity scenarios.

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). For example, 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).

This working paper reviews post-release live-discard mortality rate estimates for sharks from the primary scientific literature for use in SEDAR 34. However, the review was not exhaustive and therefore should be considered preliminary. Section-1 provides a review of some scientific literature on post-release live-discard mortality rates for sharks. Section-2 summarizes recent SEDAR 21 and SEDAR 29 panel decisions regarding post-release live-discard mortality rates for sharks. Section-3 provides post-release live-discard mortality rate estimates developed for Atlantic sharpnose shark and bonnethead shark by gear type for consideration in SEDAR 34.

Methods

The SEDAR 21 Data Workshop (DW) panel (NMFS 2011a, 2011b, 2011c, and 2011d) and the SEDAR 29 Assessment Process (AP) panel (NMFS 2012) reviewed the primary scientific and grey literature, examining at-vessel and discard mortality in order to estimate post-release survivorship. This review includes the same literature, plus one additional recent publication (Braccini *et al.*, 2012) (Table 1).

Because mortality rates likely vary among gear types as well as among species, the SEDAR 21 DW panel and SEDAR 29 AP panel developed separate estimates of discard mortality by species and gear type. The SEDAR 29 AP also emphasized that post-release live-discard mortality rates should only be applied to live discards (e.g., Hueter and Manire, 1994) using the following equation:

(Equation 1) Total discard mortality rate = (Dead-discard rate) + (Post-release live-discard mortality rate) * (Live-discard rate).

This review follows the same conventions, and attempts 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 (Table 1). Studies that include the Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) or the bonnethead shark (*Sphyrna tiburo*) are also identified (Table 1).

1. Literature Review

1.1 Longline

Pelagic longline

Campana *et al*. (2009b) estimated the post-release live-discard mortality rate for pelagic longline captured blue sharks as 19%, with a 95% confidence interval estimated from Monte Carlo Simulation ranging from 10 to 29%. The study design used by Campana *et al*., (2009b) specifically included a random sample of injured-and-released as well as healthy-and-released sharks. Blue sharks landed in apparently healthy condition by pelagic longlines are likely to survive long term if released: 5% post-release live-discard mortality based on biochemical analysis (Moyes *et al*., 2006), and 0.0% post-release live-discard mortality rate based on PSAT analysis (Moyes *et al*., 2006; Campana *et al*., 2009b). In contrast, blue sharks landed in an apparently injured condition by pelagic longlines (i.e. gut hooked or obviously badly injured) were less likely to survive: 33% post-release live-discard mortality rate based on PSAT analysis (Campana *et al*., 2009b). Consequently, Campana *et al*. (2009b) based their estimate of post-release live-discard mortality for pelagic longline captured blue sharks on the weighted average of the injured-and-released mortality rate (33%) and the healthy-and-released mortality rate (0%). Weights were the relative frequency of the injured-and-released (44%) and the healthy-and-released (56%) blue sharks scientifically sampled (n = 902) on board commercial pelagic longline fishing vessels targeting both swordfish and blue sharks (Table 2) (Campana *et al*., 2009a, 2009b). Mortality rates were estimated from post-release survival of a random sample (n = 40) of the scientifically sampled sharks tagged with satellite tags prior to release and included sharks in both injured (n = 27 reporting tags) and healthy (n = 8 reporting tags) condition upon release (Campana *et al*., 2009b). Ninety five percent of post-release live-discard mortality occurred within eleven days of release (Campana *et al*., 2009b).

A table of blue shark post-release live-discard mortality rate estimates from pelagic longline fisheries is provided below:

	Dead-discard rates	Live-discard rates			
	At-vessel mortality rates	At-vessel injury rates	Post-release mortality rates		
Literature cited			Healthy	Injured	Combined (95% CI)
Moyes *et al*. (2006) Blue shark	NA	NA	0 - 5%	NA	NA
Campana *et al*. (2009a, 2009b) Blue shark	12-13% (Observer data), 20% (Scientific subsample)	31% (Observer data), 44% (Scientific subsample)	0%	33%	19% (10-29%)
Musyl *et al*. (2011) Blue shark	NA	NA	NA	NA	15% (8.5-25.1%)

