
A review of capture and post-release mortality of elasmobranchs

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Abstract :

There is a need to better understand the survivorship of discarded fishes, both for commercial stocks and species of conservation concern. Within European waters, the landing obligations that are currently being phased in as part of the European Union's reformed common fisheries policy means that an increasing number of fish stocks, with certain exceptions, should not be discarded unless it can be demonstrated that there is a high probability of survival. This study reviews the various approaches that have been used to examine the discard survival of elasmobranchs, both in terms of at-vessel mortality (AVM) and post-release mortality (PRM), with relevant findings summarized for both the main types of fishing gear used and by taxonomic group. Discard survival varies with a range of biological attributes (species, size, sex and mode of gill ventilation) as well as the range of factors associated with capture (e.g. gear type, soak time, catch mass and composition, handling practices and the degree of exposure to air and any associated change in ambient temperature). In general, demersal species with buccal-pump ventilation have a higher survival than obligate ram ventilators. Several studies have indicated that females may have a higher survival than males. Certain taxa (including hammerhead sharks *Sphyrna* spp. and thresher sharks *Alopias* spp.) may be particularly prone to higher rates of mortality when caught.

Keywords : batoids, by-catch, discards, dogfish, sharks, survival.

INTRODUCTION

Many fisheries management bodies are currently trying to reduce discards in fisheries, whether this be to reduce regulatory discards (and so minimising waste) or to minimise bycatch of vulnerable marine species. Reducing discards is a central tenet of the European Union's (EU) reformed Common Fisheries Policy (CFP) and an obligation to land all catches of species subject to catch limits (the so-called 'discard ban') is to be phased in for various fisheries over the period 2015–2019 (EU, 2013). CFP reform, however, also notes that "*The landing obligation should be introduced on a fishery-by-fishery basis. Fishermen should be allowed to continue discarding species which, according to the best available scientific advice, have a high survival rate when released into the sea*". The interpretation of what constitutes 'high' survival, however, may vary between fisheries and taxa, and has not been quantified by the EU.

Elasmobranch fish are widely recognised as susceptible to overexploitation (Ellis *et al.*, 2008a). Within European waters, several stocks are considered depleted and, in the most extreme cases, species such as angel shark *Squatina squatina* (Linnaeus 1758) and white skate *Rostroraja alba* (Lacepède 1803) have been extirpated from areas of former habitat (ICES, 2015). Given the high conservation interest in elasmobranch stocks, a variety of national and international management measures have been introduced to protect the more vulnerable species and to ensure the sustainable exploitation of commercially-exploited species. The efficacy of management actions, however, can be dependent on the degree of discard survival.

Within the ICES area, several elasmobranchs have been managed under the traditional EU system of Total Allowable Catches (TACs), including skates (Rajiformes), spurdog *Squalus*

acanthias Linnaeus 1758 and some deep-water sharks. There have also been calls to introduce 'catch limits' for other elasmobranch species that are not currently subject to management (e.g. smooth-hounds *Mustelus* spp.). Hence, a variety of elasmobranchs may need to be considered in relation to possible future landing obligations in European waters. The CFP states that the landings obligation shall not apply to "*species for which scientific evidence demonstrates high survival rates, taking into account the characteristics of the gear, of the fishing practices and of the ecosystem*" (EU, 2013).

Consequently, there is a need to understand the fate (discard-retention pattern) and discard survival of such species. Furthermore, justifying the potential benefits of 'non-retention' management measures, as has been applied to certain skate stocks (EU, 2016), also requires an appropriate level of knowledge regarding the likely mortality of fish discarded.

Under the CFP, the landing obligation does not apply to those species for which "*fishing is prohibited and which are identified as such in a Union legal act*" (EU, 2013). Species that are currently subject to prohibitions include sawfish (Pristidae), manta and mobulid rays (Mobulidae), basking shark *Cetorhinus maximus* (Gunnerus 1765), white shark *Carcharodon carcharias* (Linnaeus 1758) and porbeagle shark *Lamna nasus* (Bonnaterre 1788) (all waters), *S. squatina* (Union waters), guitarfish (Rhinobatidae) in Union waters of ICES subareas I–XII, as well as various skates (Rajidae) and deep-water sharks in certain areas (EU, 2016). Whilst such species will not be included under the landing obligation, an appropriate knowledge of both bycatch rates and discard survival are required if the efficacy of prohibited status is to be gauged.

Similarly, several other Regional Fisheries Management Organisations (RFMOs) mandate or encourage that certain elasmobranchs are released when caught. For example, ICCAT

recommend that Contracting Parties “*prohibit, retaining onboard, transshipping, landing, storing, selling, or offering for sale any part or whole carcass*” of bigeye thresher shark *Alopias superciliosus* Lowe 1841 (Recommendation 2009–07), silky shark *Carcharhinus falciformis* (Müller & Henle 1839) (Recommendation 2011–08), oceanic whitetip shark *Carcharhinus longimanus* (Poey 1861) (Recommendation 2010–07) and all hammerhead sharks (Family Sphyrnidae, except bonnethead shark *Sphyrna tiburo* (Linnaeus 1758)) (Recommendation 2010–08). Similarly, Contracting parties to the GFCM should ensure that tope *Galeorhinus galeus* (Linnaeus 1758), if caught by bottom-set nets, longlines or tuna traps “*shall be promptly released unharmed and alive to the extent possible*”.

Given the increasing conservation and management interest in elasmobranch fish, both in European seas (including in relation to the landing obligation) and internationally, and that the effectiveness of potential management measures will be highly dependent on the degree to which fishing mortality would be reduced, a review of studies examining discard mortality of elasmobranchs is provided below. This includes a review of the various approaches that have been developed, an overview of studies by broad category of gear, and a synopsis of available data by taxonomic group.

APPROACHES TO EVALUATING DISCARD MORTALITY

In general terms, the mortality is here considered to be primarily a function of at-vessel mortality (AVM), which is the proportion of fish that are dead when the fish are brought on board (or alongside) a fishing vessel, and post-release mortality (PRM), which is the proportion of fish that are released from the vessel or gear alive but do not survive in the short term due to succumbing to injuries sustained or through predation by opportunistic

predators and scavengers. Whilst capture in commercial gears can cause physical damage, it has been suggested that elasmobranchs can have a high capacity for physical injuries to be healed (Chin *et al.*, 2015), although empirical data for fishing-related injuries are lacking and this perception is based mostly on anecdotal observations.

The capture of fish can result in both physical damage (e.g. following interactions with the fishing gear, abrasion with other contents of a trawl net, impact of scavengers on fish caught in set nets and on lines) as well as physiological stress (e.g. through increased anaerobic muscular activity, barotrauma if raised from depth, impaired respiration and air exposure, which can also include exposure to different ambient temperatures), and the handling of captured fish as they are discarded can cause further physical and physiological trauma (Chopin & Arimoto, 1995; Davis, 2002; Poisson *et al.*, 2014b). The impact of these different factors can vary not only between species, but also between sex and size, season (as a function of differences in air and water temperatures) and some may be exacerbated by poor sea states (Davis, 2002; Moyes *et al.*, 2006; Hoffmayer *et al.*, 2012; Benoît *et al.*, 2013; Coelho *et al.*, 2013).

In addition to being brought on board fishing vessels, there is also the potential for fish to become entangled in fishing gear, whether during escape or from encountering previously lost gear, which can also lead to mortality or impact on health state. Injuries following capture have been documented for various elasmobranchs (Schwartz, 1984; Seitz & Poulakis, 2006; Kabasakal, 2010; Wegner & Cartamil, 2012).

It is important to recognise that discard mortality encompasses both AVM and PRM, where a proportion of those fish discarded 'alive' may die in the short-term as a consequence of any physical injury, trauma and physiological stress sustained during capture and handling

(Pollock & Pine, 2007; Poisson *et al.*, 2014a). Injured fish may be also prone to infection (Borucinska *et al.*, 2002; Adams *et al.*, 2014), more susceptible to attack by predators and scavengers (Davis, 2002) or have sustained physiological damage that may affect the feeding and swimming behaviour, growth, the immune system or reproductive biology (Skomal, 2007), even over the longer term.

An increasing number of studies have used a combination of approaches so that AVM and PRM can be assessed, but it should also be remembered that some of these methods (e.g. maintenance in tanks, blood sampling or tagging) can also confer some degree of handling- or captive stress that may confound estimates of PRM (Pollock & Pine, 2007). In order to better differentiate the components of PRM that may relate to the capture event, as opposed to any handling associated with the scientific method employed, discard survival studies should aim to employ a more benign capture technique as a 'control' (Beardsall *et al.*, 2013).

QUALITATIVE HEALTH SCORES

Many studies have assigned the health, condition or vitality of the fish assessed, typically using a subjective evaluation by the field investigator(s) and not always with pre-defined descriptions. Such evaluations can range from more simple 'alive' or 'dead' scores (Stobutzki *et al.*, 2002) to categories of three (lively, sluggish, dead) or five (excellent condition, good, moderate, poor, dead) health states. The assignment of fish within categories is to a certain degree arbitrary, and whilst using a larger number of categories has some benefits, these may be better in studies with a restricted number of assessors. More extensive field programmes involving multiple field workers may benefit from a more restricted number of categories.

Some studies (e.g. Benoît *et al.*, 2010b) have used pre-defined criteria to assess more objectively the degree of external damage and/or vitality (Table I).

Such studies allow large numbers of fish to be assessed in the field very rapidly and cheaply, including during on-going observer programmes that collect data during normal fishing operations. Whilst providing useful information on AVM, often with larger sample sizes that can be attained in dedicated research projects, it does not necessarily provide appropriate information on PRM in the short and longer-term, which a range of other methods can help address (Skomal, 2007).

Some scientific studies have scored fish in relation to a 'Behavioural Release Condition Score' (BRCS), whereby the vigour and vitality of fish is scored on a qualitative scale when released, ranging from when fish actively swim away, to more moribund fish that sink and show minimal movements (e.g. Hyatt *et al.*, 2016). Studies have found good correlations between BRCS and blood chemistry, and so this may serve as a better indicator than vitality at capture. Such approaches, however, have not been used widely in fishery-dependent studies, possibly because there is a greater variation in sea state, light levels, vessel speed and water clarity which would impact on the ability for such data to be collected effectively.

Elasmobranch fish are able to evert part of their spiral intestine (through the cloaca) or stomach (through the mouth), which may aid in the expulsion of indigestible food remains (Crow *et al.*, 1990; Sims *et al.*, 2000; Brunnschweiler *et al.*, 2011). Whilst elasmobranchs captured in commercial fisheries can be found with parts of the alimentary tract everted, the extent to which such organs may be damaged, and influence the probability of survival following release, is unclear.

SURVIVAL TANKS

Several studies have monitored the survival of smaller demersal sharks and skates for the days following capture using on-board survival tanks (Revill *et al.*, 2005; Benoît *et al.*, 2010a), cages or pens anchored to the sea floor (Mandelman & Farrington, 2007b) or after transporting fish to tanks on land for subsequent study (Mandelman & Farrington, 2007b). Such approaches provide more robust information on the survival of fish with different health states over a period of a few days. These approaches are, however, more difficult to employ for larger and faster-swimming species. Additionally, other factors such as captive stress, stocking densities and environmental conditions may also contribute as artefacts to estimates of PRM. It has also been suggested that the use of single flow-through systems and stacked individual tanks may confound effects (e.g. through the transferral of some waste products and cross-infection) and may be better considered as pseudo-replicates (Broadhurst *et al.*, 2006).

Revill *et al.* (2005) used survival tanks mounted in a rack with a constant flow of fresh sea water to examine the survival of lesser-spotted dogfish *Scyliorhinus canicula* (Linnaeus 1758) for periods of 36–60 h following capture in commercial 8 m beam trawl with chain mat. This is a relatively small demersal species (specimens in this study were 40–70 cm total length, L_T), and so it is amenable to such studies. Short-term survival was demonstrated to be very high (98%) in this study.

Rulifson (2007) caught *S. acanthias* by commercial otter trawl and gillnet, with sampled fish left on deck for 0.17–0.25 h (to simulate the processes that may be expected during commercial operations) before being categorised as live or dead (with injuries also noted). Sub-samples ($n = 480$ for each gear type) were then placed in sea pens that were anchored

for 48 h. The direct capture mortality was 0% for trawl (0.5–1.5 h tow duration) and 17.5% for gillnet (19.5–23.5 h soak time). Following 48 h in sea pens, there was no further mortality of trawl-caught *S. acanthias*, whereas there was a further 33% mortality for those caught by gillnet. Mandelman & Farrington (2007b) also used sea pens to estimate survival of *S. acanthias* and found 29% mortality (after 72 h) of caged fish caught by trawl and 24% mortality for fish caught on short long-lines. The latter was considered a more benign capture technique, and so the mortality in captivity may have been influenced by other factors such as captive stress, physical contact with the sea pen or the presence of scavenging isopods (Mandelman & Farrington, 2007b).

CONVENTIONAL TAGGING

Mark-recapture programmes have been used in numerous discard survival studies, primarily as a way of validating that fish assessed as healthy had indeed survived. Many other factors also influence recapture and tag return rates, including tag shedding, emigration, publicity of tagging scheme, degree of active participation by fishers and degree of geographical overlap between fishing activity and the stock of fish tagged (Kohler & Turner, 2001).

Ellis *et al.* (2008b) tagged and released thornback ray *Raja clavata* Linnaeus 1758 caught in various trawls as well as on longlines and by gillnet. Preliminary analyses of these data indicated that the tag return rates were highest for fish caught by longline (22.2–23.6%) and drift trammel net (24.8%), slightly lower for trawl (15.7% for all data combined, but ranging from 12.7–24% for individual vessels) and were lowest in gillnet fisheries (9.5%). It was unclear as to whether the reduced recapture rate in the latter gear was due to higher PRM or, as the latter vessel had operated at the southern-most part of the survey area, whether

there had been spatial differences between fishing ports in terms of the likelihood of tags being returned.

Whereas the results of mark-recapture programmes can confirm that there is some longer-term survival, the exact degree of discard survival may not be quantifiable, although there are potential approaches to infer the relative survival, for example when examining the impacts of different gears. For example, Hueter *et al.* (2006) compared the relative survival of sharks captured by gillnet and then tagged and released. All sharks were assigned a condition (on a score of 1–5), and differences in the return rates between these samples were modelled to inform on the mortality, assuming that there was no delayed post-capture mortality for fish in the best condition. For example, the recapture rates of blacktip shark *Carcharhinus limbatus* (Müller & Henle 1839) that had been released in ‘good’, ‘fair’, ‘poor’ and ‘very poor’ conditions were 6.3%, 4.2%, 3.6% and 1.1%, respectively. Similarly, the recapture rates of *S. tiburo* were 6.0%, 4.8%, 2.6% and 1.2%, respectively. The results from this study suggested that 31% and 40% of tagged and released *C. limbatus* and *S. tiburo* died as a result of capture. Given an observed AVM of 40% (*C. limbatus*) and 37% (*S. tiburo*), the overall capture mortalities were then estimated at 58% and 62% for these two species.

Analyses of mark-recapture data for a broader range of species in any given geographic region to try and determine whether tag return rates can be correlated with varying categories of survivorship (e.g. low, medium, high) could usefully be undertaken. If return rates from mark-recapture studies can be used to provide surrogates of survival, this could allow mark-recapture data to be used a cost-effective option for identifying which species could be excluded from landings obligations.

ELECTRONIC TAGGING

Electronic tags have been used extensively to better understand the movements and behaviour of elasmobranchs (Hammerschlag *et al.*, 2011), but few of these studies have been undertaken to understand the post-release behaviour and fate of elasmobranchs caught under commercial fishing conditions (Hoolihan *et al.*, 2011). These studies have generally used either acoustic or archival tags. Whilst providing much more robust longer-term data for individual fish, studies using archival tags are usually limited in terms of sample size, due to the higher costs of such tags. Furthermore, in some studies using electronic tags, it is possible that specimens in better condition may be selected preferentially for tagging, and that tagged fish may be subject to more careful handling practices, whereas normal commercial fishing and handling practices may not be so benign.

ACOUSTIC TAGS

Short-term monitoring of fish behaviour using acoustic tags and either 'listening stations' and/or the active tracking of tagged fish with hydrophones has been used most successfully with coastal elasmobranchs. Early studies with this technology were conducted primarily to understand the fish behaviour, and so data are unlikely to be representative when considering mortality. Some recent studies have captured elasmobranchs and subsequently tracked individual fish tagged with self-releasing ultrasonic transmitters to understand mortality (Gurshin & Szedlmayer, 2004), but such studies are generally only conducted for short periods of time (typically periods of several hours).

ARCHIVAL TAGS

Electronic tags, including pop-up satellite archival tags (PSATs) and pop-off data storage tags (DSTs), have also been used to quantify longer-term survival of various elasmobranchs (Campana *et al.*, 2009a; Poisson *et al.*, 2014a; Francis & Jones, 2016).

Whilst several published studies have deployed PSATs and other types of electronic tags on a variety of elasmobranchs caught by commercial gears, many of these studies have aimed to better understand the behaviour and ecology of the species in question and have so tended to release individuals deemed likely to survive. Campana *et al.* (2009a) tagged a random sample of blue shark *Prionace glauca* (Linnaeus 1758) ($n = 40$; 124–251 cm fork length, L_f) with PSATs, including healthy and injured animals. Based on the time-depth-temperature information from PSAT tags, healthy *P. glauca* that were hooked in the mouth all survived ($n = 10$), whilst injured sharks that were hooked in the mouth ($n = 19$) or had swallowed the hook ($n = 8$) showed 32% and 38% mortality, respectively. Specimens categorised as ‘injured’ showed 33% mortality, with overall mortality estimated at 35% (Campana *et al.*, 2009a).

Lower rates of mortality were estimated for *P. glauca* caught in a Pacific fishery for swordfish *Xiphias gladius* Linnaeus 1758 (Musyl *et al.*, 2009), which could be related to handling practices and gear configuration, especially hook type (Campana, 2009b). A subsequent meta-analysis of available data for post-release survival for this species indicated PRM of about 15% (Musyl *et al.*, 2011).

There are, however, some issues that also need to be considered with electronic tags. Firstly, as they are generally larger than conventional, non-electronic tags, they cannot always be deployed on the juveniles of some species. Secondly, although the returned data can be used to infer ‘normal’ behaviour from ‘recovery behaviour’, this can sometimes be difficult to quantify and, depending on the nature of tag attachment, post-release mortality or evidence

of stress, may encompass elements from both the capture and tagging procedures. Finally, over what period should any observed mortality be attributed to the original capture process? Poisson *et al.* (2014a) adopted a conservative approach and considered that all observed deaths were due to the capture event, whilst Hutchinson *et al.* (2013) considered mortalities that occurred within 10 days of release to be a result of the fishing event.

BLOOD CHEMISTRY

Fish undertaking severe physical activity during the capture process can subsequently die, as anaerobic exercise leads to an accumulation of lactate and reduced pH in the blood. The build-up of lactate and/or intracellular acidosis have been hypothesised to contribute to mortality (Wood *et al.*, 1983). Blood chemistry has been increasingly used in studies on captured elasmobranchs in order to evaluate the levels at which various blood parameters (e.g. concentrations of lactate and potassium) may be correlated with physiological stress and trauma and likelihood of survival (Wells & Davie, 1985; Hoffmayer & Parsons, 2001; Mandelman & Farrington, 2007a; Brill *et al.*, 2008; Mandelman & Skomal, 2009; Brooks *et al.*, 2012; Hyatt *et al.*, 2012; Marshall *et al.*, 2012; Skomal & Mandelman, 2012; Dapp *et al.*, 2016). Most studies have examined various blood parameters in relation to quantified stress-causing events (e.g. capture time). Skomal & Chase (2002) examined the blood chemistry of *P. glauca* (and tuna and billfish) after capture by rod and line, with blood pH decreasing and blood lactate increasing as fight time increased. More recently, increasing numbers of studies have applied such methods to commercially caught fish. Brooks *et al.* (2012) examined the blood chemistry of Caribbean reef shark *Carcharhinus perezi* (Poey 1876) caught in research longlines with hook-timers, although only specimens hooked in the jaws were included.

Concentrations of lactate, carbon dioxide and glucose all increased with hooking duration for periods of up to 3 h, before declining or stabilising.

