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REVIEW PAPER

A review of capture and post-release mortality of elasmobranchs

J. R. ELLIS*†, S. R. MCCULLY PHILLIPS* AND F. POISSON‡

**Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, U.K. and ‡Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Centre de Recherche Halieutique UMR MARBEC (MARine Biodiversity Exploitation and Conservation), Avenue Jean Monnet, CS 30171, 34203 Sète, France*

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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.

Key words: batoids; by-catch; discards; dogfish; sharks; survival.

INTRODUCTION

Many fisheries management bodies are currently trying to reduce discards in fisheries, whether this is to reduce regulatory discards (and so minimizing waste) or to minimize by-catch of vulnerable marine species. Reducing discards is a central tenet of the European Unions' (E.U.) 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 (E.U., 2013). CFP reform, however, also notes that: 'The landing obligation should be introduced on a fishery-by-fishery

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†Author to whom correspondence should be addressed. Tel.: +44 1502 524300; email: jim.ellis@cefas.co.uk
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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 E.U.

Elasmobranchs are widely recognized as susceptible to overexploitation (Ellis *et al.*, 2008*a*). Within European waters, several stocks are considered depleted and, in the most extreme cases, species such as angel shark *Squatina squatina* (L. 1758) and white skate *Rostroraja alba* (Lacépède 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 area of the International Council for the Exploration of the Sea (ICES), several elasmobranchs have been managed under the traditional E.U. system of total allowable catches (TAC), including skates (Rajiformes), spurdog *Squalus acanthias* L. 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' (E.U., 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 (E.U., 2016), also requires an appropriate level of knowledge regarding the probable 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' (E.U., 2013). Species that are currently subject to prohibitions include sawfishes (Pristidae), manta and mobulid rays (Mobulidae), basking shark *Cetorhinus maximus* (Gunnerus 1765), white shark *Carcharodon carcharias* (L. 1758) and porbeagle shark *Lamna nasus* (Bonnaterre 1788) (all waters), *S. squatina* (E.U. waters), guitarfishes (Rhinobatidae) in E.U. waters of ICES subareas I–XII, as well as various skates (Rajidae) and deep-water sharks in certain areas (E.U., 2016). Whilst such species will not be included under the landing obligation, an appropriate knowledge of both by-catch rates and discard survival are required if the efficacy of prohibited status is to be gauged.

Similarly, several other regional fisheries management organizations (RFMO) mandate or encourage that certain elasmobranchs are released when caught. For example, the International Commission for the Conservation of Atlantic Tuna (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* (L. 1758)] (Recommendation 2010–08). Similarly, contracting parties to the

General Fisheries Commission for the Mediterranean (GFCM) should ensure that tope *Galeorhinus galeus* (L. 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 elasmobranchs, both in European seas (including in relation to the landing obligation) and further afield, 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 gear categories 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 fishes that are dead when the fishes are brought on-board (or alongside) a fishing vessel and post-release mortality (PRM), which is the proportion of fishes 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 have a high capacity for physical injuries to heal (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 fishes can result in both physical damage (*e.g.* following interactions with the fishing gear, abrasion with other contents of a trawl, effect of scavengers on fishes 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 fishes as they are discarded can cause further physical and physiological trauma (Chopin & Arimoto, 1995; Davis, 2002; Poisson *et al.*, 2014*b*). The effects 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 fishes to become entangled in fishing gear, whether during escape or from encountering previously lost gear, which can also lead to mortality or affect 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 recognize that discard mortality encompasses both AVM and PRM, where a proportion of those fishes 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.*, 2014*a*). Injured fishes may also be prone to infection (Borucinska *et al.*, 2002; Adams *et al.*, 2015), 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.

TABLE I. Example descriptions for condition of fishes in discard studies (adapted from Benoît *et al.*, 2010*b*)

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

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 fishes assessed, typically using a subjective evaluation by the field investigators 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 or dead) or five (excellent condition, good, moderate, poor or dead) health states. The assignment of fishes 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 (Benoît *et al.*, 2010*b*) have used pre-defined criteria to assess more objectively the degree of external damage and vitality (Table I). Such studies allow large numbers of fishes 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, they do 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 fishes in relation to a behavioural release condition score (BRCS), whereby the vigour and vitality of fishes is scored on a qualitative scale when released, ranging from when fishes actively swim away, to more moribund fishes that sink and show minimal movements (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 widely used in fishery-dependent studies, possibly because there is a greater variation in sea state, light levels, vessel speed and water clarity, which would affect the ability for such data to be collected effectively.