Post-release live-discard mortality rates estimated for blue sharks captured with pelagic longline gear (Moyes *et al.*, 2006; Campana *et al*., 2009b; Musyl *et al.*, 2011) are consistent with those for pelagic sharks in other studies. For example, the post-release live-discard mortality rate for pelagic longline captured shortfin mako sharks is ~20%, based on blood plasma catecholamine levels (adrenaline and noradrenaline concentrations) of tagged and recovered sharks (Hight *et al*., 2007). However, the shortfin mako mortality rate is probably a minimum estimate because handling practices in research longline vessels (Hight *et al*., 2007) are probably less stressful than handling practices on commercial longline vessels (e.g., Campana *et al*., 2009b).

Demersal longline

There is evidence that both at-vessel mortality and post-release live-discard mortality rates may be proportional to species-specific differences in sensitivity to capture stress (Mandelman and Skomal, 2009). For example, among carcharhinid species captured by commercial vessels using demersal longlines, the relative degree of blood acid-base disturbance reflected in physiological data is proportional to at-vessel mortality rates (Mandelman and Skomal, 2009). Evidence from conventional tagging recapture rates also suggests that the capacity of sharks to recover from longline capture may be related to the relative degree of disturbance reflected in physiological data (Mandelman and Skomal, 2009). In particular, when ranked from highest to lowest, the tag recapture rate of longline-captured sharks is proportional to capture stress inferred from blood acid-base disturbance (Mandelman and Skomal, 2009).

A table of the relative rank of blood acid-base disturbance among shark species resulting from longline capture (one is the lowest disturbance), along with at-vessel mortality rates and conventional tagging recapture rates (Adapted from Mandelman and Skomal, 2009; their Table 3) is provided below:

Species	Blood acid-base disturbance (median rank)	At-vessel mortality rate (ranked lowest to highest)	Conventional tag recovery rate (ranked highest to lowest)
Dogfish spp.	1	NA	NA
Tiger	2	9%	8.0%
Sandbar	3	36%	4.2%
Dusky	5	81%	1.7%
Atlantic sharpnose	5	NA	1.4%
Blacktip	6	88%	1.2%

It is interesting to note that within this relative ranking, Atlantic sharpnose sharks had a relatively high blood acid-base disturbance ranking and a relatively low conventional tag recapture rate (Mandelman and Skomal, 2009). In comparison, the at-vessel hooking mortality rate of Atlantic sharpnose sharks (91%, n = 94, Morgan and Burgess, 2007) observed in the Atlantic during research fishing with commercial demersal longline shark fishery vessels is substantially higher than at-vessel hooking mortality for blue sharks captured in pelagic longline fisheries (12 – 13% based on a large observer data set, and 20% based on a smaller scientific subsample of the observed data; Campana *et al*., 2009b). However, at-vessel mortality rates for species captured with commercial demersal longlines may also be influenced by fishing practices, water temperature, and body size. For example, a linear model indicated that at-vessel mortality increased with soak time and bottom water temperature, and decreased with shark size (Morgan and Burgess, 2007). Similarly, mortality rates for blacktip sharks increased with increasing time on the hook as measured by hook timers (Morgan and Carlson, 2010).

The typical duration of commercial demersal longline sets targeting sharks is 9-16 hours and can exceed 20 hours (Mandelman and Skomal, 2009). Consequently, commercial demersal longline operations can result in substantial time on the hook and, presumably, high at-vessel and post-release mortality rates (Mandelman and Skomal, 2009; Morgan and Burgess, 2007; Morgan and Carlson, 2010). However, the Caribbean reef shark (*Carcharhinus perezii*) captured with mid-water longlines exhibited the greatest level of physiological disruption after 120-180 min on the hook, whereas Caribbean reef sharks exposed to minimal or maximal time on the hook exhibited lower levels of physiological disruption (Brooks *et al*., 2012). These results suggest that for Caribbean reef sharks, longline capture appears to cause a shift in the stress response from acute at the onset of capture to sub-acute as capture event progresses, apparently facilitating a degree of physiological recovery (Brooks *et al*., 2012).