Some studies have combined multiple approaches, with Moyes *et al.* (2006) using PSAT tags and blood chemistry to try and predict post-release survival of longline caught *P. glauca*. Here, concentrations of certain plasma metabolites (lactate, Mg^{2+} , K^+ and Ca^+) were seemingly elevated in more moribund sharks. In a study of the longline catch in the eastern Pacific, Hight *et al.* (2007) examined the plasma concentrations of adrenaline, noradrenaline and lactate in pelagic sharks (*P. glauca*, shortfin mako *Isurus oxyrinchus* Rafinesque 1810 and common thresher *Alopias vulpinus* (Bonnaterre 1788)) that were then tagged and released. Based on the observed blood chemistry of those individuals that were subsequently recaptured (over periods of 34–1594 days), it was suggested that ca. 80% of released sharks would also have been expected to survive.

The adenylate energy charge (AEC), which is based on the relative proportions of adenosine monophosphate (AMP), adenosine diphosphate (ADP) and adenosine triphosphate (ATP), has also been proposed as a tool with which to examine metabolic stress (Guida *et al.*, 2016a). This study indicated that liver and white muscle were both sensitive to metabolic stress, with the latter potentially sampled non-lethally through biopsies.

Whilst such studies provide valuable biological information on understanding stress-related issues and how they may correlate with survival, such approaches might not always be the most practical approach to providing quantitative estimates of AVM and PRM under commercial fishing operations, which are the key questions for fisheries management.

LABORATORY STUDIES

Laboratory investigations have been undertaken to mimic the capture stress associated with gillnet and longline capture (Frick *et al.*, 2009, 2010a, 2012) and trawl capture, including tow duration, crowding and exposure to air (Frick *et al.*, 2010b). These studies reported no mortality of the demersal Port Jackson shark *Heterodontus portusjacksoni* (Meyer 1793) but mortality of gummy shark *Mustelus antarcticus* Günther 1870 was 8% (longline experiments), up to 70% (gillnet experiments), and variable in trawl experiments (Frick *et al.*, 2010a, b). Australian swellshark *Cephaloscyllium laticeps* (Duméril 1853) subjected to simulated gillnet capture also showed no mortality (Frick *et al.*, 2009).

Heard *et al.* (2014) used experimental tanks and a trawl cod-end to simulate trawl capture in order to evaluate the effect of blood sampling only (control, n = 8), trawl time (1 h and 3 h, n = 8 each), air exposure (0.17 h air exposure following 1 h trawl simulation, n = 8) and crowding (five fish per cod-end, n = 10) on the physiology of sparsely-spotted stingaree *Urolophus paucimaculatus* Dixon 1969. No immediate mortality was noted, although some post-experimental mortality occurred over the following 48–96 h. No mortality was observed for either the control group or fish subject to 1 h trawl duration, but there was 37.5% mortality following 3 h trawl duration, 12.5% following 1 h trawl and 0.17 h air exposure, and 20% mortality for the crowding experiment.

To examine the impacts of aerial exposure at different temperature regimes (simulating what would occur to captured fish prior to discarding), Cicia *et al.* (2012) collected samples of little skate *Leucoraja erinacea* (Mitchill 1825) caught by otter trawl (<0.33 h tow duration) and transported them to on-shore tanks. After a 10-day period of acclimatization, fish were withdrawn from tanks and exposed to the air for <1 minute (control), 0.25 h or 0.83 h. This method was applied in both winter (air and water temperature = 1°C and 4°C, respectively)

and summer (air and water temperature = 27°C and 18°C, respectively). Fish were then examined for mortality and blood sampling taken. Mortality over the following 5 days was 0%, 18% and 27% (control, 0.25 h or 0.83 h aerial exposure, respectively for winter) and 37%, 86% and 100% (control, 0.25 h or 0.83 h aerial exposure, respectively for summer). Whilst based on laboratory studies, it emphasises how fish subject to prolonged periods of time on deck prior to discarding can experience higher mortality, with this more pronounced in the summer, when the larger temperature differential and increased desiccation can exacerbate physiological stressors.

OTHER METHODS

Braccini *et al.* (2012) developed modelling approaches for which ‘immediate post-capture survival’ (using observer data for the numbers alive and dead) were combined with an estimate of ‘delayed post-capture survival’. The latter was derived from four categorical indices (activity and response to stimuli; degree of any wounding and bleeding; damage due to sea lice; damage due to physical trauma).

A few alternative approaches to better understanding the behaviour of sharks after release have also been undertaken. For example, Skomal *et al.* (2007) attached a video camera over the first dorsal fin of grey reef shark *Carcharhinus amblyrhynchos* (Bleeker 1856) (n = 6) that were caught by hand-line on a Pacific atoll, with the system programmed to detach after 2 h. Whilst such approaches allow for the short-term behaviour of individual fish to be studied and evaluated, sample sizes are often limited. Consequently, it may not allow for accurate estimates of longer-term post-release mortality and results may not be representative.

Diver surveys and photo-identification have highlighted the potential impact of line fisheries (including recreational rod and line fisheries) on sandtiger shark *Carcharias taurus* Rafinesque 1810 along the east coast of Australia (Bansemer & Bennett, 2010). This study reported that of 13–20% of identified sharks (based on sex and flank photographs) had evidence of retained gear or jaw injuries. Whilst not informing on discard mortality *per se*, such studies indicate that discarded sharks with jaw damage can survive release.

DISCARD MORTALITY OF ELASMOBRANCHS BY GEAR

Numerous studies have documented the elasmobranch bycatch in European fisheries in recent years (Berrow, 1994; Borges *et al.*, 2001; Baeta *et al.*, 2010; Storai *et al.*, 2011; Silva *et al.*, 2012). Despite the increased number of studies examining the issue of elasmobranch bycatch and discarding, both in European seas and worldwide, reviewed recently by Molina & Cooke (2012), there have been comparatively few studies examining the fate of discards, especially in European fisheries. An earlier review of incidental mortality of fish in towed gears by Broadhurst *et al.* (2006) included only three studies that specifically addressed elasmobranchs, but there have been several studies since this time (Table II). Similarly, only limited information on elasmobranch mortality in gillnets was included in the recent review by Uhlmann & Broadhurst (2015).

Discard mortality of elasmobranchs caught in fishing gears varies with a range of factors (Stobutzki *et al.*, 2002; Broadhurst *et al.*, 2006; Morgan & Carlson, 2010; Dapp *et al.*, 2015; Guida *et al.*, 2016b), and these include gear type (i.e. the gear and its configuration), fishing practices (e.g. soak time, location and depth of fishing ground), species (e.g. mode of gill ventilation, thickness of skin, size and behavioural reaction to the gear) and on-board

conditions (e.g. air temperature, time on deck, handling practices of the crew). For example, demersal elasmobranchs with thick skins and buccal pump ventilation may survive capture and handling on deck better than faster swimming taxa that are obligate ram ventilators (Revill *et al.*, 2005; Rodriguez-Cabello *et al.*, 2005).

The following section summarises the findings from previously published studies on discard survival, but it should be recognised that comparisons between disparate studies can be problematic, due to differing methods of catching and handling fish (Musyl *et al.*, 2009), and also as not all studies provide full descriptions of the gears, fishing operations and handling, and environmental conditions.

If discard mortality is high in particular fisheries, and this is considered to have a detrimental effect on any given stock, then there needs to be due consideration of mitigation measures that either reduce the likelihood of capture and/or increase the chances of live discarding (Poisson *et al.*, 2014b). In terms of reducing elasmobranch bycatch, whilst there have been numerous studies in relation to pelagic longline fisheries, options for minimising the bycatch of elasmobranchs in other fisheries are less well known (Jordan *et al.*, 2013). Studies highlighting potential mitigation measures are addressed briefly for the broad gear types.

DEMERSAL OTTER TRAWL FISHERIES (INCLUDING PRAWN TRAWLS)

Many demersal otter trawl fisheries have a bycatch of demersal batoids and smaller sharks and, depending on the height of the net, there can also be incidental catch of larger sharks. The catchability of skates may also be influenced by the type of ground gear used on the net, as escapement can increase as the height of the fishing line above the sea floor increases (Walsh, 1992). The use of a tickler chain can also increase the catch of skates and other

demersal elasmobranchs (Kynoch *et al.*, 2015), as this will disturb them from the sediment. Otter trawls are generally proportionally more effective for some of the larger skates, with a greater proportion of smaller skates escaping capture, presumably passing under the fishing line or ground gear (Kotwicki & Weinberg, 2005). The AVM of elasmobranchs caught in trawl gears may be influenced by tow duration and catch composition and weight, and PRM also affected by time on deck prior to discarding.

Rulifson (2007) reported zero mortality of trawl-caught *S. acanthias* (0.5–1.5 h tow duration), even after a further 48 h of retention in sea cages but other studies on this species have indicated a higher mortality (up to 29% over 72 h; Mandelman & Farrington, 2007a, b). Rodríguez-Cabello *et al.* (2005) examined the survival of *S. canicula* caught in an otter trawl (Spanish 'baca' type trawl) by both research vessel (0.5 h tow duration) and commercial vessels (3–6 h tow duration). Fish were then placed in tanks after being on deck for 0.33–1.0 h (research vessel) and 0.3–1.4 h (commercial vessel). The mean survival rates from research surveys and commercial trawlers were 90% and 78% respectively.

Skates (Arhynchobatidae) are a bycatch in the Falkland Island trawl fishery targeting squid, and Laptikhovsky (1994) reported that the overall survival was 59.1%, with a greater proportion of females surviving (66.7%) than males (56.4%). Other skates (Rajidae) caught in a Canadian trawl and seine fisheries were generally in good condition, with >80% in excellent or good condition after capture (Benoît *et al.*, 2010a).

Prawn trawlers operate in many areas, typically fishing for penaeids. As such there is usually a high degree of ground contact, and a variety of bycatch species can be taken. Stobutzki *et al.* (2002) examined the immediate capture mortality of elasmobranchs once the catch was on board, but no information on longer-term survival was available. Of the sharks (n = 639,

species combined, but see Table II), 66% of males were dead, but only 23% of females were dead. Similarly, of the 208 batoids caught, a greater proportion of males were dead (67%) than observed for females (56%). Fennessy (1994) examined the AVM of a range of elasmobranchs taken in the shallow (20–45 m) prawn grounds off South Africa, and whilst <50% for most of the demersal elasmobranchs studied, it was higher (97.6%) for scalloped hammerhead *Sphyrna lewini* (Griffith & Smith 1834).

Although there has been extensive work on bycatch mitigation for some species taken incidentally in trawls (e.g. sea turtles), there has been less work undertaken on reducing bycatch and/or improving survivorship of elasmobranchs (Griffiths *et al.*, 2006). Indeed, many studies on the impacts of grids and other bycatch reduction devices on the selection of marketable species have focused on teleosts and commercial shellfish and have not always provided information on elasmobranchs, possibly due to small sample sizes. Nevertheless, grids have been demonstrated to reduce the catch of skates and rays in some bottom trawl fisheries (Lomeli & Wakefield, 2013; Willems *et al.*, 2016) and bycatch reduction devices have also been shown to reduce the catches of the shovelnose guitarfish *Rhinobatos productus* Ayres 1854 in Mexican shrimp trawls (García-Caudillo *et al.*, 2000).

Brewer *et al.* (2006) examined the catches of prawn trawls with turtle excluding devices (TEDs) and bycatch reduction devices (BRDs). This study reported that nets with TEDs or combined TED/BRDs successfully reduced shark and ray bycatch, with upward-excluding TEDs more effective for reducing shark catches. The use of trawls with only BRDs was less successful. Belcher & Jennings (2011) also examined the shark bycatch in a penaeid shrimp trawl fishery, with catch rates of sharks differing between net design and type of TED/BRD used. Similarly, Raborn *et al.* (2012) estimated that catches of blacknose shark *Carcharhinus*

acronotus (Poey 1860) and *S. tiburo* would have been reduced by the uptake of TEDs in a penaeid shrimp fishery. The size, morphology and behaviour of elasmobranchs are key factors in understanding the potential benefits of the various excluder devices, and whilst grids can facilitate the escape of larger species, juveniles and smaller-bodied species may not benefit (Willems *et al.*, 2016).

Trials to reduce bycatch of *S. acanthias* by incorporating an excluder grid on the trawls used in a fishery for silver hake *Merluccius bilinearis* (Mitchill, 1814) successfully reduced catches of *S. acanthias*, and improved the quality of the catch in the cod-end (Chosid *et al.*, 2012). The 50 mm bar spacing used in this study allowed commercial quantities of the target species still to be caught, however this bar spacing may not be suitable for other fisheries targeting other species. Furthermore, Chosid *et al.* (2012) noted that *S. acanthias* would often become wedged in grids with wider (64 mm) spacings.

Some of the studies examining the use of separator grids and TEDs have found that elasmobranchs, especially batoids, can clog grids (Isaksen *et al.*, 1992; Lawson *et al.*, 2007; Lomeli & Wakefield, 2013), which can then compromise the retention of target species (and so deter fishers from using such systems voluntarily). Separator grids may also be useful in preventing the capture of large sharks, for example Isaksen *et al.* (1992) noted that Greenland shark *Somniosus microcephalus* (Bloch & Schneider 1801) would generally pass through the separating system in a shrimp trawl, although sometimes damaging this part of the trawl.

Given that skate and ray mortality can be influenced by the weight of the catch (Fennessy, 1994; Enever *et al.*, 2009) and presumably the abrasive nature of some catch components, measures to reduce the retention of, for example, benthic invertebrates (many of which can be abrasive) should decrease AVM. Such approaches can also reduce the time taken for

fishers to process catches and improve the quality of marketable fish. The effects of different configurations of cod-end mesh on the survival of skates were explored by Enever *et al.* (2010). The size, morphology and demersal nature of batoids means that they will often be caught in mixed demersal trawl fisheries, however Enever *et al.* (2010) indicated that changing from 80 mm diamond to 100 mm square mesh in the cod-end would improve the condition of skates, so increasing the potential survival of discarded individuals.

Kynoch *et al.* (2015) showed that not using a tickler chain can reduce the catch of demersal elasmobranchs in demersal trawl fisheries, the absence of this chain can also reduce the catch of some commercially valuable fish, in this instance anglerfish *Lophius* spp., and so such measures not always be popular with the fishing industry.

Whilst several studies have examined the AVM and/or short-term survival of trawl-caught elasmobranchs, most studies have presumably focused on those specimens that have been retained in the cod-end of the trawl. Depending on the mesh sizes of the trawl net, however, elasmobranchs (particularly smaller dogfish) may be entrapped in the meshes and exposed to more physical trauma. The vitalities of enmeshed elasmobranchs in comparison to those that have passed to the cod-end have, however, not been quantified.

BEAM TRAWL FISHERIES AND DREDGES

Beam trawl catches can be subject to physical damage, both from the gear, including the chain mat or tickler chains, as well as from any benthic invertebrates (including abrasive taxa such as echinoderms) and rocks that may be caught in the net. One of the earliest studies of discard survival in this gear was that of Kaiser & Spencer (1995), who maintained trawl-caught organisms (including cuckoo ray *Leucoraja naevus* (Müller & Henle 1841) and *S. canicula*) in

on-board survival tanks. The gear (4 m beam trawl) and fishing protocol (tow duration = 0.5 h) were generally more consistent with research fishing and so less representative of commercial fishing. This study indicated that 59% of *L. naevus* and 90–94% of *S. canicula* were alive five days after capture.

Revill *et al.* (2005), using survival tanks, found that the survival of *S. canicula* (n = 120) was very high in the short-term (98% over periods of 36–60 h), with these samples caught under commercial conditions (2 h tow duration; 4–5 knot trawl speed; waters of 60–80 m depth).

Skates may also be an occasional bycatch in dredge fisheries for scallops. For example, *L. naevus* is a frequent bycatch species in European dredge fisheries for scallop *Pecten maximus* and queen scallop *Aequipecten opercularis*, with a high proportion of these immature (Craven *et al.*, 2012). Whilst discard survival information is not available for northern European dredge fisheries, there are some data from elsewhere in the world. Benoît *et al.* (2010b) reported that nearly 92% of winter skate *Leucoraja ocellata* (Mitchill 1815) caught in a commercial scallop fishery were in excellent or good health state.

GILL AND TANGLE NET FISHERIES

A range of elasmobranchs are an incidental bycatch in gillnet fisheries (Benjamins *et al.*, 2010), and mortality in these gears can be relatively high (Berrow, 1994). Furthermore, some elasmobranchs may be caught in lost gillnets that continue to fish (Kaiser *et al.*, 1996). In general, at-vessel mortality in such gears is described in relation to the soak time of the net, whereas in reality mortality will be influenced by the time the fish has spent entangled in relation to the respiratory mode of the species (i.e. elasmobranchs with buccal-pump ventilation of the gills will survive longer in a net than those species that are obligate ram

ventilators). In some areas there are abundant scavengers, such as some isopods (Fig. 1), and these may increase the mortality of fish trapped in set gears (Bendall *et al.*, 2012).

Hyatt *et al.* (2012) looked at the blood chemistry of carcharhiniform sharks caught in experimental gillnets and longlines, with higher lactate concentrations and a greater pH in gillnet-caught fish, emphasising the greater physiological impact of capture by gillnet. Rulifson (2007) reported that the initial mortality of gillnet-caught *S. acanthias* was 17.5% (19–24 h soak time), but that there was further mortality for at least the next 48 h, resulting in an overall mortality estimate of 55%. Thorpe and Frierson (2009) examined the survivorship of four shark species (Atlantic sharpnose shark *Rhizoprionodon terraenovae* (Richardson 1836), *C. acronotus*, *C. limbatus* and *S. tiburo*) taken in gillnets, with an overall mortality of 78.6%. Similarly, high mortality rates have also been observed for *C. limbatus* (58%) and *S. tiburo* (62%) caught by gillnet in scientific surveys, even with short (1 h) soak times (Hueter *et al.*, 2006).

Bottom-set fixed nets can also have a bycatch of larger sharks. Valeiras *et al.* (2001) reported on 12 instances of *C. maximus* being taken in such gears (termed ‘trasmallo’) from north-western Spain, of which three were landed and sold, two released alive, three discarded dead and four of unknown fate.

Whilst not a traditional ‘fishery’, the protective shark nets deployed off tourist beaches in the southern hemisphere capture a variety of elasmobranchs. Reid & Krogh (1992) reported on the proportion of fish that were alive when the shark nets off New South Wales (Australia) were checked (usually at periods of 12–48 h). As expected, demersal species had the lowest mortality (3.3% for horn sharks *Heterodontus* spp. and 15.4% for wobbegong *Orectolobus*

spp.), with a much higher mortality for ram ventilators (91% in mako sharks *Isurus* spp. and 98% in hammerheads).

Potential bycatch mitigation measures in gillnet fisheries could include spatial and/or temporal restrictions, restricted lengths of net, limiting soak times, changes to mesh size, hanging ratio and height of the net, and modifying the thickness and colour of netting material (Thorpe & Frierson, 2009; Baeta *et al.*, 2010). However, there have been few such studies to date and appropriate field studies in conjunction with the fishing industry would be required to gauge which measures would be most effective to reduce incidental shark bycatch and/or mortality. He (2006) examined the use of a 'tie-down' gillnet in relation to a standard gillnet used in a fishery for cod *Gadus morhua* Linnaeus 1758. The lower height of the 'tie-down' gillnet reduced the catch of *S. acanthias*, but the catch of skates increased four-times and catches of *G. morhua* also decreased.

Whilst a proportion of fish can survive capture and release from gillnets, some individuals escaping from such gears may retain monofilament around parts of the body (Schwartz, 1984; Seitz and Poulakis, 2006; Fig. 2), but it is uncertain as to how frequent an event this is and how this subsequently affects individuals.

