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Dean Courtney

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A PRELIMINARY REVIEW OF POST-RELEASE LIVE-DISCARD MORTALITY ESTIMATES FOR GULF OF MEXICO BLACKTIP SHARKS

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

Executive Summary

This document reviews the primary scientific literature on post-release live-discard mortality rates in order to develop discard mortality rate estimates by gear type (longline, hook and line, gillnet, and trawl) for use in the Gulf of Mexico blacktip shark stock assessment.

Longline

The results of this review suggest that the best estimate of the post-release live-discard mortality rate for longline (pelagic and demersal) captured blacktip sharks is 19%. This estimate, obtained from pelagic longline captured blue sharks, includes injured-and-released as well as healthy-and-released sharks. There is evidence that the post-release live-discard mortality rates of sharks may increase in proportion to increasing at-vessel mortality rates. Consequently, the post-release live-discard mortality rate obtained for blue sharks captured in longlines may need to be adjusted upwards for use in the Gulf of Mexico blacktip shark stock assessment in order to reflect the higher at-vessel hooking mortality rate of demersal longline captured blacktip sharks (88%) relative to that of pelagic longline captured blue sharks (~13%). Equation 1, below, can then be used to estimate the total discard mortality rate for longline captured blacktip sharks from the post-release live-discard mortality rate. This approach is consistent with that recommended from a previous review at the SEDAR 21 Data Workshop, except that they used an ad hoc approach to estimate total discard mortality while the results of this review suggest the use of Equation 1 below.

Hook and line

The results of this review suggest that the best estimate of the post-release live-discard mortality rate for hook and line captured blacktip sharks is 10%. This estimate, obtained from hook and line captured Atlantic sharpnose sharks, includes injured-and-released as well as healthy-and-released sharks. Equation 1, below, can be used to estimate the total discard mortality rate for hook and line captured blacktip sharks from the post-release live-discard mortality rate. This contrasts with the SEDAR 21 Data Workshop, which recommended a 6% post-release live-discard mortality rate for hook and line captured sharks and used an ad hoc approach to estimate total discard mortality.

Gillnet

The results of this review suggest that the best estimate of the post-release live-discard mortality rate for gillnet captured blacktip sharks is 31%, obtained from a study of juvenile blacktip sharks captured with research gillnets. The post-release live-discard mortality rate for blacktip sharks captured in research gillnets may need to be adjusted upward for use in the Gulf of Mexico blacktip shark stock assessment in order to reflect the higher at-vessel mortality rates of blacktips captured in commercial gillnets (90%) relative to those captured with research gillnets (38%). Equation 1, below, can then be used to estimate the total discard mortality rate for gillnet captured blacktip sharks from the post-release live-discard mortality rate. The SEDAR 21 Data Workshop did not review gillnet discard mortality.

Trawl

This review was unable to identify any reliable estimates of trawl capture post-release live-discard mortality rates for use in the Gulf of Mexico blacktip shark stock assessment. Consequently, in the absence of a better alternative, the post-release live-discard mortality rate for pelagic longline captured blue sharks (19%) may provide a reasonable proxy estimate of the post-release live-discard mortality rate for trawl captured sharks. The post-release live-discard mortality rate for blue sharks captured in longlines may need to be adjusted upward for use in the Gulf of Mexico blacktip shark stock assessment in order to reflect the higher at-vessel mortality rates of sharks (including carcharhinid species) captured in trawls (~61%) relative to those of blue sharks captured with pelagic longlines (~13%). Equation 1, below, can then be used to estimate the total discard mortality rate for trawl captured blacktip sharks from the post-release live-discard mortality rate. This approach is consistent with that recommended at the SEDAR 21 Data Workshop, except that they used an ad hoc approach to estimate total mortality while this review recommends the use of Equation 1 below.

Review of Live-Discard Mortality Estimates

This document reviews the primary scientific literature on post-release live-discard mortality rates in sharks in order to develop discard mortality rate estimates for use in the Gulf of Mexico blacktip shark stock assessment (Table 1). 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*., in press; Skomal and Mandelman, in press). 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). The physiological response to capture stress may also depend on other factors such as season and water temperature (Cicia *et al*., in press; Hoffmayer *et al.*, in press).