1.2 Hook and Line

Gurshin and Szedlmayer (2004) estimated the post-release live-discard mortality rate for hook and line captured Atlantic sharpnose sharks (10 %, n = 10). The Gurshin and Szedlmayer (2004) estimate includes injured-and-released as well as healthy-and-released Atlantic sharpnose sharks captured with hook and line, tagged with acoustic transmitters while under tonic immobility, released, and then monitored from a following vessel for up to six hours (Gurshin and Szedlmayer, 2004). All sharks were captured with typical gear from the recreational fishery (Gurshin and Szedlmayer, 2004). The single mortality observed in the study was consistent with the condition of the shark at release, which was bleeding from the gills and had the longest retrieval time recorded (6 min) among all of the tagged and released sharks (Gurshin and Szedlmayer, 2004). Equation 1, above, can be used to estimate the total discard mortality rate for hook and line captured sharks from the post-release live-discard mortality rate.

This review also identified several other studies from which post-release live-discard mortality rates of hook and line captured sharks could be derived. However, the estimates (0-24%) may be biased because none of these studies had the stated objective of estimating post-release mortality (e.g., see Campana *et al*., 2009b). For example, there was no post-release mortality (0.0%) for shortfin mako sharks (n = 3) captured with hook and line, tagged with satellite tags, and then released (Holts and Bedford, 1993). Post-release mortality was about 5% for juvenile blacktip sharks (n = 92) captured with hook and line, tagged with acoustic transmitters, released, and then monitored for 24 hours (Heupel and Simpfendorfer, 2002). However, all juvenile blacktip sharks were landed in less than one minute. Consequently, the mortality rates probably reflect the stress resulting from tagging, anesthetic, and resuscitation, rather than the stress associated with hook and line capture. For example, blood physiology following tonic immobility, often used in shark tagging studies, has been shown to result in additional physiological stress (Brooks *et al*., 2011). Mandelman and Farrington (2007a) estimated at-vessel mortality (0%) and post-release discard mortality (24%±6%) in spiny dogfish captured with hook and line and then held in pens for 72 hrs after capture. Each set consisted of five squid-baited standard circle hooks hung in the water-column (not directly on the substrate) from a short makeshift longline deployed and retrieved by hand (hand line). Due to the opportunistic feeding displayed by dogfish and the general ease of capture, this method enabled landing of individuals within 3 min of hook deployment. However, because all spiny dogfish were landed in less than three minutes, the high mortality rate may reflect the cumulative stress resulting from being held in a pen as well as the stress associated with hook and line capture and release (Mandelman and Farrington, 2007a).

Several studies were also identified which examined physiological stress in hook and line captured sharks (Cliff and Thurman, 1984; Hoffmayer and Parsons, 2001; Hight *et al*., 2007; Brooks *et al*., 2011). However, none of these studies provided direct estimates of post-release live-discard mortality rates. A common theme among these studies was that the blood physiology of sharks captured on hook and line and landed within less than a few minutes was consistent with “normal” physiological levels and indicative of very low stress levels (Cliff and Thurman, 1984; Hoffmayer and Parsons, 2001; Hight *et al*., 2007; Brooks *et al*., 2011). In contrast, the blood physiology of sharks that remained on the hook for periods greater than a few minutes was indicative of quickly and substantially increasing physiological stress in proportion to the amount of time on the gear (Cliff and Thurman, 1984; Hoffmayer and Parsons, 2001; Hight *et al*., 2007). An interesting result is that levels of lactate in shark blood continued to increase for several hours after the acute stress caused by capture with hook and line (Cliff and Thurman, 1984), longline and gillnet (Frick *et al*., 2010a), and trawl (Frick *et al*., 2010b). Consequently, lactate levels measured in blood at the time of capture may not necessarily be indicative of the eventual post-release live-discard mortality rates for sharks.

Evidence from one physiological study suggests that the acute capture stress of hook and line fishing may be comparable to that of pelagic research longline fishing for mako sharks (Hight *et al*., 2007). In particular, the blood physiology of shortfin mako sharks (noradrenaline and adrenaline) captured on hook and line and then "played" on the line for 15 to 30 min (n = 3) was comparable to or greater than that of mako sharks captured on pelagic research longlines deployed for up to three hours (n = 110) (Hight *et al*., 2007). Plasma lactate levels of tagged and released (18 mM, n = 48) and moribund (20 mM, n = 7) mako sharks captured on longlines deployed for up to three hours were also similar to those reported for mako sharks captured by recreational angling (16 mM, n = 9) (Hight *et al*., 2007).