The presence of trapped fish in gillnets may attract opportunistic predators, and whilst there have been numerous studies aiming to reduce both depredation by, as well as entanglement of, marine mammals, the interactions of elasmobranchs with gillnet catches have received less attention. Rafferty *et al.* (2012) reported that *S. acanthias* would opportunistically depredate *G. morhua*, haddock *Melanogrammus aeglefinus* (Linnaeus 1758), *Lophius* spp. and skates taken in gillnets in the Georges Bank area, with *S. acanthias* also ranked fourth (in terms of biomass) and fifth (value of the catch) of the species caught in this study. Waples *et*

al. (2013) noted that depredation on gillnet-caught Spanish mackerel *Scomberomorus maculatus* (Mitchill 1815) by sharks was greater than observed for bottlenose dolphin. Further studies to ascertain the extent to which elasmobranchs may be attracted to gillnet catches, and so at potential risk of entanglement, could usefully be undertaken.

LONGLINE FISHERIES

Longline gears may be deployed in demersal, pelagic and deep-water fisheries. Longline fisheries traditionally have a large shark bycatch (or they may even be the target species), and mortality can be highly variable between species (Gilman *et al.*, 2008). The time spent hooked is an important factor to consider, especially for those fisheries with potentially long soak times. Morgan & Carlson (2010) used hook timers on a longline, and so were able to determine how mortality of several carcharhiniform shark species increased with increasing time hooked. Whilst the use of hook timers in scientific studies has increased in recent years, studies on commercial vessels have generally examined mortality in relation to overall soak time (Boggs, 1992; Poisson *et al.*, 2010).

In terms of pelagic longline fisheries, Megalofounou *et al.* (2005) reported the health state for sharks caught in swordfish and tuna fisheries in the Mediterranean. Although the overall proportions of sharks dead on capture was low (5%), data from this study indicated that whereas 84.4% of *P. glauca* were in either good or fair condition, this proportion was lower in lamniform sharks (54.8% for *I. oxyrinchus* and 43.8% for *A. vulpinus*). This study also revealed subtle differences in the health state of sharks between different longline fisheries, with a greater proportion of sharks in good or fair condition in swordfish longline fisheries (82–97%) than in longline fisheries targeting albacore *Thunnus alalunga* (Bonnaterre 1788)

(69%). Diaz & Serafy (2005) reported that about 69% of longline-caught *P. glauca* were released alive, and that at-vessel mortality was lower for larger individuals and lower for fish caught in sets with a short soak time

High estimates of *P. glauca* survival were also observed in longline fisheries in the Pacific, with 4–5.7% mortality reported (Walsh *et al.*, 2009). In contrast, Campana *et al.* (2009a) estimated a higher overall mortality of *P. glauca* caught in the Canadian Atlantic longline fishery, with AVM observed to be 20%, and live fish either injured (44%) or healthy (36%). Studies using PSATs (see above) enabled more robust estimations of post-release mortality, resulting in an estimated 35% overall mortality. More recent studies have provided better estimates of hooking mortality and post-release mortality for *P. glauca*, *I. oxyrinchus* and *L. nasus* taken in the Canadian longline fishery (Campana *et al.*, 2016). For example, 41.6% (and 14.6%) of *L. nasus* were considered healthy (injured) following capture. Data from PSATs indicated that the majority (89.7%) of healthy fish survived, but only one of the four injured fish tagged survived, resulting in an estimated 59% overall mortality (Campana *et al.*, 2016). Comparable data for the other species indicated an overall mortality of 23.1% for *P. glauca* and 49.3% for *I. oxyrinchus*.

Skates caught in Canadian bottom longline fisheries were generally in good condition (Benoît *et al.*, 2010a), with >80% categorised as either excellent or good condition after capture. Whilst demersal skates appear to generally survive capture on longlines, Morgan & Carlson (2010) estimated higher mortalities (15–91%) for the different shark species taken on bottom longlines off Florida.

Some European nations had directed longline fisheries for *L. nasus* and *S. acanthias*, though these fisheries no longer operate given the zero TAC currently in place for these species.

Currently most of the longline effort conducted by the English fleet is from smaller inshore vessels deploying demersal longlines over a short soak time, and the smaller elasmobranchs taken in these fisheries exhibit low at-vessel mortality (Ellis *et al.*, 2008b). For example, the inshore fleet operating in the southern North Sea often set longlines where the main species caught include *R. clavata*, *S. acanthias* (seasonally) as well as larger teleosts (*G. morhua* and bass *Dicentrarchus labrax* (Linnaeus 1758)). Soak times in this fishery are normally 2–4 h, and most fish are lively and unwanted elasmobranchs can be returned to the sea (Ellis *et al.*, 2008b). In other areas, longlines may be set overnight (24 h soak time), and whereas the elasmobranchs caught are also generally lively, these fish may sustain a greater degree of jaw damage (Ellis *et al.*, 2012). Some sharks, however, seem capable of surviving jaw damage and individuals showing varying degrees of recovery can be observed (Fig. 3).

There is less information for elasmobranchs caught in deep-water longline fisheries. Endicott and Agnew (2004) examined the survival of skates taken as a bycatch in the South Georgia toothfish fishery, with longlines fished at 746–1913 m. Whilst no information on AVM was presented, the results from maintaining *Amblyraja* spp. (n = 95) in tanks on deck suggested that about 34% would be expected to survive.

Bycatch mitigation measures for longline fisheries are relatively well studied, and whereas results from various trials have ostensibly provided encouraging results in terms of reducing elasmobranch bycatch, a recent meta-analysis of published studies has questioned the effectiveness of some suggested measures (Favaro & Côté, 2015). There have been numerous publications on the potential use of magnets and electropositive metals and, as these were addressed in the recent review by Favaro & Côté (2015), they are not appraised further here.

Several studies have highlighted that sharks caught with circle hooks may survive better than those caught with J-hooks (Carruthers *et al.*, 2009; Afonso *et al.*, 2011; Fernandez-Carvalho *et al.*, 2015), although other studies examining catch rates and mortality of sharks with different longline configurations have indicated circle hooks may not have such a great impact (Yokota *et al.*, 2006; Afonso *et al.*, 2012; Amorim *et al.* 2014). A meta-analysis of available data led Godin *et al.* (2012) to conclude that circle hooks did not affect catch rates of sharks, but did reduce at-vessel mortality, because these hooks are more often hooked in the mouth or jaw and are less frequently ingested (gut-hooked). Hook size can also influence catch rates, for example Piovano *et al.* (2010) found a significant reduction in the catch of pelagic stingray *Pteroplatytrygon violacea* (Bonaparte 1832) when using 16/0 circle hooks than J-hooks.

Shark catches can be reduced with nylon leaders (traces), as sharks may bite through monofilament more easily than wire (Ward *et al.*, 2008; Afonso *et al.*, 2012). For example, Ward *et al.* (2008) reported the catch rates of sharks (all species combined) on nylon and wire leaders used on pelagic longlines off north-eastern Australia were 1.17 and 2.75 sharks per 1000 hooks deployed, respectively. However, it cannot be assumed that all sharks that have bitten through nylon leaders will survive.

The use of bait (or hook) strippers on some longline vessels can increase the severity of injuries to the mouth and jaws. Whilst not quantified for elasmobranchs, Kaimmer (1994) found that Pacific halibut *Hippoglossus stenolepis* Schmidt 1904 that were de-hooked by a bait-stripper not only had a much higher mortality than when fish had the hook removed manually, but also those with sub-lethal injuries then exhibited impaired growth.

Other potential mitigation measures include modifying the depths fished and soak times (Coelho *et al.*, 2003; Mandelman *et al.*, 2008; Afonso *et al.*, 2011; Carruthers *et al.*, 2011).

Broadhurst *et al.* (2014) noted that a high proportion of hammerhead sharks were caught after sunrise, and suggested that setting lines only during the night could potentially reduce bycatch of this group. Determining the utility and efficacy of mitigation measures for any longline fishery clearly requires detailed investigations as to the likely impacts on target species, and improving handling practices may be one of the more pragmatic approaches to improving discard survival.

PELAGIC TRAWLS AND PURSE SEINES

There are few studies relating to the discard mortality in either pelagic trawl or purse seine fisheries. Some sharks predate on, or aggregate with, schooling teleosts, and so there is often a shark bycatch associated with fisheries for small pelagic fish. For example, De Silva *et al.* (2001) reported that 74% of sharks (Carcharhinidae and Sphyrnidae) taken in the Gulf of Mexico purse seine fishery for Gulf menhaden *Brevoortia patronus* Goode 1878 were dead, with 12% disorientated on release, 8% released in a healthy condition and 6% of unknown fate.

Recent studies on *C. falciformis* taken as bycatch in purse seine fisheries for tuna reported AVM of 58.5–69% and, when considering post-release mortality through studies with PSATs, estimated overall mortality rates of 81–89% (Poisson *et al.*, 2014a; Hutchinson *et al.*, 2015; Eddy *et al.*, 2016). The mortality of *C. falciformis* in these fisheries is influenced by various factors (Hutchinson *et al.*, 2013, 2015; Eddy *et al.*, 2016), including the size of the shark (smaller individuals showing higher mortality), total catch weight and the type of interaction with the gear (e.g. were they brailed or entangled in the netting). Some studies have undertaken control experiments by examining the mortality of line-caught fish (including free-

swimming *C. falciformis* within the purse seine prior to brailing), with these fish generally surviving capture and release (Filmlalter *et al.*, 2013; Hutchinson *et al.*, 2013). Modifications to fishing practices and handling practices could help reduce mortality of sharks in these fisheries, highlighting the need for collaborative research in bycatch mitigation (Poisson *et al.*, 2014b).

Whilst RFMOs involved in tuna fisheries encourage purse seine vessels to avoid setting nets in areas where whale shark *Rhincodon typus* Smith 1828 are evident, this species may still be an occasional bycatch. Most specimens are generally released alive before the catch is brailed, and reported estimates of mortality (based on observer data where fate was recorded) are thought to be low (1.4%; Capietto *et al.*, 2014). Similarly, mobulid rays can survive capture and be released when brailed from the purse seine catch, although specimens entangled in the netting and then brought onboard often do not survive (Francis & Jones, 2016).

Zeeberg *et al.* (2006) reported on the bycatch of sharks (including great hammerhead *Sphyrna mokarran* (Rüppell 1837), smooth hammerhead *Sphyrna zygaena* (Linnaeus 1758), *S. lewini*, *Isurus* spp., *Carcharhinus* spp., *Alopias* spp. and *P. glauca*) and giant manta *Manta birostris* (Walbaum 1792) associated with European industrial trawlers fishing off West Africa. Pelagic trawls were fitted with a 'filter grid', but Zeeberg *et al.* (2006) noted that "*few animals arrive on deck alive and most suffocate and succumb to water pressure while caught in the filter grid*". This study also summarised preliminary findings from incorporating an escape tunnel along the bottom of the trawl, which was suggested to have reduced elasmobranch bycatch.

RECREATIONAL FISHERIES

There is a paucity of information on the discard survival of recreationally-caught elasmobranchs, both in European seas and elsewhere (McLoughlin & Eliason, 2008). Mortality may be related to several factors, such as type and severity of hooking injury, fight time and handling practices (e.g. degree of care during hook removal and time on deck) and barometric and temperature differences (Gurshin & Szedlmayer, 2004). Once again, demersal species with thick skins and buccal-pump ventilation may fair better than obligate ram-ventilators.

The potential impact of recreational fisheries on coastal elasmobranchs that are considered endangered has attracted some attention (e.g. Bansemer & Bennett, 2010), and precautionary regulations to limit the types of recreational fishing (e.g. in terms of bait and trace) have even been established in some areas of Australia to reduce the likelihood of fishers catching protected shark species (Robbins *et al.*, 2013).

To date, few studies have examined the PRM of elasmobranchs caught by recreational methods. Gurshin & Szedlmayer (2004) tagged *R. terraenovae* ($n = 10$) with self-releasing ultrasonic transmitters. These individuals were caught by hook-and-line, with retrieval and handling times of 2–6 mins and 1.5–7 mins, respectively (total duration of event 4–11.5 mins). One individual was thought to have died within an hour of release, but the remaining nine sharks were tracked for periods of 0.85–5.9 h. The tracked fish exhibited higher rates of movement in the initial 1.5 h, possibly reflecting post-release trauma. Danylchuk *et al.* (2014) captured juvenile lemon shark *Negaprion brevirostris* (Poey 1868) ($n = 32$; 53–87.5 cm L_T) on recreational gears (fight times of 43–476 sec.), and visually tracked these individuals for 0.25 h after release: four (12.5%) individuals died in this short time frame.

In terms of larger sharks that may be taken in big-game fishing, French *et al.* (2015) examined the post-release mortality of *I. oxyrinchus* ($n = 33$; 110–265 cm L_F) caught by recreational

gears, using Pop-up Archival Transmitting tags. Fight times were up to 8.55 h, but the majority (n = 29) were caught with fight times of ≤ 1 h. Data were subsequently available for 30 individuals, of which only 10% died within 30 days.

Heberer *et al.* (2010) estimated 26% PRM for *A. vulpinus*, with mortality increasing with fight time. Given that the specimens in this study were generally hooked in the caudal fin, which restricts forward movement, and so ram ventilation, this comparatively high mortality is unlikely to be typical for other sharks. A subsequent study compared the post-release mortality of *A. vulpinus* that were successfully tagged after hooking on the caudal fin (n = 9; 111–175 cm L_F; 10–25 min fight time) or in the mouth (n = 7; 125–187 cm L_F; 9–25 min fight time). Whilst all the latter survived for periods of 10–90 days, individuals captured by the caudal fin showed low survival (n = 2; 22%), with six fish (66.7%) dying in ≤ 5 days and one fish showing mortality after 81 days (Sepulveda *et al.*, 2015).

Rod-and-line caught *C. taurus* have also been found to have a high rate of survival, but individuals that swallowed the hook (gut-hooked) exhibited higher mortality rates (Kneebone *et al.*, 2013).

TAXONOMIC OVERVIEW OF ELASMOBRANCH DISCARD SURVIVAL

Elasmobranch fish display a broad diversity in size, shape and skin structure, as well as their habitats (e.g. demersal, pelagic, deep-water) and respiratory mode (e.g. buccal-pump or ram ventilation). Consequently, there is a broad spectrum in the survival of elasmobranchs in relation to interactions with fishing gears. The following provides a synthesis of current knowledge on discard survival by order or, for the more species-rich orders, family.

HEXANCHIFORMES

Very limited published data for European fisheries (Berrow, 1994; Megalofonou *et al.*, 2003). Off the Bahamas, Brooks *et al.* (2015) noted that only 4.5% of *Hexanchus* spp. caught by scientific longline from waters of 500–790 m were dead, although the sample size (n = 22) was limited and soak times were <4 h. More data are available for broadnose sevengill shark *Notorynchus cepedianus* (Péron 1807) caught in Australian waters, with AVM of 33–83% in gillnet fisheries (Walker *et al.*, 2005; Braccini *et al.*, 2012) and 85% mortality of those taken in protective nets (Reid & Krogh, 1992).

SQUALIFORMES; FAMILY SQUALIDAE

Studies in the North-west Atlantic have shown low AVM for trawl and line-caught *S. acanthias*, with 6–29% mortality over the short-term (Mandelman & Farrington, 2007a, b; Rulifson 2007). Soak times in these studies, however, were unlikely to be as used under normal commercial fishing operations. Reported levels of AVM for *Squalus* spp. caught by gillnet are: 0–6% (Walker *et al.*, 2005; mean soak time 8.2 h), 17.5% (Rulifson, 2007, 19.5–23.5 h soak time), 22.5–38.5% (Bendall *et al.*, 2012; 11–27 h soak time) and 10–40% (Braccini *et al.*, 2012). Lyle *et al.* (2014) reported that AVM increased from 7% (soak times <8 h) to 18% (overnight soak time), with an estimated 77–86% post-release survival. Cuban dogfish *Squalus cubensis* Howell Rivero 1936 caught by longline during scientific studies (4 h soak time), showed 9.1% AVM, even though they were caught from depths of 472–730 m (Brooks *et al.*, 2015).

SQUALIFORMES; FAMILIES CENTROPHORIDAE AND SOMNIOSIDAE

Most squaliform sharks are deep-water species, and there are no published, quantified data on the AVM of commercially-caught deep-water sharks. Brooks *et al.* (2015) recorded the AVM of various deep-water sharks caught by longline off the Bahamas at depths down to about 1000 m, but soak times were <4 h. Studies with electronic tags have indicated that leafscale gulper shark *Centrophorus squamosus* (Bonnaterre 1788), one of the deep-water shark species occurring in European seas, can survive after being caught by longline (2–3 h soak time) from waters of 900–1100 m (Rodríguez-Cabello & Sánchez, 2014), but quantified data on the AVM and PRM of deep-water sharks that may be a bycatch in existing deep-water commercial fisheries are currently lacking.

PRISTIOPHORIFORMES

Sawsharks occur in the Indo-Pacific and parts of the Atlantic, but not in the North-east Atlantic. Walker *et al.* (2005) and Braccini *et al.* (2012) reported AVM of 7–42% for the two species captured in Australian gillnet fisheries.

SQUATINIFORMES

Fennessy (1994) reported AVM of 60% for African angel shark *Squatina africana* Regan 1908 caught in South African prawn trawlers, and AVM of 11–33% were reported for Australian

angel shark *Squatina australis* Regan 1906 captured in gillnet fisheries with soak times <24 h (Walker *et al.*, 2005; Braccini *et al.*, 2012). The latter species is also captured occasionally in protective shark nets (soak times 12–48 h), where Reid & Krogh (1992) reported that about 34% were dead. There are no quantitative data on the discard survival of angel sharks caught in fisheries in European waters.

HETERODONTIFORMES

Hornsharks, which are restricted to the Indo-Pacific, are an occasional bycatch in various demersal fisheries. Both Walker *et al.* (2005) and Braccini *et al.* (2012) reported a very low AVM (<1%) for those caught in an Australian gillnet fishery (soak times <24 h), with Reid & Krogh (1992) noting that only 3.3% were recovered dead from protective nets.

ORECTOLOBIFORMES

This order contains a diverse range of families, mostly occurring in tropical and sub-tropical seas, but there are few published studies relating to discard survival. Low AVM (<10%) has been recorded for spotted wobbegong *Orectolobus maculatus* (Bonnaterre 1788) caught by gillnet (Walker *et al.*, 2005; Braccini *et al.*, 2012), with parascyllids exhibiting 12.5–20% AVM in the same fishery. Carpet sharks *Orectolobus* spp. are also a bycatch in protective nets, and about 15% are recovered dead (Reid & Krogh, 1992). Nurse shark *Ginglymostoma cirratum* (Bonnaterre 1788) is an occasional bycatch in inshore longline fisheries, although no AVM was

observed by either Afonso *et al.* (2011) or Gulak *et al.* (2015). Likewise, no AVM of orectolobids was evident in demersal longline studies (Butcher *et al.*, 2015).

LAMNIFORMES; FAMILIES ODONTASPIDIDAE AND PSEUDOCARCHARIIDAE

Three studies have provided estimates of AVM for members of the family Odontaspidae, ranging from 0% in demersal longline (Butcher *et al.*, 2015; Gulak *et al.*, 2015) to 41% in protective gillnets (Reid & Krogh, 1992). Crocodile shark *Pseudocarcharias kamoharai* (Matsubara 1936) is a bycatch in offshore, pelagic longline fisheries, with a very broad range in reported AVM: 4.7–9.1% (Fernandez-Carvalho *et al.*, 2015); 13.3% (Coelho *et al.*, 2012); 38.7% (Bromhead *et al.*, 2012); 66.7% (Musyl *et al.*, 2011) and as high as 91% (Afonso *et al.*, 2012), although the latter study was based on a limited sample size.

LAMNIFORMES; FAMILY ALOPIIDAE

No published, quantitative data on the survival of *Alopias* spp. taken as bycatch in European trawl and set net fisheries, but data are available for European longline fisheries (e.g. Megalofonou *et al.*, 2003). In general, *Alopias* spp. exhibit a relatively high mortality, with *ca.* 90% recovered dead from protective nets (Reid & Krogh, 1992) and reported AVM in gillnets of 60–66.7%, even where soak times are relatively short (Walker *et al.*, 2005; Braccini *et al.*, 2012). Varying levels of mortality in pelagic longline fisheries have been reported in range of studies and, whilst a few studies have reported ‘lower’ estimates of 18–40% AVM (Boggs, 1992; Musyl *et al.*, 2011; Gilman *et al.*, 2015), most studies have reported 48–68% AVM

(Beerkircher *et al.*, 2004; Bromhead *et al.*, 2012; Coelho *et al.*, 2011, 2012; Fernandez-Carvalho *et al.*, 2015). The higher AVM (89%) reported by Afonso *et al.* (2012) was based on a small sample size.