The SEDAR 21 Data Workshop reviewed the primary scientific and grey literature, examining at-vessel and discard mortality in order to estimate post-release survivorship (NMFS 2011a, 2011b, 2011c, 2011d; their Section II: Data Workshop Report, sub-section 2.5 Discard Mortality). This review includes the same literature available to the SEDAR 21 Data Workshop plus some additional recent publications (Table 1). Because mortality rates likely vary among gear types as well as among species, the SEDAR 21 Data Workshop chose to provide species specific estimates of discard mortality by gear type. This review follows the same convention and develops estimates of blacktip shark post-release live-discard mortality rates by gear type.

1. Longline (Pelagic and Demersal)

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 Data Workshop 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 Data Workshop applied this 6% increase in mortality to the at-vessel mortality estimates 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 estimates of discard mortality of 38.24% for longline captured sandbar sharks, 71.18% for longline captured blacknose sharks, and 65.17% for longline captured dusky sharks.

However, the results of the current review suggest a different interpretation of Campana *et al*. (2009b). In particular, the Campana *et al*. (2009b) estimate of post-release live-discard mortality for pelagic longline captured blue sharks (19%) specifically excluded dead-discard mortality (i.e., at-vessel mortality). Consequently, in contrast to the ad-hoc approach recommended at the SEDAR 21 Data Workshop, the results of this review suggest that total discard mortality which includes the post-release live-discard estimate from Campana *et al*. (2009b) should be calculated (e.g., following the methods in Hueter and Manire, 1994) as

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

The post-release live-discard mortality rate for pelagic longline captured blue sharks (19%, with a 95% confidence interval estimated from Monte Carlo Simulation of 10 to 29%) (Campana *et al*., 2009b) is the best estimate of post-release mortality because it specifically includes 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).

Longline capture post-release live-discard mortality rates estimated for pelagic sharks in other studies are consistent with those from Campana *et al*. (2009b). The post-release live-discard mortality rate for pelagic longline captured blue sharks estimated from meta-analysis is 15% with a 95% confidence interval of 8.5 to 25.1% (Musyl *et al*., 2011). 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).

The post-release live-discard mortality rate for longline captured blue sharks (19%) may need to be adjusted upward to reflect the substantially higher at-vessel hooking mortality rate for demersal longline captured blacktip sharks. For example, at-vessel hooking mortality for blue sharks captured in pelagic longline fisheries is estimated to be between 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). In contrast, the at-vessel mortality rate of blacktip sharks (n = 1,982) observed in the northwest Atlantic and Gulf of Mexico commercial shark fishery observer program (CSFOP) from January 1994 to April 2005 is substantially higher (88% total, 86.4%

young, 90.5% juvenile, and 87.3% adult) (Morgan and Burgess, 2007). 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).

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. For example, among carcharhinid species, the relative degree of blood acid-base disturbance reflected in physiological data is proportional to at-vessel mortality rates (Table 3) (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 (Table 3) (Mandelman and Skomal, 2009). It is interesting to note that within this relative ranking, blacktip sharks have the highest relative blood acid-base disturbance, the highest at-vessel mortality rate, and the lowest conventional tag recapture rate (Table 3) (Mandelman and Skomal, 2009).

2. Hook and Line

The SEDAR 21 Data Workshop reviewed the available literature in order to develop estimates of hook and line post-release mortality and recommended a 6% post-release mortality rate for dusky sharks (NMFS 2011a, 2011b, 2011c, 2011d; their Section II: Data Workshop Report, sub-section 2.5 Discard Mortality). The SEDAR 21 Data Workshop then used at-vessel hooking mortality from Morgan and Burgess (2007) and two Observer Program data sets (CSFOP and SBLOP) as proxies for a comparison of the survival of sandbar sharks compared to dusky sharks. 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%. 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% for blacknose sharks.

However, the results of this review suggest a different interpretation of post-release total discard mortality in hook and line fisheries. In particular, the results of this review suggest that the best estimate of post-release live-discard mortality rates for hook and line captured blacktip sharks is 10%. This estimate, obtained from hook and line captured Atlantic sharpnose sharks (n = 10) (Gurshin and Szedlmayer, 2004), 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, below, can be used to estimate the total discard mortality rate for hook and line captured blacktip 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). Post-release mortality was 24% for spiny dogfish captured with hook and line and monitored in pens for 72 hours after release (Mandelman and Farrington, 2007). 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 (Mandelman and Farrington, 2007) as well as the stress associated with hook and line capture and release (Mandelman and Farrington, 2007).