1.3 Gillnet

Hueter and Manire (1994) estimated delayed mortality for juvenile and small adult sharks captured with research gillnets as 34.8% (n = 51 tag returns from all sharks combined, including bonnethead and Atlantic sharpnose, their Table 50). The at-vessel gillnet mortality rate for all juvenile and small adult sharks captured in research gillnets, combined, was 31% (n = 1,862 captured, with 570 dead at the vessel; Hueter and Manire 1994). Hueter and Manire (1994) then estimated total discard mortality for all sharks in their study using Eq. (1) as Total mortality = Immediate mortality + (Delayed mortality X Proportion released) = .306 + (.348 X .694) = .548.

Hueter *et al*. (2006) estimated the post-release live-discard mortality rate of juvenile blacktip sharks (31%; n = 2,898 tagged with 125 tag returns) and bonnethead sharks (40%; n = 4,352 tagged with 155 tag returns) captured with research gillnets set for one hour, tagged, released, and subsequently recaptured. The percentage of tagged and subsequently recaptured sharks declined with worsening condition category for both species which suggested that the condition at release influenced subsequent post-release live-discard mortality rates (Hueter *et al*., 2006). Shark catch in the research gillnets (Hueter *et al*., 2006) consisted of predominantly juveniles and small adults. The numerically dominant shark species in the research gillnet catch were bonnethead, blacktip, and blacknose (Hueter and Manire, 1994).

Rulifson (2007) estimated the post-release live-discard mortality rate of spiny dogfish (33%, n = 480) captured with gillnets of various mesh sizes set for 19- to 24-hour periods and retained after release in rectangular cages anchored to the sea floor for 48 hours. The study included both tagged and untagged spiny dogfish, and there was no significant difference in post-release mortality between tagged and untagged sharks (Rulifson, 2007). The study also included 480 trawl caught fish, and there was no post-release mortality in trawl caught spiny dogfish held 48 hours (Rulifson 2007), which indicated that the additional stress resulting from being held in net-pens did not lead to additional mortality.

The at-vessel mortality rate for sharks captured in research gillnets appears to be lower than that for the same sharks captured in commercial gillnets. For example, the at-vessel research gillnet mortality rate for bonnethead (31.4%, n = 1,115, juvenile and adult; Hueter and Manire 1994, their Tables 39 and 48) and Atlantic sharpnose (34.2 %, n = 38, primarily juvenile; Hueter and Manire 1994, their Tables 39 and 48) was about the same as that estimated for all juvenile and small adults sharks, combined, captured in research gillnets deployed for about one hr (31%; Hueter and Manire 1994). In contrast, scientifically modified commercial gillnets had substantially higher at vessel mortality rates for both Atlantic sharpnose (80.4%) and bonnethead (71.5%) irrespective of scientific modifications to the commercial gillnets or of the primary mode of entanglement (PEM) (Thorpe and Frierson, 2009). The numerically dominant shark species in the scientifically modified commercial gillnet catch were Atlantic sharpnose (n = 1,025), bonnethead (n = 148), blacktip (n = 78), and blacknose (n = 67). All life stages of Atlantic sharpnose were available to scientifically modified commercial gillnets (Thorpe and Frierson, 2009). Soak time with scientifically modified commercial gillnets was not reported (Thorpe and Frierson, 2009).

The physiological response of sharks to gillnet capture also varies among species (Manire *et al*., 2001; Frick *et al*., 2009; Frick *et al*., 2010a). The physiological stress of capture also increases with the duration of the capture event for shark species that are physiologically sensitive to gillnet capture (Frick *et al*., 2010a).

Differences in at-vessel mortality rates among species captured with gillnets may reflect differences in the physiology of pelagic, demersal, and bottom dwelling chondrichthyans (Braccini *et al.,* 2012). Braccini *et al*. (2012) used risk assessment to estimate total (immediate plus delayed) post-capture survival (PCS) for chondrichthyans captured with gillnets. For each individual alive at capture, delayed PCS was calculated "semi – quantitatively" as the product of four scores (activity and stimuli; wounds and bleeding; sea lice; and skin damage and bruising) each ranging from zero to one. Total PCS was then calculates as:

(Equation 2) Total PCS = (Immediate post capture survival)*(Delayed post capture survival).