LAMNIFORMES; FAMILY LAMNIDAE

Lamnids are fast-swimming pelagic sharks and whilst several species are a frequent catch in longline fisheries, these species can be an occasional bycatch in some gillnet fisheries and as an incidental catch in trawl fisheries. *C. carcharias* and *I. oxyrinchus* have been shown to exhibit 44% and 37.5–75% AVM in gillnet fisheries, respectively (Lyons *et al.*, 2013; Walker *et al.*, 2005; Braccini *et al.*, 2012). Within European waters, *L. nasus* taken as a bycatch in bottom-set gillnets in the Celtic Sea have shown 80% AVM (Bendall *et al.*, 2012). Given the occasional (or seasonal) nature of such bycatch, these studies were all based on low sample sizes. Within the protective nets of Australia, 49% of *C. carcharias* and 91% of *Isurus* spp. were recovered dead (Reid & Krough, 1993).

More data are available for longline fisheries, especially with regards *I. oxyrinchus* and *L. nasus*. Reported AVM of the former may be as low as ca. 5–30% (Megalofonou *et al.* 2003; Epperly *et al.*, 2012; Gallagher *et al.*, 2014a; Gilman *et al.*, 2015; Campana *et al.*, 2016), but studies with greater sample sizes have generally reported AVM to be in the region of 35–56% (Beerkircher *et al.*, 2004; Coelho *et al.*, 2011, 2012; Bromhead *et al.*, 2012). These estimates of AVM are of a similar magnitude to that reported for *L. nasus*, 21–44% (Coelho *et al.*, 2012; Epperly *et al.*, 2012; Gallagher *et al.*, 2014a; Campana *et al.*, 2016). Campana *et al.* (2016) also

used PSATs to understand PRM, which allowed overall mortality to be estimated at 49 and 59% for *I. oxyrinchus* and *L. nasus*, respectively.

CARCHARHINIFORMES; FAMILY SCYLORHINIDAE

Catsharks are a frequent bycatch in demersal fisheries, and published estimates of AVM have ranged from <5% (Kaiser & Spencer, 1995; Walker *et al.*, 2005; Braccini *et al.*, 2012; Lyle *et al.*, 2014) to 19.2% (Fennessy, 1994). In European waters, there have been three studies examining the short-term survival of *S. canicula* following capture, with survival rates ranging from 78–90% in otter trawl (Rodríguez-Cabello *et al.*, 2005), to 90–98% survival in beam trawl (Kaiser & Spencer, 1995; Revill *et al.*, 2005). Whilst there are no comparable data for European gillnet fisheries, Lyle *et al.* (2014) reported 100% survival of catsharks taken in Tasmanian gillnet fisheries (<24 h soak time). Scyliorhinids are generally regarded as robust to capture (Frick *et al.*, 2009) and available data for shelf-living scyliorhinids indicate low AVM and low PRM. Many scyliorhinid species, however, occur in deeper water and data on the survival of deep-water scyliorhinids are lacking for European fisheries and limited for other parts of the world (Brooks *et al.*, 2015).

CARCHARHINIFORMES; FAMILIES TRIAKIDAE AND HEMIGALEIDAE

Survival appears to be quite variable across this family, and published quantitative data are lacking for European species. Fennessy (1994) reported 29% AVM for Arabian smooth-hound *Mustelus mosis* Hemprich & Ehrenberg 1899 taken in the South African prawn trawl fishery,

whilst the AVM of the sicklefin weasel shark *Hemigaleus microstoma* Bleeker 1852 was 62% in the Australian prawn trawl fishery (Stobutzki *et al.*, 2002). AVM ranged from 57–93% for three triakid sharks taken in an Australian gillnet fishery, where the soak times were <24 h (Braccini *et al.*, 2012), which were comparable to earlier studies in this area (Walker *et al.*, 2005). Whilst a lower AVM (24%) was reported for *M. antarcticus* in Tasmanian gillnet fisheries, subsequent post-release survival was estimated at 58.7% (Lyle *et al.*, 2014), indicating that PRM is an important source of the overall mortality, in agreement with the experimental studies of Frick *et al.* (2010a). Lower AVM, of up to 25%, has been reported for various triakid sharks captured by longline (Frick *et al.*, 2010a; Coelho *et al.*, 2012; Brooks *et al.*, 2015; Butcher *et al.*, 2015), but these data are either based on small sample sizes and/or from short soak times.

CARCHARHINIFORMES; FAMILY CARCHARHINIDAE

Those members of this family that occur in northern European seas are generally pelagic, although there are several more demersal species in sub-tropical and tropical waters. Overall, survival appears to be highly variable across this family (see Table II).

On one extreme, tiger shark *Galeocerdo cuvier* (Péron & Lesueur 1822) is one of the more robust carcharhinid sharks, and multiple studies have indicated AVM of <10% following capture by longline (Beerkircher *et al.*, 2004; Morgan & Burgess, 2007; Coelho *et al.*, 2012; Gallagher *et al.*, 2014a; Butcher *et al.*, 2015; Gulak *et al.*, 2015), with high post-release survival also reported (Afonso & Hazin, 2014; Gallagher *et al.*, 2014b).

Similarly, *P. glauca*, which is a frequent bycatch of pelagic longline fisheries and one of the most studied pelagic sharks, typically exhibits an AVM of <25% (Boggs, 1993; Megalofonou *et al.*, 2003; Beerkircher *et al.*, 2004; Moyes *et al.*, 2006; Campana *et al.*, 2009, 2011, 2016; Coelho *et al.*, 2011, 2012; Musyl *et al.*, 2011; Bromhead *et al.*, 2012; Epperly *et al.*, 2012; Serafy *et al.*, 2012; Gallagher *et al.*, 2014a; Gilman *et al.*, 2015). There is, however, some post-release mortality (see Campana *et al.*, 2016) and some other field studies (e.g. Poisson *et al.*, 2010; Afonso *et al.*, 2012) have reported a higher AVM (30–50%).

Several studies have reported AVM of 15–35% AVM for *C. longimanus* taken in longline fisheries (Boggs, 1993; Beerkircher *et al.*, 2004; Bromhead *et al.*, 2012; Coelho *et al.*, 2012; Gallagher *et al.*, 2014a; Fernandez Carvalho *et al.*, 2015), with those studies reporting either a higher or lower AVM (Musyl *et al.*, 2011; Poisson *et al.*, 2010; Afonso *et al.*, 2012) being based on more limited sample sizes.

In contrast to the above, other carcharhinids may be more prone to die during capture. Several studies have reported that night shark *Carcharhinus signatus* (Poey 1868) and *C. falciformis* exhibit higher AVM in relation to other members of the family taken in the same studies, ranging from 67–81% in the former and typically 42–75% in the latter (e.g. Beerkircher *et al.*, 2004; Coelho *et al.*, 2011, 2012; Serafy *et al.*, 2012; Gallagher *et al.*, 2014a). Interestingly, two studies have reported AVM of *C. falciformis* when caught by longline to be <30% (Musyl *et al.*, 2011; Gilman *et al.*, 2015). *C. falciformis* is also bycatch in purse seine fisheries, where AVM and PRM can result in >80% total mortality (Poisson *et al.*, 2014a; Hutchinson *et al.*, 2015; Eddy *et al.*, 2016).

Most studies on members of this family have explored survival following capture by longline fisheries, with far fewer studies examining the impacts of other gears. Fennessy (1994)

examined the survival of several species caught in a prawn trawl fishery and, of those species taken in meaningful numbers, AVM ranged from 29% (*Rhizoprionodon acutus* (Rüppell 1837)) to 56% (*Carcharhinus brevipinna* (Müller & Henle 1839)). The various carcharhinids taken in a prawn trawl fishery in Australian waters exhibited 52–82% AVM (Stobutzki *et al.*, 2002). Capture in scientific gillnets (soak times ≤ 1 h) can result in AVM of 18–40% (Manire *et al.*, 2001; Hueter *et al.*, 2006). In relation to commercial gillnet fisheries, whilst some carcharhinids may be more robust (for example, 36% AVM was reported for copper shark *Carcharhinus brachyurus* (Günther 1870) by Braccini *et al.* (2012)), higher AVM has been reported in other studies: 80.4–90.5% for three carcharhinid species (Thorpe & Frierson, 2009), with 61–77% of two species of carcharhinid recovered dead from protective nets (Reid and Krogh, 1992).

CARCHARHINIFORMES; FAMILY SPHYRNIDAE

Hammerhead sharks appear to be particularly vulnerable to the effects of capture in commercial gears. High AVM for *Sphyrna* spp. has been reported in trawls (97.6%; Fennessy, 1994), protective nets (98.3%; Reid & Krogh, 1992) and commercial gillnets (71.5–89.3%; Thorpe & Frierson, 2009; Braccini *et al.*, 2012). Even capture in gillnets set for short periods (≤ 1 h) during scientific studies can result in an AVM of 31–37% (Manire *et al.*, 2001; Hueter *et al.*, 2006). Furthermore, estimates of overall mortality in the latter study, using mark-recapture data from fish at different categories of vitality, suggested mortality of 62%. Within commercial longline fisheries, though some studies have indicated AVM of 54–71% (Beerkircher *et al.*, 2004; Coelho *et al.*, 2012; Gallagher *et al.*, 2014a; Fernandez-Carvalho,

2015), higher estimates (AVM = 70–90% or more) have also been reported widely (Morgan & Burgess, 2007; Coelho *et al.*, 2011; Bromhead *et al.*, 2012; Butcher *et al.*, 2015). Afonso *et al.* (2011) noted a higher mortality when *Sphyrna* spp. were caught by J-hooks in comparison to circle hooks, but this was based on a low sample size. There have been fewer studies on PRM of hammerhead sharks. Gallagher *et al.* (2014b) noted that 43% of *S. mokarran* tagged were thought to have died within two weeks of release, despite the comparatively ‘benign’ capture technique (baited drum lines, 17–131 min fight times). Eddy *et al.* (2016) reported full PRM of *S. lewini* released after capture in tuna purse seine, but this was only based on tagging three specimens.

PRISTIFORMES

There are no published studies on the discard survival of sawfish. Given the scarcity of these species in many parts of their biogeographic range, most recent ecological studies have been from Florida and Australia. In such areas, they have been observed with fragments of monofilament around the rostrum (Seitz & Poulakis, 2006), indicating that they may potentially survive interactions with fishing gear, although survival has not been quantified and the longer-term survival is unknown.

RHINIFORMES AND RHINOBATIFORMES

Guitarfish are a bycatch in various bottom fisheries, mostly in tropical and sub-tropical seas. Two species occur in southern European waters, but there are no data on their discard

survival in this region. In South African waters, Fennessy (1994) provided data for four species from these closely-related orders, and whilst sample sizes were limited for individual species, aggregated data indicated AVM of 32.5% in trawl-caught specimens. Within Australian waters, Stobutzki *et al.* (2002) recorded 10% AVM in a prawn trawl fishery, Walker *et al.* (2005) reported an AVM of 16.6% in a gillnet fishery, and AVM after capture on longline ranged from 0–25%, depending on the time they were hooked for (Butcher *et al.*, 2015).

TORPEDINIFORMES

Electric rays are an occasional bycatch in various bottom fisheries, mostly in tropical and sub-tropical seas. Three species occur in European waters, but there are no published data on the discard survival of these species. Indeed, discard data are very limited for this group, with a single study reporting AVM (40%) for Gulf torpedo ray *Torpedo sinuspersici* Olfers 1831 in the South African prawn trawl fishery, albeit based on only five fish (Fennessy, 1994). Electric rays are generally considered to use their electric charge when in nets and, as it is possible that they are physiologically-impaired when discarded, studies on the PRM of members of this order could usefully be undertaken.

RAJIFORMES

Skates are a frequent bycatch, or even a target species-complex, in various demersal fisheries. Low AVM (<5%) has been reported in *R. clavata* taken in various inshore fisheries, including longline, trawl and gillnet (Ellis *et al.*, 2008b), and similarly low rates of AVM also reported for

some other fisheries (Mandelman *et al.*, 2013; Lyle *et al.*, 2014; Saygu and Deval, 2014). AVM is higher on more offshore grounds where tow durations and soak times are greater (e.g. Bendall *et al.*, 2012), but there is less information from fisheries that catch skates from deeper water (but see Endicott & Agnew, 2004; Laptikhovsky, 2004).

Studies using on-board survival tanks have shown survival of about 40–72% over various time periods, typically over 2–5 days (Kaiser & Spencer, 1995; Laptikhovsky, 2004; Enever *et al.*, 2009, 2010; Benoît *et al.*, 2010a; Depestele *et al.*, 2014), but some of these studies have combined data across the species-complex taken in the fishery and it should be recognised that there may be important species-specific differences in survival (Mandelman *et al.*, 2013). Whilst there have been several ecological studies using electronic tags on skates, there have been no published studies using such technologies to better understand longer-term PRM of rajids.

MYLIOBATIFORMES; FAMILIES DASYATIDAE AND UROLOPHIDAE

Stingrays are a bycatch in various bottom fisheries, especially in tropical and sub-tropical seas. Various stingrays occur in European waters, including some demersal species and the pelagic *P. violacea*. Whilst there are extensive data on the AVM of the latter species, as it is taken in longline fisheries, the majority of stingrays are demersal and published data are more limited. Fennessy (1994) recorded four species from prawn trawl catches off South Africa, for which AVM ranged from 17.7–70% (34.6% overall), and Stobutzki *et al.* (2002) found AVM of 53–59% for two species captured in an Australian prawn trawl fishery. Within gillnet fisheries, >90% of dasyatids were found to be released alive when caught in shallow estuarine waters

(Gray, 2002), with reported AVMs for urolophids ranging from 0% and up to 23% in various other gillnet fisheries (Walker *et al.*, 2005; Braccini *et al.*, 2012; Lyle *et al.*, 2014). Both Afonso *et al.* (2011) and Butcher *et al.* (2015) conducted scientific studies with demersal longline, and reported that there was no AVM for those stingrays caught.

Pelagic longline fisheries can have a high bycatch of *P. violacea*, with estimates of AVM generally low: 1–10% (Carruthers *et al.*, 2009; Coelho *et al.*, 2011, 2012; Afonso *et al.*, 2012; Amorim *et al.*, 2014), but ranging up to 10–30% (Boggs, 1992; Bromhead *et al.*, 2012; Gilman *et al.*, 2015). Although Poisson *et al.* (2010) reported that nearly 59% were dead, this study was based on a small sample size.

MYLIOBATIFORMES; FAMILIES GYMNURIDAE, MYLIOBATIDAE AND MOBULIDAE

Butterfly rays (Gymnuridae) have a sole representative in European waters, but there are no data on the discard survival when captured in European fisheries. Elsewhere in the world, reported AVM for members of this family ranges from 41–46% (prawn trawl; Fennessy, 1994; Stobutzki *et al.*, 2002).

Eagle rays (Myliobatidae) are only an infrequent bycatch in European fisheries, and this family is more diverse and abundant in warmer waters. Published data on members of this family have often been based on small sample sizes or have aggregated data at family-level. Estimates of AVM include 27% in prawn trawl (Fennessy, 1994; three species combined), 5–21% in gillnet (Walker *et al.*, 2005; Braccini *et al.*, 2012). Coelho *et al.* (2012) did not record any AVM of members of this family caught by longline.

Manta and devil rays (Mobulidae) are a bycatch in various pelagic fisheries in tropical and sub-tropical waters. Reported AVM ranges from about 1.4–5.2% for pelagic longline fisheries (Coelho *et al.*, 2011, 2012; Mas *et al.*, 2015), but there is potentially higher mortality in purse seine fisheries (Zeeberg *et al.*, 2006; Croll *et al.*, 2015), and improved estimates of both AVM and PRM are required for such fisheries. Francis & Jones (2016) recently noted that spinetail devilray *Mobula japanica* (Müller & Henle 1841) caught by purse seine and brought onboard by brail net could survive release (n = 3), although specimens entangled in the netting when brought on board (n = 4) did not survive release.

CONCLUSIONS AND FUTURE DIRECTIONS

There has been increased management interest in elasmobranch fish in recent decades, and consequently there has been a notable increase in discard survival studies over the last ten years. This is highlighted by the fact that the review by Broadhurst *et al.* (2006) cited only three studies that quantified estimates of the mortality (AVM or PRM) of elasmobranchs captured in towed commercial gears. Whilst there have been numerous studies examining the AVM of elasmobranchs captured in various longline fisheries (primarily pelagic longline fisheries for tuna and tuna-like species, with these data often collected during observer programmes), data on AVM for many other fisheries are typically very limited. Improved international-coordination to collect standardised data on AVM for other fisheries could usefully be considered.

The various studies that have collected data on the vitality of fish after capture have used a range of scales, ranging from 5-point scales to a simpler binary (live or dead) scoring system. Those studies using 3–5 point scales have generally defined how the categories are selected

(e.g. based on the degree of body movements, spiracular movements and body damage), but the application of these in the field may be somewhat more subjective in more extensive observer programmes. Whilst more categories can provide valuable data for any individual study, an increased number of categories could result in observer-related differences in more extensive data collection programmes. Hence, studies to examine the extent of between-observer variation and to better determine an optimal scoring system for the collection of vitality and AVM data for multi-observer field programmes are required.

Whilst there have been an increased number of published studies on AVM, there is still a paucity of data on PRM, with existing studies based typically on short-term survival in tanks or cages (e.g. Rodríguez-Cabello *et al.*, 2005; Mandelman & Farrington, 2007b; Lyle *et al.*, 2014), or from using electronic tags (e.g. Gallagher *et al.*, 2014b; Campana *et al.*, 2016). Whilst the former may be suitable for smaller-bodied elasmobranchs, including juveniles, the potential effects of captive stress should always be addressed where possible. There has been an increased use of electronic tags to better understand and quantify PRM, especially for larger pelagic sharks, but improved coordination of such studies could be considered, given the resources required to provide robust estimates based on appropriate sample sizes.

Data on various facets of the survival of elasmobranchs are now available for both a range of taxa and fisheries. The identification of data gaps and the prioritisation of data requirements should be undertaken by RFMOs, or other competent bodies, in order to identify where there are significant discarding issues, with particular reference to the discarding of (a) species that are prohibited or not to be retained; (b) discarding of unmarketable bycatch species, especially if the discarded species are considered vulnerable taxa; (c) discarding of small individuals (which may be either regulatory discarding, if a minimum landings size is enforced,

or economic discarding that is influenced by low market value of smaller-sized fish); and (d) regulatory discarding (e.g. when a quota is enforced and is set at a restrictive level), which can include the discarding of larger fish of marketable size. Whilst such analyses are required for many fish and shellfish, specific analyses for elasmobranchs (and other vulnerable taxa) should be considered.

Within European waters, several elasmobranch stocks, including rajiform skates and spurdog, will potentially be included within the landing obligation, unless there is an appropriate body of scientific evidence to demonstrate high survival. In relation to spurdog, limited data on AVM are available for gillnet capture (Bendall *et al.*, 2012), but these were derived mostly from sets with reduced soak time and so are expected to give higher estimates of survival than may be expected under normal fishing operations. Other published studies to date have been from field studies undertaken elsewhere in the world (Rulifson, 2007; Mandelman & Farrington, 2007a, b; Braccini *et al.*, 2012; Lyle *et al.*, 2014), but these studies will not reflect the range of fishing operations catching spurdog in European seas.

There have been several studies examining 'discard survival' of skates, both in European seas (Kaiser & Spencer, 1995; Ellis *et al.*, 2008b; Enever *et al.*, 2009, 2010; Bendall *et al.*, 2012; Depestele *et al.*, 2014) and elsewhere (Fennessy, 1994; Endicott & Agnew, 2004; Laptikhovskiy, 2004; Benoît *et al.*, 2010a, b, 2012; Mandelman *et al.*, 2013; Lyle *et al.*, 2014; Saygu & Deval, 2014). Whilst providing data on AVM and short-term survival, there are currently no published quantitative estimates of longer-term PRM. Hence, robust, quantitative estimates of survival are required for a variety of elasmobranchs captured in various European fisheries.