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 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. 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). The typical duration of demersal longline sets targeting sharks is

9-16 hours and can exceed 20 hours (Mandelman and Skomal, 2009). Consequently, commercial longling operations can result in substantially more time on the hook and, presumably, higher at-vessel and post-release mortality rates (Mandelman and Skomal, 2009; Morgan and Burgess, 2007; Morgan and Carlson, 2010). However, Caribbean reef sharks captured with longlines exhibited the greatest level of physiological disruption after 120-180 min on the hook, whereas sharks exposed to minimal or maximal time on the hook exhibited lower levels of physiological disruption (Brooks *et al*., in press). These results suggest that, at least for some shark species, 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*., in press). Consequently, at least for some shark species, capture stress from hook and line gear may be comparable to that of longline gear.

3. Gillnet

The results of this review suggest that the best estimate of the post-release live-discard mortality rate of blacktip sharks captured in gillnets is 31%, obtained from juvenile blacktip sharks captured with research gillnets (Hueter *et al*., 2006). The post-release live-discard mortality rate of blacktip sharks captured in gillnets (31%) may need to be adjusted upward to reflect the relative difference in the at-vessel gillnet mortality rate for juvenile blacktips captured with research gillnets (38%) (Hueter and Manire, 1994) relative to that of subadult blacktips captured in scientifically monitored commercial gillnets (90%) (Thorpe and Frierson, 2009). Equation 1 can then be used to estimate total discard mortality rates. The SEDAR 21 Data Workshop did not develop estimates of post-release mortality for gillnets.

Hueter *et al*. (2006) estimated the post-release live-discard mortality rate of juvenile blacktip sharks (69%) and bonnetheads (60%) captured with research gillnets, tagged, and then released. 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). The at-vessel gillnet mortality rate for juvenile blacktips (38%, n = 323 captured with 122 dead at the vessel) was about the same as that of all juvenile and small adults sharks combined (31%, n = 1,862 captured with 570 dead at the vessel). Soak time with research gillnets was approximately one hour (Hueter *et al*., 2006). In contrast, scientifically modified commercial gillnets had substantially higher at vessel mortality rates (79% for all sharks, 80.4% for Atlantic sharpnose, 81.3% for blacknose, and 90.5% for blacktips) (Thorpe and Frierson, 2009) irrespective of scientific modifications to the commercial gillnets or of the primary mode of entanglement (PEM). 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 and blacknose were available to and selected by the scientifically modified commercial gillnets, but only a narrow range of subadult blacktips were available to the scientifically modified commercial gillnets (modal length 88-96 cm FL) (Thorpe and Frierson, 2009). Soak time with scientifically modified commercial gillnets was not reported (Thorpe and Frierson, 2009). The proportion of sharks retrieved alive from scientifically modified commercial gillnets and subsequently released in good condition was also reported: 64% for Atlantic sharpnose, 57% for blacknose, 62% for blacktips, and 40% for bonnethead (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). For example, the post-release live-discard mortality rate of spiny dogfish (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 was relatively low (33%) (Rulifson, 2007). The study included both tagged and untagged spiny dogfish, but there was no significant difference in post-release mortality between tagged and untagged sharks (Rulifson, 2007). The study also included 480 trawl caught fish, but there was no post-release mortality in trawl caught spiny dogfish held 48 hours (Rulifson 2007). In a separate study, for shark species that are physiologically sensitive to gillnet capture, the physiological stress of capture increased with the duration of the capture event (Frick *et al*., 2010a).

4. Trawl

The SEDAR 21 Data Workshop reviewed the available literature in order to develop estimates of trawl post-release mortality (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.