Risk assessment estimates of total (immediate plus delayed) post-capture survival (PCS) by species type (Adapted from Braccini *et al.,* 2012) are provided below:

Species type	Total PCS (± SE) (Adapted from Braccini *et al.,* 2012)
Bottom-dwelling	0.94 (± 0.08)
Demersal	~0.4 (± 0.10)
Pelagic	0.14 (± 0.10)

1.4 Trawl

Mandelman and Farrington (2007a) estimated at-vessel mortality (0%) and post-release discard mortality (29%±12%) in spiny dogfish captured with trawls on commercial fishing vessels and then held in pens for 72 hrs after capture. However, the estimated post-release discard mortality rate may reflect the cumulative stress resulting from the net-pen design used in the study as well as the stress associated with trawl capture and release (Mandelman and Farrington, 2007a). In comparison, Rulifson (2007) found no post-release mortality in trawl caught spiny dogfish (n = 480 trawl caught dogfish) held in pens for 48 hours after capture.

In contrast, Stobutzki *et al*. (2002) estimated a 61% at-vessel mortality rate for all sharks combined captured in the Australian northern prawn trawl fishery, which included three species of the family Sphyrnidae and two species of the genus *Rhizoprionodon.* This review also identified several studies that examined the physiological stress of trawl capture (Cain *et al*., 2004; Frick *et al*., 2010b; 2007b). Unfortunately, none of these studies provide explicit estimates of post-release live-discard mortality rates. However, results of these studies suggest that physiological adaptations may make some shark species more resilient to the stress of trawl net capture than others (e.g., also see Stobutzki *et al*., 2002). For example, experiments which simulated the stress of trawl capture within the laboratory found that Port Jackson sharks experienced a low degree of physiological disturbance in response to simulated trawl capture treatments, and no mortality (capture or delayed) was observed for this species. In contrast, the homeostatic balance of gummy sharks was severely disrupted by simulated trawl capture, and both immediate and delayed capture mortality was substantial (up to 87%) during some simulated trawling experiments. An interesting result was that moribund gummy sharks (sharks which died subsequent to capture) showed significantly increased blood lactate and potassium levels relative to surviving sharks, but these differences did not become evident until 6-12 hours after the capture event (Frick *et al*., 2010b). Consequently, as noted above, lactate levels measured in blood at the time of capture may not necessarily be indicative of the eventual post-release live-discard mortality rates for trawl captured sharks.

2. Review of previous SEDAR decisions

The SEDAR 21 Life History (LH) Working Group (WG) developed post-release mortality rate estimates for sandbar, blacknose, and dusky sharks (Table 3) (NMFS 2011a, 2011b, 2011c, 2011d; their Section II: Data Workshop Report, sub-section 2.5 Discard Mortality). The SEDAR 21 Catch WG also presented estimates of post-release discard mortality, based on information provided by industry representatives at the meeting (Table 3) (NMFS 2011a, 2011b, 2011c, and 2011d; their Section II: Data Workshop Report, sub-section 3.4.2. Post Release Mortality). Final the SEDAR 21 Data Workshop (DW) panel decisions on post-release mortality rates were based on the LHWG and Catch WG recommendations (Table 3) (NMFS 2011a, 2011b, 2011c, 2011d; their Section II: Data Workshop Report, sub-section 3.4.2. Post Release Mortality).

Similarly, the SEDAR 29 Assessment Process (AP) panel developed post-release mortality rate estimates for Gulf of Mexico blacktip sharks (Table 4) (NMFS 2012; their sections 2.2.2.3—Commercial Discards Datasets—and 2.2.2.5—Recreational Discards Datasets and Decisions).

2.1 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

The SEDAR 29 AP panel applied a post-release live-discard mortality 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 SEDAR 29 AP panel recommended the use of juvenile blacktip shark post-release live-discard mortality rate estimates from research gillnets (31%; Hueter *et al.*, 2006) as a "central" estimate of GOM blacktip shark longline mortality. In order to evaluate the effect of uncertainty on model results, the panel recommended the use of 19% as a minimum estimate (Campana et al. 2009) and 73% as a maximum estimate. 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 assume that post-release live-discard mortality rate for blacktip sharks captured in commercial gillnets (73%) is proportional to (2.4 times higher than) that in research gillnets (31%).