Fisheries managers are increasingly using lists of prohibited species to reduce fishing mortality on the most vulnerable taxa that may be captured in fisheries. Whilst such measures will prevent fisheries legally targeting such species, the overall efficacy of such listings is dependent on whether fisheries have a reduced encounter rate (i.e. they do not fish in any areas where prohibited species occur regularly or in higher abundance) and whether or not there is a low mortality (including AVM and PRM). Hence, improved studies to better understand the AVM and PRM of prohibited species is required in order to determine whether a prohibited listing alone will reduce fishing mortality or whether other measures (e.g. gear modifications, improved catch processing and handling, or spatial management) are also required. Whilst species that are prohibited in European fisheries are exempt from the landing obligation, there is still a scientific need to understand the degree of discard survival of such species.

Fisheries management has traditionally tried to afford protection of juvenile fish, whether through spatial management (e.g. closures or gear restrictions in nursery grounds), or through a minimum landing size). Additionally, smaller fish are often of lower market value, and so may be more likely to be discarded by fishers. Some studies have confirmed that smaller fish may display higher capture mortality (Diaz & Serafy, 2005; Ellis *et al.*, 2008b) and smaller individuals are intuitively more likely to be predated on by scavengers following discarding. Hence, further studies to better identify the discarding levels, AVM and PRM of juvenile elasmobranchs are required, especially in relation to trawl and dredge fisheries which can have a relatively higher bycatch of juveniles.

Several studies have indicated that females of some elasmobranch species may survive better than males (e.g. Stobutzki *et al.*, 2002; Laptikhovsky, 2004). This may be linked to females

having a thicker skin, although the increased thickness of the skin in females has only been established for very few species (Pratt, 1979; Kajiura *et al.*, 2000). It can also be noted that elasmobranchs often display a sexual dimorphism in maximum size (females attaining a larger size) and fecundity generally increases with length. Maximum landing lengths for elasmobranchs have been used as management measures in some areas, in order to reduce fishing mortality on the female spawning stock. Quantifying potential sex-based (and size-based) differences in AVM and PRM could provide important data to inform the relative merits of the various options for size restrictions that might be considered. Another area that has not been subject to meaningful study is the chances of near-term females giving birth to their young successfully, even if PRM of the mother could be high. Several studies have shown that females may birth their young (including term pups, but also mid-term embryos) on capture (e.g. Trinnie *et al.*, 2012), and this is widely presumed to be stress-related. Dissection of dead *S. acanthias* and other sharks shortly after capture can even allow live pups to be removed from the uteri (J. R. Ellis, pers. obs.). For some species, there may need to be due consideration of the potential for gravid females to give birth after discarding, even if the mother has a low chance of longer-term survival, and how this should be considered under any landing obligations.

Some published studies have combined data across families, in order to maximise sample sizes. Some of the more species-rich families (e.g. Carcharhinidae and Rajidae), however, can have differing levels of AVM despite their morphological and ecological similarities. Hence, future studies should endeavour to provide species-specific data on AVM wherever possible, even if more detailed analyses use aggregated data.

Certain elasmobranch taxa, including *Sphyrna* spp. and *Alopias* spp., are of particular concern to some RFMOs, and these species are identified as species that should not be retained in some fisheries. Studies to date have generally indicated that AVM and/or PRM of both *Sphyrna* spp. and *Alopias* spp. can be higher than observed in other elasmobranch taxa taken in the same fisheries. Further studies to identify what modifications to fishing gears, fishing practices and handling may successfully improve the survivorship of such taxa are required.

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Fig. 1. Gillnet-caught spurdog *S. acanthias* in which the internal organs have been partially eaten by scavenging isopods (inset).



Fig. 2. Trawl-caught starry smooth-hound *M. asterias* showing evidence of prior capture by gillnet.

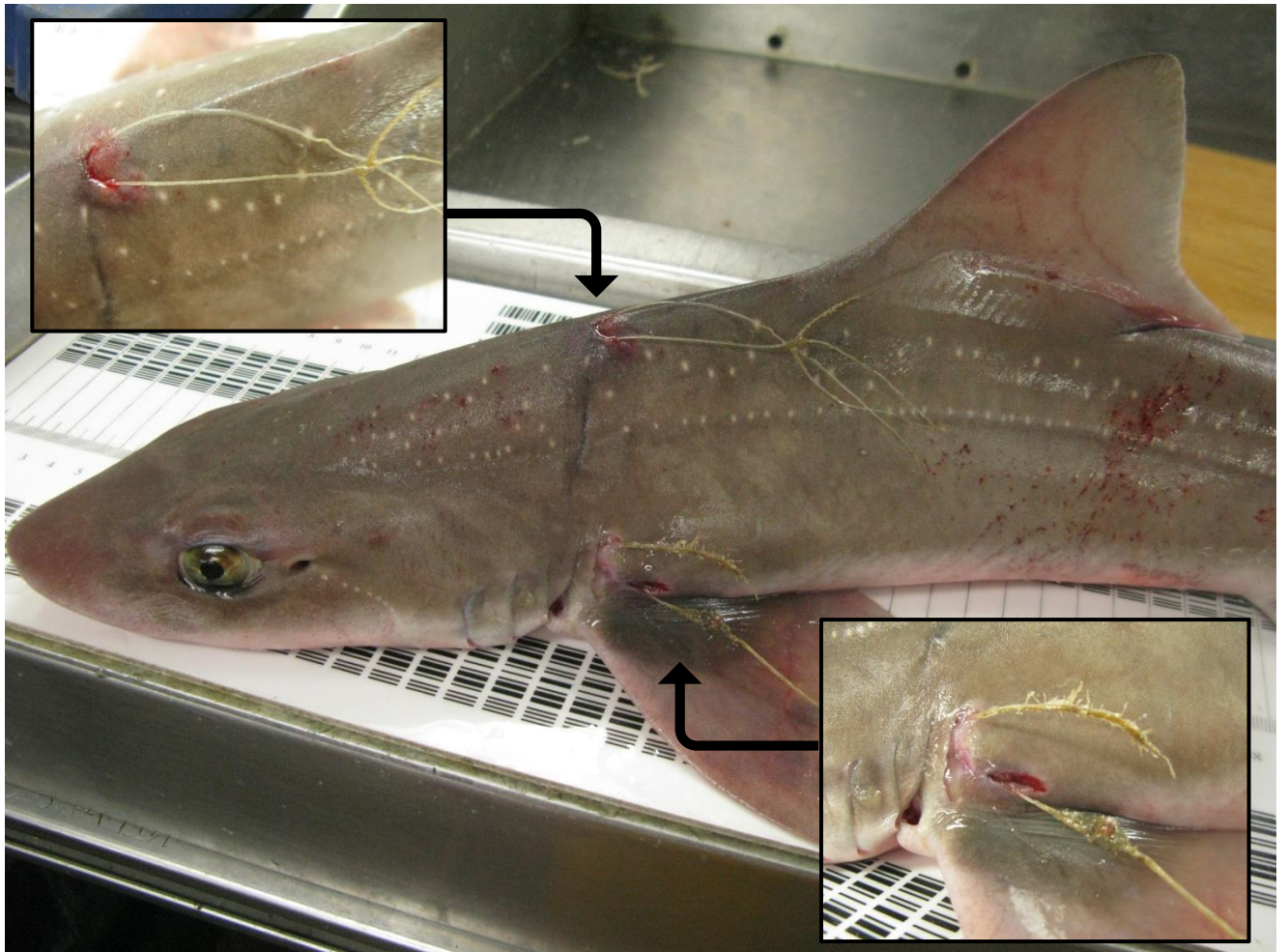


Fig. 3. Trawl or gillnet-caught spurdog *S. acanthias* showing evidence of prior capture by longline showing (a-b) various stages of healing of jaws, (c) hook in body cavity (note that the poor state of the liver may be an artefact of freezing and thawing), and (d) hook that has penetrated into the pericardial cavity, close to the heart.

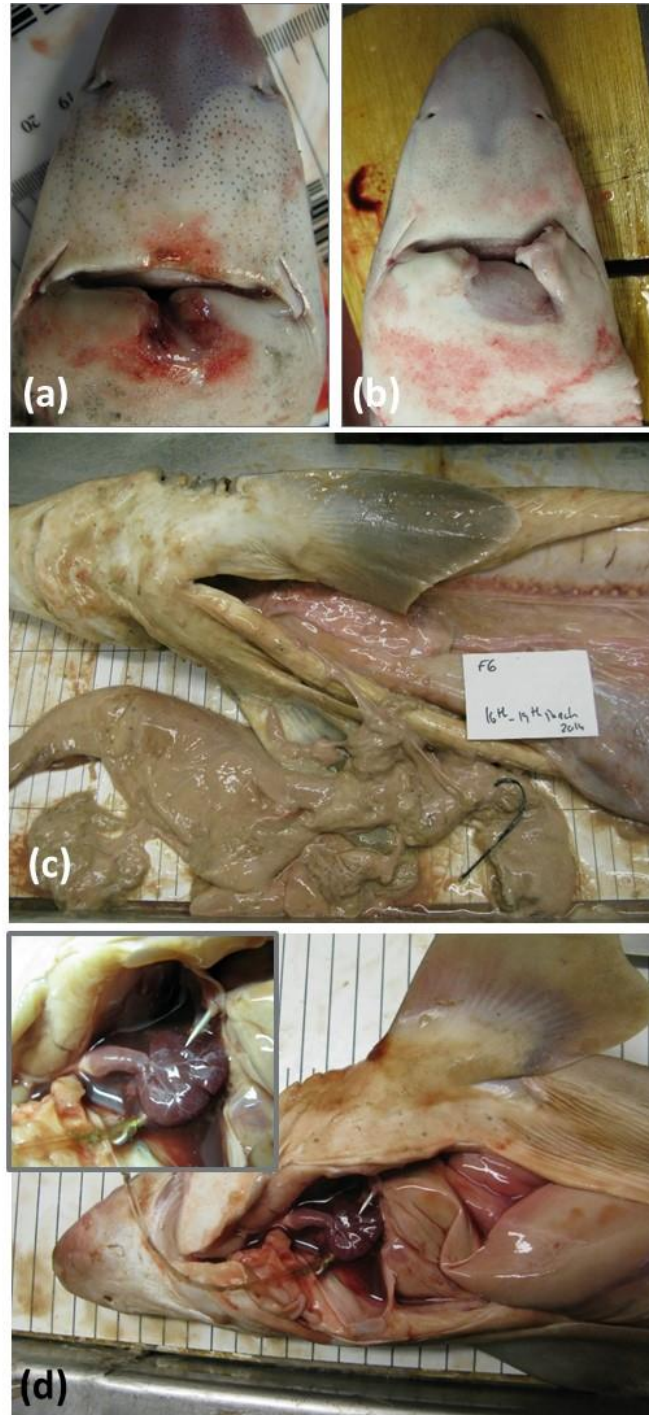


Table I: Example descriptions for condition of fish in discard studies (Adapted from Benoît *et al.* 2010b)

Condition	Number	Category	Description
Vitality	1	Good	Strong body movements; spiracles (if present) moving; no or only minor injuries
	2	Fair	Weak body movements; some spiracular movement; minor injuries
	3	Poor	No obvious body movements; limited spiracular movements; minor or major injuries
	4	Moribund	No movements of body or spiracle
Injury	1	None	No bleeding or injuries apparent
	2	Minor	Minor bleeding; some damage to mouth parts (e.g. in longline fisheries)
	3	Major	Major bleeding; extensive damage to mouth parts

Table II: Summary of studies examining AVM (%) and other elements of discard survival of elasmobranch fish by gear. Data for AVM in parentheses relate to small sample sizes.

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
TRAWL								
Commercial prawn trawl (otter trawl, 38 mm stretched mesh cod-end, 2–3 knot trawl speed; fishing depths of 20–45 m)	Natal (Indian Ocean)	AVM		Squatinae	<i>Squatina africana</i> (n = 10)	60%	AVM = 32.5% for rhinobatoids (all species combined)	Fennessy (1994)
					<i>Stegostoma fasciatum</i> (n = 1)	(0%)		
				Scyliorhinidae	<i>Halaelurus lineatus</i> (n = 47)	19.2%		
				Triakidae	<i>Mustelus mosis</i> (n = 14)	28.6%		
				Carcharhinidae	<i>Carcharhinus amboinensis</i> (n = 1)	–		
					<i>Carcharhinus brevipinna</i> (n = 25)	56%		
					<i>Carcharhinus obscurus</i> (n = 8)	(12.5%)		
					<i>Carcharhinus plumbeus</i> (n = 6)	(33.3%)		
					<i>Rhizoprionodon acutus</i> (n = 24)	29.2%		
				Sphyrnidae	<i>Sphyrna lewini</i> (n = 169)	97.6%		
				Rhinidae and Rhinobatidae	<i>Rhina ancylostoma</i> (n = 1)	–		
					<i>Rhynchobatus djiddensis</i> (n = 11)	18.2%		
					<i>Rhinobatus annulatus</i> (n = 9)	(11.1%)		
					<i>Rhinobatus leucospilus</i> (n = 19)	52.6%		
				Torpedinidae	<i>Torpedo sinuspersici</i> (n = 5)	(40%)		
				Rajidae	<i>Raja miraletus</i> (n = 2)	(0%)		
Dasyatidae	<i>Dasyatis chrysonata</i> (n = 34)	17.7%						
	<i>Dasyatis thetidis</i> (n = 10)	70%						
	<i>Himantura gerrardi</i> (n = 47)	42.6%						
	<i>Himantura uarnak</i> (n = 16)	25%						