The results of the current review suggest a slightly different interpretation of post-release total discard mortality in trawl fisheries. This review was unable to identify any reliable estimates of trawl post-release live-discard mortality for use in the Gulf of Mexico blacktip shark stock assessment. Consequently, in the absence of a better alternative, the post-release live-discard mortality rate for pelagic longline captured blue sharks (19%) may provide a reasonable proxy estimate of the post-release live-discard mortality rate for trawl captured sharks. This result is consistent with the review at the SEDAR 21 Data Workshop. Stobutzki *et al*. (2002) estimated a 61% at-vessel mortality rate for all sharks in the Australian northern prawn trawl fishery, which included three species of the genus *Carcharhinus* and one species of the genus *Rhizoprionodon.* Consequently, the post-release live-discard mortality rate for blue sharks captured in longlines (19%) may need to be adjusted upward for use in the Gulf of Mexico blacktip shark stock assessment in order to reflect the higher at-vessel mortality rates of sharks captured in the Australian northern prawn trawl fishery (~61%) relative to those of blue sharks captured pelagic longlines (~13%). This result is also consistent with the review at the SEDAR 21 Data Workshop. However, in contrast to the ad-hoc approach used at the SEDAR 21 Data Workshop to estimate total discard mortality, the results of this review suggest the use of Equation 1 to estimate the total discard mortality rate from the post-release live discard mortality rate for trawl captured sharks.

This review also identified several studies which examined the physiological stress of trawl capture (Cain *et al*., 2004; Frick *et al*., 2010b; Mandelman and Farrington, 2007a, 2007b; Rulifson, 2007). 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.

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Table 1. Literature reviewed in this report.

	Species		Gear type					Study type	
Primary Literature	Blacktip	Other species	Pelagic longline	Demersal longline	Hook and Line	Gillnet	Trawl	Physiological	Electronic tagging
<u>Longline (pelagic)</u>									
Moyes *et al*. (2006)		Blue shark	X					X	
Musyl *et al*. (2009)		Blue shark	X					X	
Campana *et al*. (2009a, 2009b)		Blue shark	X						X
Diaz (2011)	X	Many species	X						
Musyl *et al*. (2011)		Blue shark	X						X
<u>Longline (demersal)</u>									
Holland *et al*. (1999)		Tiger shark		X					
Morgan and Burges (2007)	X	Many species		X					
Morgan and Carlson (2010)	X	Many species		X					
Morgan *et al*. (2010)	X	Many species		X					
<u>Hook and line</u>									
Holts and Bedford (1993)		Shortfin mako			X				X
Gurshin and Szedlmayer (2004)		Atlantic sharpnose			X				X
Heupel and Simpfendorfer (2002)	X				X				X
<u>Gillnet</u>									
Hueter and Manire (1994)	X	Many species				X			X
Hueter *et al*. (2006)	X	Bonnetheads				X			
Thorpe and Frierson (2009)	X	Many species				X			
<u>Trawl studies</u>									
Stobutzki *et al*. (2002)		Many species					X		
Mandelman and Farrington (2007a)		Spiny dogfish			X		X		
Rulifson (2007)		Spiny dogfish				X	X		
<u>Phiysological</u>									
Cliff and Thurman (1984)		Dusky shark			X			X	
Hoffmayer and Parsons (2001)		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)		Shortfin mako	X		X			X	
Mandelman and Farrington (2007b)		Spiny dogfish					X	X	
Skomal (2007)		Many species						X	
Frick *et al*. (2009)		Benthic sharks				X		X	
Mandelman and Skomal (2009)	X	Carcharhinid sharks		X				X	
Frick *et al*. (2010a)		Gummy shark		X		X		X	
Frick *et al*. (2010b)		Gummy shark					X	X	
Brooks *et al*. (2011)		Lemon shark			X			X	
Brooks *et al*. (in press)		Caribbean reef		X				X	
Cicia *et al*. (in press)		Skates						X	
Hoffmayer *et al*. (in press)		Atlantic sharpnose						X	
Renshaw *et al*. (in press)		Many species						X	
Skomal and Mandelman (in press)		Many species						X	
<u>Government reports</u>									
McLoughlin and Eliason (2008)		Many species							

Table 2. Blue shark post-release live-discard mortality rates in pelagic longline fisheries (Adapted from Campana *et al*., 2009b).

	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)	NA	NA	0 - 5%	NA	NA
Campana *et al*. (2009a, 2009b)	12-13% (Observer data), 20% (Scientific subsample)	31% (Observer data), 44% (Scientific subsample)	0%	33%	19% (10-29%)
Musyl *et al*. (2011)	NA	NA	NA	NA	15% (8.5-25.1%)

Table 3. The relative degree (median rank) of blood acid-base disturbance among shark species resulting from longline capture (1 is the lowest disturbance); the relative rank (lowest to highest) of longline at-vessel mortality rates; and the relative rank (highest to lowest) of conventional tagging recapture rates (Adapted from Mandelman and Skomal, 2009; their Table 3).

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%