2.2 Hook and Line

SEDAR 21

The SEDAR 21 DW panel recommended 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

The SEDAR 29 AP panel recommended applying a 10% discard mortality rate (Gurshin and Szedlmayer, 2004) to the live discards (B2) from MRIP/MRFSS, and including 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).

2.3 Gillnet

SEDAR 21

The SEDAR 21 DW panel recommended a 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. 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 (Table 2).

2.4 Trawl

SEDAR 21

The SEDAR 21 DW panel recommended a post-release discard mortality rates 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

The SEDAR 29 AP panel did not record a decision for post-release live-discard mortality rate estimates for blacktip sharks captured in commercial trawls.

Section 3

3.1 Post-release live-discard mortality rate estimates

Post-release live-discard mortality rate estimates were available in the literature for the Atlantic sharpnose shark captured with recreational hook and line (10%), and for bonnethead shark captured with research gillnets (40%) (Table 2). Post-release live-discard mortality rate estimates were also available in the literature for juvenile and small adult sharks, including Atlantic sharpnose, captured with research gillnets (35%) (Table 2). As a result, these values are recommended as post-release live-discard mortality rate estimates for consideration in SEDAR 34 (Table 5).

3.2 Model sensitivity scenarios

The SEDAR 29 AP panel applied the post-release live-discard mortality rate estimated for research gillnets to commercial bottom longline for the base model with a range for the low and high sensitivity scenarios. The low range value was the post-release live-discard mortality rate estimated for blue sharks captured with pelagic longlines (Campana et al., 2009). The high range value was obtained from the ratio of at-vessel mortality rate for sub adult blacktip sharks (Thorpe and Frierson, 2009) to the at-vessel mortality rate for juvenile blacktip sharks captured in research gillnets (Hueter and Manire, 1994) multiplied by the research gillnet post-release live-discard mortality rate of juvenile blacktip sharks captured in research gillnets (Hueter *et al.*, 2006) as described above.

The SEDAR 29 AP panel applied 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.

Atlantic sharpnose

Applying the SEDAR 29 AP panel rational for bottom longline here for Atlantic sharpnose sharks would result in a post-release live-discard mortality rate of 35% for commercial bottom longline for the base model, with a range of 19-82% for the low and high sensitivity scenarios. 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), and used here as a "central" estimate of longline mortality. 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 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 assume that post-release live-discard mortality rate for Atlantic sharpnose captured in commercial gillnets (82%) is proportional to (~2.3 times higher than) that in research gillnets (34.8%).

Applying the SEDAR 29 AP panel rational for hook and line here for Atlantic sharpnose would result in a post-release live-discard mortality rate of 10% for the base model, with a range of 5-15% for the low and high sensitivity scenarios (Table 6).

Bonnethead shark

Applying the SEDAR 29 AP panel rational for bottom longline here for bonnethead sharks would result in a post-release live-discard mortality 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 6). The value of 40% is the bonnethead shark post-release live-discard mortality rate estimate from research gillnets (Hueter *et al.*, 2006), and used here as a "central" estimate of longline mortality. 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 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 post-release live-discard mortality rate estimate from research gillnets; Hueter *et al.*, 2006) as:

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

These calculations assume that post-release live-discard mortality rate for bonnethead sharks captured in commercial gillnets (91%) is proportional to (~2.3 times higher than) that in research gillnets (40%).

Applying the SEDAR 29 AP panel rational for hook and line here for bonnethead sharks would result in a post-release live-discard mortality rate of 10% for the base model, with a range of 5-15% for the low and high sensitivity scenarios (Table 6).

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Table 1. Literature reviewed in this report.