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
				Gymnuridae	<i>Gymnura natalensis</i> (n = 84)	46.4%	AVM was lower in tows of <2 h duration; AVM higher in larger catches	
				Myliobatidae	<i>Aetobatus narinari</i> (n = 3) <i>Myliobatis aquila</i> (n = 4) <i>Pteromylaeus bovinus</i> (n = 4)	(0.0%) (50.0%) (25.0%)	AVM = 27.3% for myliobatids (all species combined)	
Commercial prawn trawl (research surveys and observer data)	Northern Australia	AVM	Elasmobranchs categorised as live or dead	Carcharhinidae	<i>Carcharhinus dussumieri</i> (n = 321) <i>Carcharhinus sorrah</i> (n = 23) <i>Carcharhinus tilstoni</i> (n = 73) <i>Rhizoprionodon acutus</i> (n = 116)	52% 65% 82% 82%		Stobutzki <i>et al.</i> (2002)
				Hemigaleidae	<i>Hemigaleus microstoma</i> (n = 68)	62%		
				Rhinidae	<i>Rhynchobatus djiddensis</i> (n = 59)	10%		
				Dasyatidae	<i>Dasyatis leylandi</i> (n = 41) <i>Himantura toshi</i> (n = 58)	59% 53%		
				Gymnuridae	<i>Gymnura australis</i> (n = 34)	41%		
Bottom trawl squid fishery (cod-end mesh size of 110 mm; 3.8–4.2 km trawl speed; 80–190 m fishing depth)	SW Atlantic (Falkland Islands)	Short-term survival	Random sample of skates placed in on-board tanks to assess health over periods of up to 2.3 h	Arhynchobatidae	<i>Bathyraja albomaculata</i> (n = 14) <i>Bathyraja brachyrops</i> (n = 11) <i>Bathyraja griseocauda</i> (n = 3) <i>Bathyraja macloviana</i> (n = 2) <i>Bathyraja magellanica</i> (n = 5) <i>Bathyraja</i> sp. (n = 16) <i>Psammobatis</i> sp. (n = 15)	–	For species combined (n = 66), mortality was 31.8% and a further 9.1% were dead or moribund after the recovery time. Overall mortality was 40.9%. Females showed a greater survival (66.7%) than males (56.4%)	Laptikhovsky (2004)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Otter trawl (baca) with cod-end liner deployed from research vessel (0.5 h tow duration)	NE Atlantic (Cantabrian Sea)	Short-term survival	Specimens left on deck for known periods to simulate catch processing time, then maintained in a tank for 1 h before categorisation as alive or dead	Scyliorhinidae	<i>Scyliorhinus canicula</i>	–	Mean survival rate was 90%, ranging from 60–100%. Survival decreased with increased sorting time	Rodríguez-Cabello <i>et al.</i> (2005)
Otter trawl (baca) deployed from commercial vessels (3–6 h tow duration)	NE Atlantic (Cantabrian Sea)		As above	Scyliorhinidae	<i>Scyliorhinus canicula</i>	–	Mean survival rate was 78%, ranging from 47–98%. Suggestion of reduced survival with increased depth and increased sorting time, but results not significant	Rodríguez-Cabello <i>et al.</i> (2005)
‘Danish’ otter trawl deployed from commercial vessel (0.75 h haul duration)	NW Atlantic	Short-term survival and blood sampling	Spurdog caught, transported ashore and held in captivity (n = 34)	Squalidae	<i>Squalus acanthias</i>	–	AVM not reported, but no immediate post-capture mortality observed in sub-sample examined. 5.9% mortality following transport and captive period of 30 days	Mandelman and Farrington (2007a)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
'Danish' otter trawl deployed from commercial vessel (cod-end of 152 mm mesh size; 0.75–1.0 h haul duration; 60–72 water depth)	NW Atlantic	Short-term survival and blood sampling	Samples of trawl-caught spurdog used for examining short-term (72 h) survival in sea pens or used in sampling blood parameters. A control group were sampled with hook-and-line (46–56 m depth)	Squalidae	<i>Squalus acanthias</i>	–	AVM not reported, but no immediate post-capture mortality observed in sub-samples examined. Trawl-caught fish exhibited 29% mortality over 72 hours. No at-vessel mortality for fish caught by hook-and-line, with this control group showing 24% mortality over 72 hours. Catch weight in the trawl found to be an important factor affecting survival, with catches >200 kg leading to higher 72 h mortality estimates	Mandelman and Farrington (2007b)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Trawl (101 mm stretch mesh; 0.5–1.5 h haul duration)	NW Atlantic	AVM and short-term survival	Immediate post-capture mortality recorded, live fish maintained in sea cages for 48 h	Squalidae	<i>Squalus acanthias</i>	0%	All spurdog (n = 635) that were captured were alive; all specimens maintained in sea cages (n = 480) survived for 48 hours. Some trawl caught specimens (26%) had evidence of prior gillnet damage. Punctures and gashes were more frequent in trawl-caught fish than gillnet-caught fish.	Rulifson (2007)
Demersal trawls deployed from commercial inshore vessels. The tow durations (ca. 0.5–1.5 h), were as normal practise for this fishery	NE Atlantic (southern North Sea)	AVM and tagging	Health state recorded on a three point (lively, sluggish, dead) and fish tagged and released	Rajidae	<i>Raja clavata</i> (n = 3822)	0.6%	Overall, 86.9% were categorised as lively, 12.5% as sluggish and 0.6% as dead. These data were aggregated across three vessels. AVM highest for fish <50 cm long (1.2%). These data were collected by observers, and so fish were processed immediately after capture. Mortality would likely increase if fish remained on deck whilst catch processed.	Ellis <i>et al.</i> (2008a)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Demersal trawl (twin-rig otter trawl)	NE Atlantic (Bristol Channel)	Vitality and short-term survival	Survival of skates examined in tows of normal commercial duration (2.7–4.3 h) and shorter tows (0.75–2.0 h). Health state of skates scored (1–3) and maintained in survival tanks on board. Health scored for other skates that were tagged and released. Cod-end weight estimated.	Rajidae	Various skates, including: <i>Leucoraja naevus</i> <i>Raja brachyura</i> <i>Raja clavata</i> <i>Raja microocellata</i> <i>Raja montagui</i>	–	<p>No information on AVM. Of the skates that were held in tanks for up to 64 h, the mortality rates from commercial and short tows were 45% (n = 124) and 13% (n = 38), respectively. Skates rated as ‘poor’, ‘moderate’ and ‘good’ health showed mortality rates of 79%, 16% and 5%.</p> <p>The proportion of skates deemed of ‘good’ health in commercial tows ranged from 3–6% (<i>R. brachyura</i>, <i>R. microocellata</i> and <i>R. montagui</i>) to 35% (<i>R. clavata</i>). A greater proportion of skates (18–69%) were considered to be in ‘good’ condition in shorter tows. Cod-end weight, species and sex all found to be important factors influencing health state.</p>	Enever <i>et al.</i> (2009)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Trawls with different designs of cod-end (80 and 100 mm diamond mesh and 100 mm square mesh)	NE Atlantic (Bristol Channel)	Vitality	Health state assessed visually for vitality (poor health = 1, moderate health = 2; good health = 3).	Rajidae	Various skates, including: <i>Leucoraja naevus</i> <i>Raja brachyura</i> <i>Raja clavata</i> <i>Raja microocellata</i> <i>Raja montagui</i>	–	80 mm diamond mesh: Mean vitality = 1.2; 25% of skates with vitality >1 100 mm diamond mesh: Mean vitality = 1.3; 34% of skates with vitality >1 100 mm square mesh: Mean vitality = 1.5; 47% of skates with vitality >1	Enever <i>et al.</i> (2010)
		Short-term survival	Survival in onboard holding tanks (to >48 h).	Rajidae	<i>Raja microocellata</i>	–	The percentage of individuals that survived >48 h were 55–57% (80 mm cod-end), 59% (100 mm diamond) and 67% (100 mm square mesh)	
Trawl and line fisheries	NW Atlantic (Gulf of St Lawrence)	Vitality and short-term survival	Health state assessed visually for vitality (1–4) and survival of specimens held in on-board tanks assessed (to >48 h).	Rajidae	Various skates, including: <i>Amblyraja radiata</i> <i>Leucoraja ocellata</i> <i>Malacoraja senta</i>	–	>50% and 70% of skates were scored as 'excellent' following capture in trawl and longline, respectively. Fish surviving for at least 48 h ranged from 42% (vitality 4) to 100% (vitality 1)	Benoît <i>et al.</i> (2010a)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Bottom trawl (2.75 knot tow speed; tow duration of 1–2 h)	NW Atlantic (Canada)	AVM and short-term survival	Vitality scored at capture and then fish monitored in on-board holding tanks for 14–110 h	Rajidae	Various skates (n = 160), including: <i>Amblyraja radiata</i> <i>Leucoraja ocellata</i> <i>Malacoraja senta</i>	13.75%	75.6% survived capture and holding, and 10.6% died whilst being held in tanks.	Benoît <i>et al.</i> (2012)
Trawl (165 mm diamond mesh cod-end) deployed from commercial vessels, duration for 'control' tows of 0.25–0.33 h, with other tows of moderate (1.5–2 h) or extended (3–4 h) duration	NW Atlantic (Massachusetts and New Hampshire)	AVM and short-term survival	Injuries scored (1 = no obvious injury; 3 = extensive injury); submerged net pens for examining survival (72 h); laboratory tanks for 7-day monitoring	Rajidae	Various skates, including: <i>Amblyraja radiata</i> <i>Leucoraja erinacea</i> <i>Leucoraja ocellata</i> <i>Malacoraja senta</i>	<1%	44% injured (categories 2 and 3) and <1% skates dead on capture; 19% mortality over 72 h overall for fish caught under commercial conditions (ranging from 9% in winter skate to 60% in smooth skate); mortality over 7 day trials increased to 66% (thorny skate) and 22% (little skate)	Mandelman <i>et al.</i> (2013)
Research trawl (17 m ground rope; 44 mm cod-end mesh; 2.3–2.7 knot trawl speed). Tow duration either control (1 h) or 'commercial' (3 h)	Western Mediterranean	AVM and short-term survival	Catch processed, skates left on deck for 10–20 minutes and then placed in holding tanks. Health state recorded on a 4-point scale (0 = dead; 1 = poor health; 2 = moderate health; 3 = good health). Short-term survival checked over 48 h	Rajidae	<i>Raja clavata</i> (n = 120)	1.7%	90.8% of specimens in moderate or good health. Specimens caught in short tows (n = 52; 98% in moderate/good health) were in a better health state than those taken in 'commercial' tows (n = 68; 85% in moderate/good health). The overall proportion alive after 48 h was 80.8%.	Saygu & Deval (2014)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
					<i>Raja miraletus</i> (n = 68)	26.5%	Only 42.6% of specimens were in moderate or good health. The overall proportion alive after 48 h was 20.6%.	
Pilbara trawl fishery (trawl depths of 50–100 m, tow durations of ca. 2.5 h)	Australia	AVM		–	Sharks (aggregated, n = 66)	90.9%	Data reported for higher taxonomic groups only	Jaiteh <i>et al.</i> (2015)
				–	Batoids (aggregated, n = 53)	66%		
BEAM TRAWL AND DREDGE								
Beam trawl (4 m beam, chain mat, 80 mm diamond mesh cod-end; 0.5 h tows)	NE Atlantic (Irish Sea)	AVM and short-term survival	Animals caught from beam trawl placed in on-board tanks with fresh seawater supply and assessed for up to 5 days	Rajidae Scyliorhinidae	<i>Leucoraja naevus</i> (n = 32) <i>Scyliorhinus canicula</i> (n = 42)	0% 0–3%	No AVM, but 41% dead after 5 days 90–94% of fish survived periods of 120 h	Kaiser and Spencer (1995)
8 m beam trawl with chain mat and 80 mm cod-end mesh	NE Atlantic (Western English Channel)	Short-term survival	Specimens maintained in on-board survival tanks for periods of 36–60 h	Scyliorhinidae	<i>Scyliorhinus canicula</i>	–	Mean survival rate of 98%	Revill <i>et al.</i> (2005)
Scallop dredge (commercial fishery and experimental)	NW Atlantic (Gulf of St Lawrence)	Vitality	Health state assessed visually for vitality (1–4) and degree of injury (1–3)	Rajidae	<i>Leucoraja ocellata</i> (n = 49 in commercial fishery; n = 77 in experimental fishery)	–	In both commercial and experimental conditions, >80% of winter skate were scored as 'excellent' condition and >70% with 'no injury'. Fish in poor or moribund condition accounted for only 8.2% (commercial) and 4% (experimental) of specimens	Benoit <i>et al.</i> (2010b)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Beam trawls deployed from research vessel	NE Atlantic (North Sea)	Short-term survival	Fish maintained in on-board holding tanks for periods of up to 65–80 h	Rajidae	Data collected at family level (n = 249)	–	72% of skates survived	Depestele <i>et al.</i> (2014)
Scallop dredges (commercial vessels with standard fishing operations; 15–15.5' commercial scallop dredges with 4" rings and 10" square mesh top; 0.17–1.5 h tows)	NW Atlantic	Vitality and short-term survival	Condition reported (1 = minimal injuries to 3 = extensive injuries). Sub-samples held in survival tanks to examine post-release mortality, with specimens from 10 min tows acting as control fish	Rajidae	<i>Leucoraja erinacea</i> (n = 2634 for condition / 179 for post-release mortality)	–	The proportion of fish with minor, moderate and extensive injuries were 22, 49 and 29%, respectively. Post-release mortality estimated at 49.1% over 72 h.	Rudders <i>et al.</i> (2015)
					<i>Leucoraja ocellata</i> (n = 1313 / 116)	–	The proportion of fish with minor, moderate and extensive injuries were 19, 52 and 29%, respectively. Post-release mortality estimated at 65.2% over 72 h.	
					<i>Dipturus laevis</i> (n = 269 / 39)	–	The proportion of fish with minor, moderate and extensive injuries were 11, 58 and 31%, respectively	

GILLNET AND TANGLE NET

Protective nets set off beaches. Soak times generally 12–48 h	Australia (New South Wales)	AVM	Information on the proportion alive recorded, but no specific information in relation to soak time	Hexanchidae	<i>Notorynchus cepedianus</i> (n = 54)	85.1%	Values relate to the percentage recovered dead from protective shark nets, which is analogous to AVM	Reid and Krogh (1992)
				Squatinae	<i>Squatina australis</i> (n = 651)	34.4%		
				Heterodontidae	<i>Heterodontus</i> spp. (n = 60)	3.3%		
				Orectolobidae	<i>Orectolobus</i> spp. (n = 13)	15.4%		
				Odontaspidae	<i>Carcharias taurus</i> (n = 62)	41.3%		
				Alopiidae	<i>Alopias</i> spp. (n = 22)	90.9%		
Lamnidae	<i>Carcharodon carcharias</i> (n = 185)	49.2%						

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
					<i>Isurus</i> spp. (n = 17)	90.9%		
				Carcharhinidae	<i>Carcharhinus</i> spp. (n = 724)	61%		
					<i>Galeocerdo cuvier</i> (n = 177)	76.7%		
				Sphyrnidae	<i>Sphyrna</i> spp. (n = 2031)	98.3%		
Scientific fishing with gillnet (10 cm stretch mesh, soak time ca. 12 h, but nets checked every 0.25 h)	Bahamas	AVM	Mortality recorded after capture, handling, tagging and maintenance in a pen	Carcharhinidae	<i>Negaprion brevirostris</i> (n = 655)	0–11.1%	Overall, handling mortality (including capture) of juvenile lemon sharks was 3.5% (ranging from 0–11.1% for the various study sites and years reported).	Gruber <i>et al.</i> (2001)
Gillnet (11.75–15.25 mm stretched mesh size; 0.75–1.0 h soak time; depth <3 m)	NW Atlantic (South-west Florida)	AVM and blood sampling	Sharks sampled in research programme, with blood samples taken and condition recorded (5-point scale)	Carcharhinidae	<i>Carcharhinus limbatus</i> (n = 33)	24.2%	39.4% in good or fair condition and 36.4% in poor or very poor condition.	Manire <i>et al.</i> (2001)
					<i>Carcharhinus leucas</i> (n = 27)	18.5%	74.1% in good or fair condition and 7.4% in poor condition	
				Sphyrnidae	<i>Sphyrna tiburo</i> (n = 39)	30.8%	35.9% in good or fair condition and 33.3% in poor or very poor condition	
Commercial gillnets (>80 mm stretched mesh) set overnight	SW Pacific (New South Wales)	AVM	Commercial catches examined and proportion of fish discarded alive recorded	Dasyatidae	<i>Dasyatis</i> sp. (n = 112)	7.2%		Gray (2002)
Commercial gillnets (6–6.5" mesh; mean soak time of 8.2 h; fishing depths of 17–	South Australia	AVM	AVM recorded for two fishing grounds (Bass Strait and South Australia)	Hexanchidae	<i>Notorynchus cepedianus</i> (n = 83)	79–83%		Walker <i>et al.</i> (2005)
				Squalidae	<i>Squalus megalops</i> (n = 325)	0–6%		
					<i>Squalus acanthias</i> (n = 1)	(0%)		

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
130 m (mostly <80 m)				Heterodontidae	<i>Heterodontus portusjacksoni</i> (n = 778)	0%		
				Squatinae	<i>Squatina australis</i> (n = 43)	11–33%		
				Orectolobidae	<i>Orectolobus maculatus</i> (n = 4)	(0%)		
				Alopiidae	<i>Alopias vulpinus</i> (n = 20)	60%		
				Lamnidae	<i>Isurus oxyrinchus</i> (n = 4)	(75%)		
				Pristiophoridae	<i>Pristiophorus cirratus</i> (n = 1051)	7–23%		
					<i>Pristiophorus nudipinnis</i> (n = 250)	22–33%		
				Scyliorhinidae	<i>Cephaloscyllium laticeps</i> (n = 1034)	0%		
				Triakidae	<i>Furgaleus macki</i> (n = 1)	–		
					<i>Galeorhinus galeus</i> (n = 187)	2–70%		
					<i>Mustelus antarcticus</i> (n = 4625)	53–60%		
				Carcharhinidae	<i>Carcharhinus brachyurus</i> (n = 42)	0%		
				Sphyrnidae	<i>Sphyrna zygaena</i> (n = 77)	3%		
				Rhinobatidae	<i>Aptychotrema vincentiana</i> (n = 6)	(16.6%)		
				Rajidae	Rajidae indet. (n = 5)	(0%)		
				Urolophidae	<i>Urolophus paucimaculatus</i> (n = 43)	23–50%	AVM ranged from 23% (n = 41) to 50% (n = 2) in the two fishing areas studied	
				Myliobatidae	<i>Myliobatis australis</i> (n = 94)	9–21%		
Callorhynchidae	<i>Callorhynchus milii</i> (n = 763)	23–29%						

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Scientific gillnet surveys, soak times usually 1 h	NW Atlantic (Gulf of Mexico)	AVM and tagging	Vitality scored (1 = Good, 4 = very poor, 5 = dead). Return rates of tagged fish of different vitality scores used to model relative survival	Carcharhinidae	<i>Carcharhinus limbatus</i>	40%	Approximately 60% of individuals were tagged on capture (vitality 1–4) and 40% dead. Of the tagged fish, a further 31% of fish tagged and released were estimated to have died subsequently (overall mortality of 58%).	Hueter <i>et al.</i> (2006)
				Sphyrnidae	<i>Sphyrna tiburo</i>	37%	Approximately 63% of individuals were tagged on capture (vitality 1–4) and 37% dead. Of the tagged fish, a further 40% of fish tagged and released were estimated to have died subsequently (overall mortality of 62%).	

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Gillnet (101–165 mm mesh sizes; 19.5–23.5 h soak time)	NW Atlantic	AVM and short-term survival	Immediate post-capture mortality recorded, live fish maintained in sea cages for 48 h	Squalidae	<i>Squalus acanthias</i> (n = 2284)	17.5%	The majority of captured specimens had evident damage from gillnets, but a lower proportion had other damage (c.f. trawl caught specimens). Evidence of females aborting young. Of the specimens (n = 480) held in sea cages, 17–33% died. Overall gillnet mortality was 55%.	Rulifson (2007)
Experimental fishing with gillnets in inshore waters. Soak times not specified.	NW Atlantic (North Carolina)	AVM	Sharks caught recorded as live or dead	Carcharhinidae	<i>Carcharhinus acronotus</i>	81.3%	Study primarily looking at gillnet selectivity, with observations on mortality rates given.	Thorpe and Frierson (2009)
					<i>Carcharhinus limbatus</i>	90.5%		
					<i>Rhizoprionodon terraenovae</i>	80.4%		
				Sphyrnidae	<i>Sphyrna tiburo</i>	71.5%		
Gillnets deployed from commercial inshore vessels. Fixed tangle nets were soaked overnight; drift trammel nets fished for 1–3 h	NE Atlantic (southern North Sea)	AVM and tagging	Health state recorded on a three point (lively, sluggish, dead) and fish tagged and released	Rajidae	<i>Raja clavata</i> (n = 975)	0–2%	AVM = 2% for the vessel with overnight soak times. No-mortality observed in drift trammel nets with short soak times	Ellis <i>et al.</i> (2008a)
Chartered surveys on board two commercial gillnetters; commercial trammel nets and gillnets deployed for different soak times	NE Atlantic (Celtic Sea)	AVM	Vitality scored on a 5-point scale (lively, sluggish, very sluggish, dead and scavenged)	Squalidae	<i>Squalus acanthias</i> (n = 388)	22.5–38.5%	AVM = 22.5–38.5% (n = 384) after 11–27 h soak times. Sample size (n = 4) limited in sets with a longer soak time	Bendall <i>et al.</i> (2012)
				Lamnidae	<i>Lamna nasus</i> (n = 20)	80%		

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
				Rajidae	<i>Dipturus batis</i> -complex (n >1200)	6.6–8.6%	AVM increased from 6.6% (12–26 h soak time) to 8.6% (36–48 h soak time)	
Gillnet fishery (2.4–20.6 h soak times)	South-east Australia	AVM	Vitality scored according to activity, presence of wounds and skin damage, and any damage by sea lice	Hexanchidae	<i>Notorynchus cepedianus</i> (n = 202)	33.2%		Braccini <i>et al.</i> (2012)
				Squalidae	<i>Squalus acanthias</i> (n = 52)	13.5%		
					<i>Squalus chloroculus</i> (n = 5)	(40%)		
					<i>Squalus megalops</i> (n = 1178)	10.3%		
				Pristiophoridae	<i>Pristiophorus cirratus</i> (n = 562)	24.7%		
					<i>Pristiophorus nudipinnis</i> (n = 113)	41.6%		
				Squatinae	<i>Squatina australis</i> (n = 56)	25%		
				Heterodontidae	<i>Heterodontus portusjacksoni</i> (n = 1452)	0.8%		
				Parascyllidae	<i>Parascyllium ferrugineum</i> (n = 24)	12.5%		
					<i>Parascyllium variolatum</i> (n = 5)	(20%)		
				Orectolobidae	<i>Orectolobus maculatus</i> (n = 5)	(0%)		
					<i>Sutorectus tentaculatus</i> (n = 6)	(0%)		
				Alopiidae	<i>Alopias vulpinus</i> (n = 9)	(66.7%)		
				Lamnidae	<i>Isurus oxyrinchus</i> (n = 8)	(37.5%)		
				Scyliorhinidae	<i>Cephaloscyllium laticeps</i> (n = 1977)	0.5%		
				Triakidae	<i>Furgaleus macki</i> (n = 223)	92.8%		
					<i>Galeorhinus galeus</i> (n = 1361)	72.7%		
					<i>Mustelus antarcticus</i> (n = 3726)	56.9%		
				Carcharhinidae	<i>Carcharhinus brachyurus</i> (n = 152)	36.2%		
				Sphyrnidae	<i>Sphyrna zygaena</i> (n = 122)	89.3%		
				Urolophidae	<i>Urolophus paucimaculatus</i> (n = 26)	3.8%		
					<i>Urolophus viridis</i> (n = 15)	0%		

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
				Myliobatidae	<i>Myliobatis australis</i> (n = 133)	5.3%		
Commercial gillnets, including set gillnets (>89 mm; variable soak times) and drift gillnets (89–150 mm; 4–12 h soak times)	California (Eastern Pacific)	AVM and PRM	PRM quantified from satellite and acoustic tags	Lamnidae	<i>Carcharodon carcharias</i>	20–68%	Average annual AVM for sharks caught in gillnet fisheries was 44 ± 24%. Mortality increased with soak time. Post-release mortality (n = 28) was 7.1%	Lyons <i>et al.</i> (2013)
Commercial and recreational gillnets (graball nets of 114 mm mesh size; mullet nets of 64 mm mesh size). Soak time ranged from 2–24 h	Tasmania	AVM and short-term survival	Vitality recorded (1 = lively, no visible damage, 2 = lively, minor damage, 3 = alive, moderate damage, 4 = alive but poor condition, 5 = dead) for various fish species. Some species were also used in tank experiments to determine delayed mortality.	Squalidae	<i>Squalus acanthias</i> (n = 502)	7–18%	Usually alive but damaged. AVM ranged from 7% (soak time ≤8 h, n = 270) to 18% (overnight sets, n = 232). Fish in poor condition or dead (stages 4 and 5) accounted for 21% and 33% of specimens for short and overnight sets. Post-release survival estimated at 77–86%.	Lyle <i>et al.</i> (2014)
				Scyliorhinidae	<i>Cephaloscyllium laticeps</i> (n = 990)	0%	No AVM (n = 990) and no delayed mortality (n = 71). Post-release survival estimated at 100%.	

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
				Triakidae	<i>Mustelus antarcticus</i> (n = 67)	24%	Usually alive but damaged. AVM = 24% (all data combined), and whilst 57% only had minor or moderate damage (condition 1–3), 19% were in poor condition. Post-release survival estimated at 58.7%.	
				Rajidae	<i>Zearaja maugeana</i> (n = 177) and <i>Raja whitleyi</i> (n = 61)	0–9%	No AVM observed for either <i>Z. maugeana</i> (n = 50) or <i>R. whitleyi</i> (n = 61) when soak times were short, with 98% of specimens rated as lively or with only minor damage. Overnight sets resulted in 80% of <i>Z. maugeana</i> (n = 127) being lively or with only minor damage, and AVM was 9%. Post-release survival was estimated at >87.2%.	
				Urolophidae	<i>Urolophus cruciatus</i> (n = 30) and <i>U. paucimaculatus</i> (n = 33)	0%	No AVM observed, with 90% of specimens either lively or with only minor damage, although all specimens were caught in soak times of ≤8 h	

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
				Callorhynchidae	<i>Callorhynchus milii</i> (n = 314)	5–20%	Usually alive but damaged. AVM ranged from 5% (soak time ≤3.5 h, n = 235) to 20% (overnight sets, n = 10). Including both stages 4 and 5 in estimates of at-vessel mortality would increase estimates to 10% and 40%. Delayed mortality ranged from 8.3% (condition 1 and 2; n = 24) to 33.3% (condition 3 and 4; n = 6). Post-release survival estimated at 74–82%.	
LONGLINE								
Longline deployed from research vessel (soak times <12 h)	Pacific (Hawaii)	AVM		Alopiidae	<i>Alopias</i> spp. (n = 6)	(40%)		Boggs (1992)
				Carcharhinidae	<i>Carcharhinus longimanus</i> (n = 26)	15%		
					<i>Prionace glauca</i> (n = 21)	0%		
				Dasyatidae	<i>Pteroplatytrygon violacea</i> (n = 8)	(12%)		
Commercial longline vessels targeting tuna, including foreign- licensed and foreign-chartered (with 2500–3000 hooks per line) and domestic fleets (300–2700 hooks per line)	New Zealand	AVM	AVM recorded by observers	Lamnidae	<i>Isurus oxyrinchus</i> (n = 299)	28.4%		Francis <i>et al.</i> (2001)
					<i>Lamna nasus</i> (n = 2370)	39.2%		
				Carcharhinidae	<i>Prionace glauca</i> (n = 7838)	13.5%	AVM lower for domestic fleet (8.3%) than observed in foreign- licensed and foreign-chartered fleets (13.9%)	
	Mediterranean	AVM		Hexanchidae	<i>Hexanchus griseus</i> (n = 3)	(0%)		

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Commercial longlines targeting swordfish, albacore or blue-fin tuna. Limited data for commercial driftnet			Vitality and AVM recorded (1 = good; 2 = fair; 3 = poor; 4 = dead or no response to stimuli)	Lamnidae	<i>Isurus oxyrinchus</i> (n = 31)	16%	Most fish in fair or poor condition (32% and 29%), and only 22.6% in good condition. Whilst AVM was low (5.9%), just over half the specimens of this genus were in poor condition or dead, and only 47% of specimens were in fair or good condition.	Megalofonou <i>et al.</i> (2003)
				Alopiidae	<i>Alopias superciliosus</i> (n = 1) and <i>A. vulpinus</i> (n = 16)	5.9%		
				Triakidae	<i>Galeorhinus galeus</i> (n = 5)	(0%)		
				Carcharhinidae	<i>Carcharhinus plumbeus</i> (n = 2) <i>Prionace glauca</i> (n = 513)	(0%) 4.5%		
Pelagic longline fishery (hooks of 7/0 to 11/0; hook depths usually 35–60 m)	NW Atlantic (south-eastern coast of the USA)		Condition of captured sharks recorded by observers	Alopiidae	<i>Alopias superciliosus</i> (n = 82)	53.7%		Beerkircher <i>et al.</i> (2004)
				Lamnidae	<i>Isurus oxyrinchus</i> (n = 80)	35.0%		
				Carcharhinidae	<i>Carcharhinus falciformis</i> (n = 1446)	66.3%		
					<i>Carcharhinus longimanus</i> (n = 131)	27.5%		
					<i>Carcharhinus obscurus</i> (n = 679)	48.7%		
					<i>Carcharhinus plumbeus</i> (n = 112)	26.8%		
				Carcharhinidae	<i>Carcharhinus signatus</i> (n = 572)	80.8%		
					<i>Galeocerdo cuvier</i> (n = 263)	3%		
					<i>Prionace glauca</i> (n = 434)	12.2%		
				Sphyrnidae	<i>Sphyrna lewini</i> (n = 199)	61.0%		
Dasyatidae and Mobulidae	Unidentified batoids (n = 113)	0%						

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Deep-water longlines (746–1913 m depth)	SW Atlantic (South Georgia)	Short-term survival	Skates randomly selected and placed in deck tanks (one skate per tank) for 12 h	Rajidae	<i>Amblyraja</i> sp. (n = 95)	–	No information on AVM. Of the skates that were held in tanks for 12 h: 44.2% were dead; 13.7% in poor condition (thought likely to die); 16.8% in moderate condition and 25.3% in good condition. Mortality increased with depth	Endicott and Agnew (2004)
Commercial longline targeting swordfish and/or tuna	NW Atlantic	AVM	Observer data for fish recorded as 'discarded alive' or 'discarded dead' analysed in relation to fish size, water temperature, soak time, area and season	Carcharhinidae	<i>Prionace glauca</i>	31%	Overall, 69% of records were for 'discarded alive'. The proportion released alive increased with increasing fish length and decreasing soak time.	Diaz and Serafy (2005)
Longline deployed from research vessel (10–18 h soak time)	Pacific Ocean (Hawaii)	AVM	Health assessed, with 23 individuals tagged with PSATs and selected sharks also examined for blood chemistry	Carcharhinidae	<i>Prionace glauca</i>	ca. 5.2%	Only nine of 172 blue sharks were assessed as 'moribund' (5.2%).	Moyes <i>et al.</i> (2006)
Commercial longline fisheries with observer coverage	NW Atlantic (Gulf of Mexico)	AVM	AVM assessed visually (alive /dead).	Carcharhinidae	<i>Carcharhinus limbatus</i> (n = 1982)	88%		Morgan and Burgess (2007)
					<i>Carcharhinus obscurus</i> (n = 662)	81%		
					<i>Carcharhinus plumbeus</i> (n = 8583)	36%		
					<i>Galeocerdo cuvier</i> (n = 2466)	8.5%		
				Sphyrnidae	<i>Sphyrna lewini</i> (n = 455)	91.4%		

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
					<i>Sphyrna mokarran</i> (n = 178)	93.8%		
Bottom longlines deployed from commercial inshore vessels. Soak times of ca. 2–4 h	NE Atlantic (southern North Sea)	AVM	Vitality recorded on a three point (lively, sluggish, dead) and fish tagged and released	Rajidae	<i>Raja clavata</i> (n = 817)	0%	No AVM observed, although fish were generally unhooked manually. Fish going through the bait-stripper would be more likely to sustain damage to the jaws and mouth.	Ellis <i>et al.</i> (2008a)
Commercial longline targeting swordfish and/or tuna	NW Atlantic	AVM and PRM	Estimates of both AVM (scientific observers) and PRM (electronic tagging of healthy and injured fish)	Carcharhinidae	<i>Prionace glauca</i>	12–20%	Estimates of AVM ranged from 12% (observers) to 20% (scientific researchers). PRM reported at 19%. Total mortality of discarded blue shark estimated at 29–35%. Assumed 50% mortality for shortfin mako and porbeagle	Campana <i>et al.</i> (2009, 2011)
Commercial longline targeting swordfish and/or tuna	NW Atlantic	AVM	Observer data (2001–2004) for fish recorded as ‘alive’ or ‘dead’ analysed in relation to hook type, soak time and fish size.	Lamnidae	<i>Isurus oxyrinchus</i> and <i>Lamna nasus</i>	–	– <i>Isurus oxyrinchus</i> of larger size had increased probability of surviving	Carruthers <i>et al.</i> (2009)
				Carcharhinidae	<i>Prionace glauca</i>	–	– Improved survival for <i>P. glauca</i> caught on circle hooks than J-hooks	
				Dasyatidae	<i>Pteroplatytrygon violacea</i>	–	– AVM low for both J-hooks (10%) and circle hooks (2%)	

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source			
Commercial longline (demersal sets; 5/0 hooks; 2–2.5 h soak time)	Australia (Victoria)	AVM and blood sampling	Sharks taken for blood sampling; AVM also reported	Triakidae	<i>Mustelus antarcticus</i> (n = 93)	2.2%		Frick <i>et al.</i> (2010a)			
Research longline fishing from commercial vessels, soak times ranging from 4–6 h (day) and 6–10 h (night), 18/0 circle hooks	NW Atlantic (Gulf of Mexico)	AVM	AVM assessed visually (alive /dead). Hook timers used to assess the time each shark had been hooked	Carcharhinidae	<i>Carcharhinus acronotus</i>	77%	Mortality generally increased with time the shark was hooked. In the case of <i>C. plumbeus</i> , larger individuals typically had a higher mortality	Morgan and Carlson (2010)			
					<i>Carcharhinus leucas</i>	15%					
					<i>Carcharhinus limbatus</i>	85%					
					<i>Carcharhinus plumbeus</i>	21%					
Longline fishery targeting swordfish	Réunion Island (Indian Ocean)	AVM	AVM data (and proportion alive after 8 h hooking)	Carcharhinidae	<i>Carcharhinus longimanus</i> (n = 17)	58.9%		Poisson <i>et al.</i> (2010)			
					<i>Prionace glauca</i> (n = 92)	51.1%					
					Dasyatidae <i>Pteroplatytrygon violacea</i> (n = 12)	58.8%					
Research longline (pelagic) with 18/0 circle hooks and 9/0 J-hooks)	SW Atlantic (Brazil)	AVM	Catch rates and AVM compared between hook types	Ginglymostomidae	<i>Ginglymostoma cirratum</i> (n = 6)	(0%)	No AVM observed	Afonso <i>et al.</i> (2011)			
					Lamnidae	<i>Isurus oxyrinchus</i> (n = 6)			–	Sample size limited, but AVM was 20% (circle hooks) and 100% (J-hooks)	
						Carcharhinidae			<i>Carcharhinus falciformis</i> (n = 14)	–	Lower AVM reported for circle hooks (22.2%) than J-hooks (80%)
									<i>Carcharhinus leucas</i> (n = 2)	(50%)	
									<i>Carcharhinus longimanus</i> (n = 12)	–	Lower AVM reported for circle hooks (22.2%) than J-hooks (66.5%)
<i>Carcharhinus obscurus</i> (n = 10)	–	Lower AVM reported for circle hooks (28.5%) than J-hooks (100%)									

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
					<i>Carcharhinus signatus</i> (n = 33)	100%	AVM was 100% for both hook types	
					<i>Galeocerdo cuvier</i> (n = 8)	–	Lower AVM reported for circle hooks (16.6%) than J-hooks (50%)	
					<i>Prionace glauca</i> (n = 32)	–	Lower AVM reported for circle hooks (27.2%) than J-hooks (70%)	
				Sphyrnidae	<i>Sphyrna lewini</i> (n = 11)	–	Lower AVM reported for circle hooks (33.3%) than J-hooks (87.5%)	
Research longline (demersal and mid-water) with 18/0 circle hooks and 9/0 J-hooks)	SW Atlantic (Brazil)	AVM	Catch rates compared for demersal and mid-water hooks; AVM compared between hook types. Limited data also available for five other elasmobranch species	Ginglymostomidae	<i>Ginglymostoma cirratum</i> (n = 14)	0%	No AVM observed	Afonso <i>et al.</i> (2011)
				Carcharhinidae	<i>Carcharhinus acronotus</i> (n = 41)	23–74%	AVM ranged from 23% (circle hooks) to 74% (J-hooks)	
				Dasyatidae	<i>Dasyatis americana</i> (n = 43)	0%	No AVM observed	
Commercial longliners targeting swordfish	Atlantic and Indian Oceans	AVM	AVM recorded	Alopiidae	<i>Alopias superciliosus</i>	48.6–68.4%	AVM ranged from 48.6% (n = 849; Atlantic) to 68.4% (n = 19; Indian Ocean)	Coelho <i>et al.</i> (2011)
				Lamnidae	<i>Isurus oxyrinchus</i>	32.8–56.0%	AVM ranged from 32.8% (n = 1,004; Atlantic) to 56.0% (n = 430; Indian Ocean)	
				Carcharhinidae	<i>Carcharhinus falciformis</i>	55.1–74.2%	AVM ranged from 55.1% (n = 296; Atlantic) to 74.2% (n = 31; Indian Ocean)	

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
					<i>Prionace glauca</i>	12.7–24.7%	AVM ranged from 12.7% (n = 22,887; Atlantic) to 24.7% (n = 2,358; Indian Ocean)	
				Sphyrnidae	<i>Sphyrna zygaena</i>	70.1–84.0%	AVM ranged from 70.1% (n = 338; Atlantic) to 84.0% (n = 25; Indian Ocean)	
				Dasyatidae	<i>Pteroplatytrygon violacea</i>	0–1.1%	AVM ranged from 0% (n = 16; Indian Ocean) to 1.1% (n = 351; Atlantic)	
				Mobulidae	Mobulidae indet.	0–1.5%	AVM ranged from 0% (n = 14; Indian Ocean) to 1.5% (n = 130; Atlantic)	
Longline fishery targeting swordfish	Pacific	AVM	AVM recorded	Pseudocarchariidae	<i>Pseudocarcharias kamoharai</i> (n = 3)	66.7%		Musyl <i>et al.</i> (2011)
				Alopiidae	<i>Alopias pelagicus</i> (n = 28)	35.7%		
					<i>Alopias superciliosus</i> (n = 12)	25%		
				Lamnidae	<i>Isurus oxyrinchus</i> (n = 8)	0%	No AVM observed	
				Carcharhinidae	<i>Carcharhinus falciformis</i> (n = 35)	11.4%		
					<i>Carcharhinus longimanus</i> (n = 19)	5.3%		
					<i>Prionace glauca</i> (n = 203)	5.9%		
Bottom longline fishery for reef fish. Average fishing depth = 94 m. Most hooks were 13/0 but ranged from 12/0 to 15/0. Mean soak	Gulf of Mexico	AVM	Condition and fate recorded by observers, (but data lacking for some specimens and estimates of AVM are given here)	Hexanchidae	<i>Heptranchias perlo</i> (n = 33)	24.2%		Scott-Denton <i>et al.</i> (2011)
				Squalidae	<i>Squalus cubensis</i> (n = 49)	10.2%		
					<i>Squalus</i> sp. (n = 92)	0%	Of the live-caught fish that were subsequently discarded, 42.2% were dead	

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
time was 5.1 h (range = 0.9–32.2 h)				Centrophoridae	<i>Centrophorus granulosus</i> (n = 35)	0%	Of the live-caught fish that were subsequently discarded, 14.3% were dead AVM not estimated, but 87.1% released alive Of the live-caught fish that were subsequently discarded, 1.4% were dead Of the live-caught fish that were subsequently discarded, 34.8% were dead	
				Ginglymostomidae	<i>Ginglymostoma cirratum</i> (n = 163)	NA		
				Triakidae	<i>Mustelus canis</i> (n = 1279)	0.8%		
					<i>Mustelus</i> sp. (n = 72)	0%		
				Carcharhinidae	<i>Carcharhinus acronotus</i> (n = 801)	8.0%		
					<i>Carcharhinus brevipinna</i> (n = 26)	3.8%		
					<i>Carcharhinus falciformis</i> (n = 94)	26.6%		
					<i>Carcharhinus leucas</i> (n = 43)	2.3%		
					<i>Carcharhinus limbatus</i> (n = 87)	23.0%		
					<i>Carcharhinus plumbeus</i> (n = 59)	3.4%		
					<i>Carcharhinus porosus</i> (n = 48)	0%		
					<i>Galeocerdo cuvier</i> (n = 102)	0.9%		
					<i>Negaprion brevirostris</i> (n = 157)	1.9%		
					<i>Rhizoprionodon terraenovae</i> (n = 2090)	19.1%		
Sphyrnidae	<i>Sphyrna lewini</i> (n = 73)	19.2%						
Rajidae	<i>Leucoraja eglanteria</i> (n = 50)	4%						

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Vertical line fishery for reef fish. Average fishing depth = 50 m. Most hooks were 8/0 or 9/0. Mean soak time was 0.7 h (range = 0.02–15.3 h)	Gulf of Mexico	AVM	Condition and fate recorded by observers, (but data lacking for some specimens and estimates of AVM are given here)	Ginglymostomi dae	<i>Ginglymostoma cirratum</i> (n = 33)	0%	Whilst no AVM was reported, 6.1% of the specimens subsequently discarded were dead	Scott-Denton <i>et al.</i> (2011)
				Triakidae	<i>Mustelus canis</i> (n = 35)	0%	Whilst no AVM was reported, 12.5% of the specimens subsequently discarded were dead	
				Carcharhinidae	<i>Carcharhinus acronotus</i> (n = 32)	3.1%	Of those specimens caught alive, 12.9% were subsequently discarded dead	
					<i>Carcharhinus falciformis</i> (n = 71)	0%	Whilst no AVM was reported, 1.4% of the specimens subsequently discarded were dead	
				<i>Carcharhinus limbatus</i> (n = 39)	0%	Whilst no AVM was reported, 15.8% of the specimens subsequently discarded were dead		
					<i>Rhizoprionodon terraenovae</i> (n = 83)	0%	Whilst no AVM was reported, 7.6% of the specimens subsequently discarded were dead	
Research fishing from a commercial longline vessel	SW Atlantic (Brazil)	AVM	AVM recorded; catch rates and 'bite-offs' recorded	Pseudocarcharii dae	<i>Pseudocarcharias kamoharai</i> (n = 11)	91%		Afonso <i>et al.</i> (2012)
				Alopiidae	<i>Alopias</i> spp. (n = 9)	89%		

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
(pelagic), with combinations of wire and monofilament leaders, and circle and J-hooks				Lamnidae	<i>Isurus</i> spp. (n = 4)	75%		
				Carcharhinidae	<i>Carcharhinus falciformis</i> (n = 24)	75%		
					<i>Carcharhinus longimanus</i> (n = 11)	82%		
					<i>Galeocerdo cuvier</i> (n = 3)	(67%)		
					<i>Prionace glauca</i> (n = 77)	31%		
				Sphyrnidae	<i>Sphyrna</i> spp. (n = 3)	100%		
Dasyatidae	<i>Pteroplatytrygon violacea</i> (n = 40)	5%						
Commercial longline fishery	Pacific	AVM	AVM recorded from observer coverage	Pseudocarchariidae	<i>Pseudocarcharias kamoharai</i> (n = 139)	38.7%		Bromhead <i>et al.</i> (2012)
				Alopiidae	<i>Alopias pelagicus</i> (n = 1353)	63.8%		
					<i>Alopias superciliosus</i> (n = 1636)	50.0%		
					<i>Alopias vulpinus</i> (n = 87)	52.9%		
				Lamnidae	<i>Isurus oxyrinchus</i> (n = 171)	50.3%		
					<i>Isurus paucus</i> (n = 151)	53.6%		
				Carcharhinidae	<i>Carcharhinus albimarginatus</i> (n = 20)	15.0%		
					<i>Carcharhinus amblyrhynchos</i> (n = 4)	(50.0%)		
					<i>Carcharhinus brachyurus</i> (n = 19)	5.6%		
					<i>Carcharhinus falciformis</i> (n = 3242)	26.5%		
					<i>Carcharhinus galapagensis</i> (n = 8)	(25.0%)		
					<i>Carcharhinus limbatus</i> (n = 10)	60.0%		
					<i>Carcharhinus longimanus</i> (n = 917)	30.6%		
					<i>Carcharhinus plumbeus</i> (n = 1)	(0%)		
					<i>Galeocerdo cuvier</i> (n = 5)	(60.0%)		
				<i>Prionace glauca</i> (n = 3452)	19.6%			