Primary Literature	Species			Gear type					Study type				Notes
	Atlantic sharpnose	Bonnethead	Other species	Pelagic longline	Demersal longline	Hook and Line	Gillnet	Trawl	Physi-ological	Electronic tagging	Lab.	Other	
<u>Longline (pelagic)</u>													
Moyes *et al.* (2006)			Blue shark	X					X	X			Post-release live-discard mortality
Musyl *et al.* (2009)			Blue shark	X					X	X			Post-release live-discard mortality
Campana *et al*. (2009a, 2009b)			Blue shark	X						X			Post-release live-discard mortality
Diaz (2011)			Many	X								Observer data	At-vessel mortality
Musyl *et al.* (2011)			Blue shark	X						X		Meta-analysis	Post-release live-discard mortality
<u>Longline (demersal)</u>													
Holland *et al*. (1999)			Tiger shark		X					X			Movement rates
Morgan and Burges (2007)			Many		X							Observer data	Observer data
Morgan and Carlson (2010)	X		Many		X							Research/ commercial longline	At-vessel mortality
Morgan *et al*. (2010)	X	X	Many		X							Observer data	Bycatch rates
<u>Hook and line</u>													
Holts and Bedford (1993)			Shortfin mako			X				X			Movement rates
Heupel and Simpfendorfer (2002)			Blacktip			X				X			Post-release live-discard mortality
Gurshin and Szedlmayer (2004)	X		Atlantic sharpnose			X				X			Post-release live-discard mortality
<u>Gillnet</u>													
Hueter and Manire (1994)	X	X	Many				X			X			Post-release live-discard mortality
Hueter *et al.* (2006)		X	Bonnethead and Blacktip				X						Post-release live-discard mortality
Thorpe and Frierson (2009)	X	X	Many species				X					Bycatch mitigation	At-vessel mortality
Braccini *et al.* (2012)			Many species				X					Risk assessment	Total discard survival
<u>Trawl</u>													
Stobutzki *et al*. (2002)			Many species					X					At-vessel mortality
Mandelman and Farrington (2007a)			Spiny dogfish			X		X			X	Captured and held in net-pen (72 hrs)	Post-release live-discard mortality
Rulifson (2007)			Spiny dogfish				X	X				Captured and held in net-pen (48 hrs)	Post-release live-discard mortality

Table 1. Continued.

Primary Literature	Species			Gear type					Study type				Notes
	Atlantic sharpnose	Bonnethead	Other species	Pelagic longline	Demersal longline	Hook and Line	Gillnet	Trawl	Physi-ological	Electronic tagging	Lab.	Other	
<u>Physiological</u>													
Cliff and Thurman (1984)			Dusky shark			X			X				
Hoffmayer and Parsons (2001)		X	Atlantic sharpnose			X			X				
Cain *et al*. (2004)			Southern stingray					X	X				
Manire *et al*. (2001)		X	Bonnethead, bull				X		X				
Hight *et al*. (2007)			Pelagic and benthic	X		X			X				
Mandelman and Farrington (2007b)			Spiny dogfish					X	X				
Skomal (2007)	X	X	Many species	X		X	X	X	X			Review article	
Frick *et al*. (2009)			Benthic sharks				X		X				
Mandelman and Skomal (2009)	X		Carcharhinid sharks		X				X				
Frick *et al*. (2010a)			Benthic sharks		X		X		X				
Frick *et al*. (2010b)			Benthic shark					X	X				
Brooks *et al*. (2011)			Lemon shark			X			X				
Brooks *et al*. (2012)			Caribbean reef		X				X				
Cicia *et al*. (2012)			Skates						X				
Hoffmayer *et al*. (2012)	X		Atlantic sharpnose						X				
Renshaw *et al*. (2012)			Many species						X			Review article	
Skomal and Mandelman (2012)	X	X	Many species	X	X	X	X	X	X			Review article	
<u>Government reports</u>													
McLoughlin and Eliason (2008)	X		Many species			X						Review article	

Table 2. Post-release live-discard mortality rate estimates obtained from a review of the primary literature for evaluation in SEDAR 34.

Source	Species				
	Atlantic sharpnose	Bonnethead	Other species	Post-release live-discard mortality rate	Notes
Longline (pelagic)					
Campana *et al*. (2009b)			Blue shark	19% (10 – 29%)	Includes injured-and-released; Range is 95% confidence interval
Musyl *et al*. (2011)			Blue shark	15% (8.5 – 25.1%)	Meta-analysis; Range is 95% confidence interval
Longline (demersal)					
Hook and line					
Holts and Bedford (1993)			Shortfin mako	0%	Only tagged healthy sharks
Heupel and Simpfendorfer (2002)			Blacktip	5%	May reflect stress from anesthetic and resuscitation
Gurshin and Szedlmayer (2004)	X		Atlantic sharpnose	10%	Includes injured-and-released
Mandelman and Farrington (2007a)			Spiny dogfish	24±6% (mean±SE)	May reflect additional stress of being held in a net-pen after capture (72 hrs)
Gillnet					
Hueter and Manire (1994)	X	X	Many	34.8%	Estimate is for all juvenile and small adult sharks, combined, captured with research gillnets in Florida estuaries
Hueter et al. (2006)		X	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)
Trawl					
Mandelman and Farrington (2007a)			Spiny dogfish	29±12% (mean±SE)	May reflect 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)

Table 3. Previous post-release live-discard mortality estimates developed for sandbar, blacknose and dusky sharks by the SEDAR 21 Life History (LH) Working Group (WG) (Adapted from NMFS 2011a, 2011b, 2011c, 2011d; their Section II: Data Workshop Report, sub-section 2.5 Discard Mortality); Along with those developed by the SEDAR 21 Catch WG, and the final decisions made by SEDAR 21 Data Workshop (DW) panel (Adapted from NMFS 2011a, 2011b, 2011c, 2011d; their Section II: Data Workshop Report, sub-section 3.4.2. Post Release Mortality).

	Post-release live-discard mortality rate estimates by gear type			
SEDAR 21 Working Group	Longline	Hook and Line	Gillnet	Trawl
	A. Sandbar shark			
LH WG	38.24 %	3.25 %	NA	NA
Catch WG	2% (Pelagic longline); 5% (Bottom longline)	NA	5 %	NA
DW panel*	28.5% (Pelagic longline); 28.5 – 38.0 % (Bottom longline)	NA	5 – 10 %	NA
	B. 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 panel*	50 – 71 % (Bottom longline)	NA	50% (Drift gillnet); 5% (Strike gillnet); 25% (Sink gillnet)	NA
	C. Dusky shark			
LH WG	65.17%	6.0 %	NA	NA
Catch WG	5 % (Pelagic longline); 35 % (Bottom longline)	NA	50 %	NA
DW panel*	44.2 % (Pelagic longline); 44.2 – 65 % (Bottom longline)	NA	50 %	NA

*Final decisions.

Table 4. Previous post-release live-discard mortality rate estimates developed for Gulf of Mexico (GOM) blacktip sharks by the SEDAR 29 Assessment Process (AP) panel (Adapted from NMFS 2012; their sections 2.2.2.3—Commercial Discards Datasets—and 2.2.2.5—Recreational Discards Datasets and Decisions).

	Post-release live-discard mortality rate estimates by gear type			
Working Group	Longline	Hook and Line	Gillnet	Trawl
		GOM blacktip shark		
SEDAR 29 AP panel*	31 % (Base) 19 – 73% (Range)	10 % (Base) 5 – 15 % (Range)	31% (Base)	NA

*Final decisions.

Table 5. Post-release live-discard mortality rate estimates for Atlantic sharpnose shark (Panel A) and bonnethead shark (Panel B) by gear type for consideration in SEDAR 34.

Post-release live-discard mortality rate estimates by gear type			
Longline	Hook and Line	Gillnet	Trawl
	A. Atlantic sharpnose shark		
NA	10%	35%	NA
	B. Bonnethead shark		
NA	NA	40%	NA

Table 6. Model sensitivity scenarios previously developed by the SEDAR 29 AP panel for post-release live-discard mortality rate estimates by gear type (bottom longline, hook and line, and gillnet) applied here for Atlantic sharpnose shark (Panel A) and Bonnethead shark (Panel B).

	Post-release live-discard mortality rate estimates by gear type (Model sensitivity scenarios)			
Scenario	Longline	Hook and Line	Gillnet	Trawl
		A. Atlantic sharpnose shark		
Base	35%	10%	35%	NA
Low	19%	5%	NA	NA
High	82%	15%	NA	NA
		B. Bonnethead shark		
Base	40%	10%	40%	NA
Low	19%	5%	NA	NA
High	91%	15%	NA	NA