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
				Sphyrnidae	<i>Sphyrna lewini</i> (n = 5) and <i>S. mokarran</i> (n = 3)	(75%)	Although data were limited, AVM was 75% for this genus	
				Dasyatidae	<i>Pteroplatytrygon violacea</i> (n = 501)	18.5%		
Pelagic longline	Atlantic	AVM	AVM recorded by observers on commercial vessels	Pseudocarchariidae	<i>Pseudocarcharias kamoharai</i> (n = 1621)	13.3%		Coelho <i>et al.</i> (2012)
				Alopiidae	<i>Alopias superciliosus</i> (n = 1061)	50.6%		
					<i>Alopias vulpinus</i> (n = 3)	(66.7%)		
				Lamnidae	<i>Isurus oxyrinchus</i> (n = 1414)	35.6%		
					<i>Isurus paucus</i> (n = 168)	30.7%		
					<i>Lamna nasus</i> (n = 10)	30.0%		
				Triakidae	<i>Galeorhinus galeus</i> (n = 25)	0%		
				Carcharhinidae	<i>Carcharhinus altimus</i> (n = 11)	60.0%		
					<i>Carcharhinus falciformis</i> (n = 310)	55.8%		
					<i>Carcharhinus longimanus</i> (n = 281)	34.2%		
					<i>Galeocerdo cuvier</i> (n = 36)	2.9%		
					<i>Prionace glauca</i> (n = 30168)	14.3 %		
				Sphyrnidae	<i>Sphyrna lewini</i> (n = 21)	57.1%	Whilst no AVM was observed for <i>S. mokarran</i> , this was based on a small sample size	
					<i>Sphyrna mokarran</i> (n = 3)	(0%)		
					<i>Sphyrna zygaena</i> (n = 372)	71%		
				Dasyatidae	<i>Pteroplatytrygon violacea</i> (n = 396)	1.0%		
				Mobulidae	Data collected at family level (n = 145)	1.4%		
				Myliobatidae	Data collected at family level (n = 19)	0%	No AVM observed for this family	
Pelagic longline	NW Atlantic (Grand Banks)	AVM	Observers recorded condition of fish brought aboard	Lamnidae	<i>Isurus oxyrinchus</i> (n = 543)	21.3–26.5%	AVM of <i>I. oxyrinchus</i> was 26.5% (9/0 J-	Epperly <i>et al.</i> (2012)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
			commercial vessels that were chartered to use sets with J-hooks and circle hooks. AVM provided based on fish recorded as alive or dead (fish that were damaged, entangled in the mainline or for undetermined hook type were excluded)		<i>Lamna nasus</i> (n = 866)	29.5–31.6%	hook), falling to 21.3% and 23.7% for 18/0 circle hooks with no and 10° offset, respectively. AVM of <i>L. nasus</i> was similar (29.5–31.6%) for all hook types.	
				Carcharhinidae	<i>Prionace glauca</i> (n = 21,684)	18.8–22.6%	AVM was 22.6% (9/0 J-hook), falling to 19.9% and 18.8% for 18/0 circle hooks with no and 10° offset, respectively	
Pelagic longline	NW Atlantic	AVM	Observer data on condition (live/dead) used to compare hooking survival for periods before and after the introduction of circle hook requirements. Fish that were recorded as 'damaged' or of 'unknown' fate were excluded	Carcharhinidae	<i>Prionace glauca</i> (n = 10,977)	10–11%	AVM did not change between the two periods	Serafy <i>et al.</i> (2012)
					<i>Carcharhinus falciformis</i> (n = 2,071)	44–59%	AVM decreased from 59% to 44% after the introduction of circle hook regulations	
Pelagic longline	Tropical north-east Atlantic	AVM	Fate recorded for sharks taken on different hook types (J, circle and offset circle hooks) and baits (squid and mackerel)	Pseudocarcharii dae	<i>Pseudocarcharias kamoharai</i> (n = 664)	4.7–9.1%	AVM = 4.7% (J-hooks, n = 190), 8.1% (circle hooks, n = 211) and 9.1% (offset circle hooks, n = 263)	Fernandez-Carvalho <i>et al.</i> (2015)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
				Alopiidae	<i>Alopias superciliosus</i> (n = 815)	49.6–58.5%	AVM = 49.6% (offset circle hooks, n = 248) and 49.8% (J-hooks, n = 295), but higher with circle hooks (58.5%, n = 272)	
				Carcharhinidae	<i>Carcharhinus longimanus</i> (n = 152)	11.1–28.4%	AVM = 28.4% (offset circle hooks, n = 81) and 22.7% (J-hooks, n = 44), but lower with circle hooks (11.1%; n = 27)	
				Sphyrnidae	<i>Sphyrna zygaena</i> (n = 203)	62.0–62.9%	AVM was higher for this species (62.0–62.9% for the three hook types)	
Demersal longline (scientific) with 14–14 h soak time	Brazil	PRM	Satellite tags used to evaluate PRM; dead specimens landed.	Carcharhinidae	<i>Galeocerdo cuvier</i>	–	AVM not reported. Healthy specimens released with satellite tags. Data available for 19 specimens, no post-release mortality reported. Sharks handled with a higher degree of care than would be expected in commercial fisheries.	Afonso & Hazin (2014)
Pelagic longline (targeting tuna or swordfish)	NW Atlantic	AVM	AVM data collected by observers (1995–2012). Data used for fish classed as alive and dead (those reported as	Alopiidae	<i>Alopias superciliosus</i> (n = 367)	51.7%		Gallagher <i>et al.</i> (2014a)
				Lamnidae	<i>Isurus oxyrinchus</i> (n = 2126)	28.6%		
					<i>Isurus paucus</i> (n = 139)	51.1%		
					<i>Lamna nasus</i> (n = 255)	21.4%		

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
			'damaged' were excluded from analysis). Mean survival given for tuna and swordfish longline fisheries	Carcharhinidae	<i>Carcharhinus falciformis</i> (n = 1090) <i>Carcharhinus longimanus</i> (n = 213) <i>Carcharhinus obscurus</i> (n = 274) <i>Carcharhinus plumbeus</i> (n = 189) <i>Carcharhinus signatus</i> (n = 1141) <i>Galeocerdo cuvier</i> (n = 1348) <i>Prionace glauca</i> (n = 17780)	42.2% 25.7% 27.9% 26.7% 67% 3.2% 15.1%		
				Sphyrnidae	<i>Sphyrna lewini</i> (n = 727)	54.1%		
Experimental drumline, (soak time of 1 hour, circle hooks)	Florida	PRM and blood sampling	Satellite tags used to examine PRM Blood chemistry examined.	Carcharhinidae	<i>Carcharhinus leucas</i> (n = 27) <i>Galeocerdo cuvier</i> (n = 28)	–	Based on data from satellite tags, 26% of <i>C. leucas</i> (and no <i>G. cuvier</i>) were thought to have died within two weeks of release.	Gallagher <i>et al.</i> (2014b)
				Sphyrnidae	<i>Sphyrna mokarran</i> (n = 28)	–	Based on data from satellite tags, 43% were thought to have died within two weeks of release.	
Demersal longline survey (10/0 to 16/0 hooks; 472–1024 m water depth; 4 h soak time)	Bahamas	AVM	AVM reported for scientific fishing	Hexanchidae	<i>Hexanchus griseus</i> (n = 8) <i>Hexanchus nakamurai</i> (n = 14)	0% 7.1%	Specimens caught at depths of 504–791 m	Brooks <i>et al.</i> (2015)
				Centrophoridae	<i>Centrophorus</i> sp. (n = 51)	29.4%	Specimens caught at depths of 580–830 m	
				Somniosidae	<i>Centroscymnus owstoni</i> (n = 5)	80%	Specimens caught at depths of 841–1024 m	
				Squalidae	<i>Squalus cubensis</i> (n = 55)	9.1%	Specimens caught at depths of 472–730 m	

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
				Scyliorhinidae	<i>Galeus springeri</i> (n = 3)	66.7%	Specimens caught at depths of 630–807 m	
				Pseudotriakidae	<i>Pseudotriakis microdon</i> (n = 1)	–	No AVM, but based on a single specimen caught at 790 m depth	
				Triakidae	<i>Mustelus canis</i> (n = 7)	0%	Specimens caught at depths of 504–651 m	
Demersal longline with nylon trace and 16/0 non-offset circle hook (water depths 50–100 m; 7–14 h soak times; hook timers used)	New South Wales (Australia)	AVM and blood sampling	Survival and condition examined in relation to hooking time. Blood samples also collected.	Orectolobidae	<i>Orectolobus halei</i> (n = 3)	0%	No AVM for soak times up to 14 h	Butcher <i>et al.</i> (2015)
					<i>Orectolobus maculatus</i> (n = 10)	0%		
					<i>Orectolobus ornatus</i> (n = 5)	0%		
				Odontaspidae	<i>Carcharias taurus</i> (n = 12)	0%	No AVM for soak times up to 14 h	
				Triakidae	<i>Mustelus antarcticus</i> (n = 22)	20–25%	AVM for soak times up to 14 h	
				Carcharhinidae	<i>Carcharhinus brachyurus</i> (n = 6)	(66.7%)	Higher estimates of AVM for 14 h soak times, lower estimates for 7 h soak times	
					<i>Carcharhinus brevipinna</i> (n = 50)	94.4–96.9%		
					<i>Carcharhinus leucas</i> (n = 1)	(0%)		
					<i>Carcharhinus limbatus</i> (n = 113)	86–95.5%		
					<i>Carcharhinus obscurus</i> (n = 74)	53.3–79.5%		
					<i>Carcharhinus plumbeus</i> (n = 160)	43–62.7%		
					<i>Galeocerdo cuvier</i> (n = 123)	4.3–6.6%		
				Sphyrnidae	<i>Sphyrna lewini</i> (n = 52)	87.5–90.1%	Higher AVM with longer soak time	
					<i>Sphyrna zygaena</i> (n = 2)	(100%)		
<i>Sphyrna mokarran</i> (n = 11)	100%							
Rhinidae	<i>Rhynchobatus australiae</i> (n = 8)	0–25%	AVM increased from 0% (7 h) to 25% (14 h)					
Rhinobatidae	<i>Aptychotrema rostrata</i> (n = 2)	(0%)	No AVM recorded					

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
				Dasyatidae	<i>Dasyatis brevicaudata</i> (n = 18)	0%	No AVM recorded	
Pelagic longline fishery for tuna	Palau (Pacific)	AVM	AVM data collected by observers	Squatinae	<i>Squatina tergocellatoides</i> (n = 1)	(0%)	Sample size limited	Gilman <i>et al.</i> (2015)
				Pseudocarchariae	<i>Pseudocarcharias kamoharai</i> (n = 2)	(0%)	Sample size limited	
				Alopiidae	<i>Alopias superciliosus</i> (n = 41)	34.2%		
					<i>Alopias vulpinus</i> (n = 16)	18.75%		
					<i>Alopias pelagicus</i> (n = 22)	36.4%		
				Lamnidae	<i>Isurus oxyrinchus</i> (n = 19)	5.3%		
					<i>Isurus paucus</i> (n = 10)	40.0%		
				Carcharhinidae	<i>Carcharhinus altimus</i> (n = 2)	(0%)	Data available for nine carcharhinid sharks, but data limited for most species	
					<i>Carcharhinus brachyurus</i> (n = 10)	0%		
					<i>Carcharhinus falciformis</i> (n = 368)	29.1%		
					<i>Carcharhinus galapagensis</i> (n = 1)	(0%)		
					<i>Carcharhinus longimanus</i> (n = 4)	(0%)		
					<i>Carcharhinus melanopterus</i> (n = 5)	(0%)		
					<i>Carcharhinus plumbeus</i> (n = 6)	(50%)		
					<i>Galeocerdo cuvier</i> (n = 8)	(0%)		
<i>Prionace glauca</i> (n = 215)	15.35%							
Sphyrnidae	<i>Sphyrna mokarran</i> (n = 1) and <i>S. lewini</i> (n = 1)	(100%)	Data limited, but AVM = 100%					
Dasyatidae	<i>Pteroplatytrygon violacea</i> (n = 372)	29.1%						
Mobulidae	<i>Mobula japanica</i> (n = 1)	(0%)	Data limited, but no AVM recorded					
Bottom longlines deployed from chartered fishing vessels (soak times of 1.5–22.6 h; 16/0, 18/0, 20/0 circle)	NE Atlantic and Gulf of Mexico (North Carolina to Louisiana)	AVM	AVM data recorded; hook timers deployed	Ginglymostomidae	<i>Ginglymostoma cirratum</i> (n = 311)	0.3%		Gulak <i>et al.</i> (2015)
				Odontaspidae	<i>Carcharias taurus</i> (n = 13)	0.0%		
				Carcharhinidae	<i>Carcharhinus acronotus</i> (n = 110)	66.4%		

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
hooks and 12/0 J hooks)					<i>Carcharhinus brevipinna</i> (n = 32)	81.3%		
					<i>Carcharhinus falciformis</i> (n = 35)	57.1%		
					<i>Carcharhinus leucas</i> (n = 122)	2.5%		
					<i>Carcharhinus limbatus</i> (n = 902)	70.8%		
					<i>Carcharhinus obscurus</i> (n = 104)	70.2%		
					<i>Carcharhinus plumbeus</i> (n = 933)	16.9%		
					<i>Galeocerdo cuvier</i> (n = 270)	8.9%		
					<i>Negaprion brevirostris</i> (n = 24)	4.2%		
					<i>Rhizoprionodon terraenovae</i> (n = 902)	89.4%		
					<i>Sphyrna lewini</i> (n = 175)	62.9%		
				Sphyrnidae	<i>Sphyrna mokarran</i> (n = 75)	56%		
Demersal longline deployed from research vessel (18/0 circle hooks with 10° offset; soak times of 0.5-12.5 h)	NW Atlantic	AVM and PRM	AVM data recorded (alive, dead, moribund). PSATs deployed to estimate PRM	Carcharhinidae	<i>Carcharhinus obscurus</i> (n = 50)	22%	A further 18% of specimens were moribund. PRM estimated at 28.6% from PSAT data (n = 21). A further 2% of specimens were moribund. PRM estimated at 20% from PSAT data (n = 10)	Marshall <i>et al.</i> (2015)
					<i>Carcharhinus plumbeus</i> (n = 119)	5%		
Pelagic longline fishery targeting tuna, swordfish and blue shark	Uruguay (SW Atlantic)	AVM		Mobulidae	Mobulidae (n = 191 with fate information, 10 lost during hauling)	5.2%	Of those specimens identified to species, most were <i>Mobula japonica</i> or <i>M. thurstoni</i>	Mas <i>et al.</i> (2015)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Commercial pelagic longline targeting swordfish and tuna	NW Atlantic	AVM and PRM	Fish condition (healthy, injured, dead, unknown) scored at unhooking; PRM studied using pop-up satellite archival tags	Lamnidae	<i>Isurus oxyrinchus</i> (n = 520 (vitality) and n = 26 (PSATs))	26.2%	Specimens of 80–229 L _F . Whilst AVM = 26.2%, a further 22.5% were injured. PRM (healthy fish; n = 23) = 30.4% PRM (injured fish; n = 3) = 33.3%	Campana <i>et al.</i> (2016)
					<i>Lamna nasus</i> (n = 683 (vitality) and n = 33 (PSATs))	43.8%	Specimens of 101–249 L _F . Whilst AVM = 43.8%, a further 14.6% were injured. PRM (healthy fish; n = 29) = 10.3% PRM (injured fish; n = 4) = 75%	
				Carcharhinidae	<i>Prionace glauca</i> (n = 15,592 (vitality) and n = 37 (PSATs))	14.7%	Specimens of 125–209 L _F . Whilst AVM = 14.7%, a further 25.1% were injured. PRM (healthy fish; n = 10) = 0% PRM (injured fish; n = 27) = 33.3%	
PURSE SEINE FISHERIES								
Commercial purse seine targeting gulf menhaden <i>Brevoortia patronus</i>	NW Atlantic (Gulf of Mexico)	Vitality	Observers recorded fate of sharks (caught and released; caught and retained; gilled; kept by crew; released but disorientated; released in a healthy state; discarded dead)	Carcharhinidae and Sphyrnidae	Not all identified to species-level. Main species encountered were <i>Carcharhinus limbatus</i> , <i>C. brevipinna</i> , <i>C. obscurus</i> , <i>C. leucas</i> , <i>C. falciformis</i> , <i>C. plumbeus</i> , <i>C. isodon</i> , <i>C. acronotus</i> and <i>Rhizoprionodon terraenovae</i> (Carcharhinidae). A small number of <i>Sphyrna tiburo</i> also caught	–	Most fish were dead and either discarded (50%) or retained on board (24%). Some live fish were released in either a disorientated (12%) or healthy (8%) condition. Fate of 6% unknown.	De Silva <i>et al.</i> (2001)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Tuna purse seine fishery	Western Central Indian Ocean and eastern central Atlantic Ocean	AVM	Analyses of observer data (where fate recorded)	Rhincodontidae	<i>Rhincodon typus</i>	0.9–2.6%	Single instances of mortality reported for both Atlantic Ocean (n = 107; AVM = 0.9%) and Indian Ocean (n = 38; AVM = 2.6%).	Capietto <i>et al.</i> (2014)
Tuna purse seine fishery	Indian Ocean	AVM and PRM	Health state of sharks recorded (4-point scale); selected sharks tagged with PSATs and released	Carcharhinidae	<i>Carcharhinus falciformis</i> (n = 202)	69%	AVM = 69% (but lower for the small number that were entangled in the meshes compared to those that were brailled). Of the 31 sharks tagged, nine (29%) survived for periods of 6–100 days with a further three (9.7%) recaptured, 11 (35.5%) died after periods of 0–35 days and the remaining eight (25.8%) tags did not give conclusive results. Overall mortality estimated at 81%.	Poisson <i>et al.</i> (2014a)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Tuna purse seine fishery	Western Central Pacific	AVM, PRM and blood sampling	Health state recorded for sharks taken at various stages of the fishing process. Blood chemistry and satellite tags used to examine post-release survival	Carcharhinidae	<i>Carcharhinus falciformis</i> (n = 295 for condition; n = 26 for satellite tags; n = 87 for blood chemistry)	0–75.9%	AVM was 0% (free-swimming and encircled sharks), 8.3% (entangled sharks), 51.9% (sharks in the first brail) and 75.9% (subsequent brails). Total mortality rate estimated at 84.2%	Hutchinson <i>et al.</i> (2015)
Tuna purse seine fishery. Work undertaken on commercial fishing vessel, fishing operations of 1–2 h and catch brailed on board	Eastern Pacific Ocean	AVM and PRM	Vitality (1–5 scale) and AVM data recorded; PRM assessed with PSATs	Lamnidae Carcharhinidae	<i>Isurus oxyrinchus</i> (n = 1) <i>Carcharhinus falciformis</i> (n = 53)	– 58.5%	Single fish in moderate condition 35.8% in fair/poor condition and 5.7% in excellent/good condition. Studies with PSATs indicated that sharks in excellent/good condition (n = 2) survived, sharks in fair condition (n = 5) showed 40% survival, all sharks in poor condition (n = 6) showed post-release mortality.	Eddy <i>et al.</i> (2016)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
				Sphyrnidae	<i>Sphyrna</i> spp. (n = 6)	(0%)	Small sample size; 50% in excellent/good condition; 50% in fair/poor condition. Three specimens were tagged with PSATs, showing 100% post-release mortality	
Commercial purse seine fishery for skipjack tuna	New Zealand	PRM	Pop-up archival transmitting tags attached to commercially caught fish	Mobulidae	<i>Mobula japanica</i> (n = 9)	–	Seven of the nine tags provided data. Three rays (that had all been brailed on board) survived for periods of 30–82 days. Four rays (that had all been entangled in the netting and hauled aboard) died 1–4 days after release.	Francis & Jones (2016)
RECREATIONAL FISHERIES								
Recreational gears	Bahamas	PRM	Sharks caught in shallow water by rod and line. Captured fish kept fully or partially submerged. Blood sampling undertaken and site of hooking recorded. Visual floats attached and post-release survival assessed over 15 minutes.	Carcharhinidae	<i>Negaprion brevirostris</i> (n = 32)	–	Post-release mortality (monitored for 0.25 h post-release) of 12.5%.	Danylchuk <i>et al.</i> (2014)

Fishery	Study area	Approach	Details	Family	Species	AVM	Key findings	Source
Recreational gears (either circle or J-hooks; fight times of 1–513 mins, but most samples were for fight times ≤ 1 h)	Southeast Australia	AVM and PRM	Catch condition recorded, and survivorship Pop-up Archival Transmitting (sPAT) tags deployed.	Lamnidae	<i>Isurus oxyrinchus</i>	0%	No AVM (n =33), with 84.8%, 6.1% and 9.1% in good, average and poor condition, respectively. From specimens tagged with sPAT tags (n = 30), post-release mortality was 10%	French <i>et al.</i> (2015)
Recreational gears	California	AVM and PRM	Satellite tagging of sharks that were hooked by the mouth (n = 7) or caudal fin (n = 9)	Alopiidae	<i>Alopias vulpinus</i>	0%	Specimens hooked by the mouth (125–187 cm L _F ; fight time = 9–25 mins) all survived release. Nearly 78% of specimens hooked by the caudal fin (111–175 cm L _F ; fight time = 10–25 mins) died.	Sepulveda <i>et al.</i> (2015)