Elasmobranchs 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 gut 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.*, 2010*a*), cages or pens anchored to the sea floor (Mandelman & Farrington, 2007*b*) or after transporting fishes to tanks on land for subsequent study (Mandelman & Farrington, 2007*b*). Such approaches provide more robust information on the survival of fishes 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* (L. 1758) for periods of 36–60 h following capture in a commercial 8 m beam trawl with a 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. The 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 10–15 min (to simulate the processes that may be expected during commercial operations) before being categorized 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 (2007*b*) 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 longlines. 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, 2007*b*).

CONVENTIONAL TAGGING

Mark–recapture programmes have been used in numerous discard survival studies, primarily as a way of validating that fishes 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 fishes tagged (Kohler & Turner, 2001).

Ellis *et al.* (2008*b*) tagged and released thornback ray *Raja clavata* L. 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 to 24·0% 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 by which to infer the relative survival, *e.g.* when examining the effects 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 fishes 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 and 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 as 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 fishes 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 or the active tracking of tagged fishes 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 (PSAT) and pop-off data storage tags (DST), have also been used to quantify longer-term survival of various elasmobranchs (Campana *et al.*, 2009*a*; Poisson *et al.*, 2014*a*; 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 tended towards released individuals deemed likely to survive. Campana *et al.* (2009*a*) tagged a random sample of blue shark *Prionace glauca* (L. 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 PSATs, all healthy *P. glauca* that were hooked in the mouth 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 categorized as injured showed 33% mortality, with overall mortality estimated at 35% (Campana *et al.*, 2009*a*).

Lower rates of mortality were estimated for *P. glauca* caught in a Pacific fishery for swordfish *Xiphias gladius* L. 1758 (Musyl *et al.*, 2009), which could be related to handling practices and gear configuration, especially hook type (Campana *et al.*, 2009*b*). 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 some issues, however, 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.* (2014*a*) 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

Fishes 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 intracellular acidosis has been hypothesized 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 variables (*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, 2007*a*; 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*a*).

Most studies have examined a range of blood variables in relation to quantified stress-causing events (*e.g.* capture time). Skomal & Chase (2002) examined the blood chemistry of *P. glauca* (and tunas and billfishes) 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 fishes. 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 stabilizing.

Some studies have combined multiple approaches, with Moyes *et al.* (2006) using PSATs 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 34–1594 days, it was suggested that *c*. 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.*, 2016*a*). 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, 2010*a*, 2012) and trawl capture, including tow duration, crowding and exposure to air (Frick *et al.*, 2010*b*).

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.*, 2010*a*, *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 codend to simulate trawl capture in order to evaluate the effect of blood sampling only (control, $n = 8$), trawl time (1 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 codend, $n = 10$) 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 effects 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 onshore tanks. After a 10 day period of acclimatization, fish were withdrawn from tanks and exposed to the air for <1 (control), 15 or 50 min. This method was applied in both winter (air and water temperature = 1 and 4° C, respectively) and summer (air and water temperature = 27 and 18° C, respectively). Fish were then examined for mortality and blood samples taken. Mortality over the following 5 days was 0, 18 and 27% (control, 15 or 50 min aerial exposure, respectively for winter) and 37, 86 and 100% (control, 15 or 50 min aerial exposure, respectively for summer). Whilst based on laboratory studies, it emphasizes 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 postcapture 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 effect 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 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 by-catch 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 by-catch 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 fishes 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.*, 2016*b*; Guida *et al.*, 2016*b*) 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 and 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; Rodríguez-Cabello *et al.*, 2005).

The following section summarizes the findings from previously published studies on discard survival, but it should be recognized that comparisons between disparate studies can be problematic, due to differing methods of catching and handling fishes (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 or increase the chances of live discarding (Poisson *et al.*, 2014*b*). In terms of reducing elasmobranch by-catch, whilst there have been numerous studies in relation to pelagic longline fisheries, options for minimizing the by-catch 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 by-catch of demersal batoids and smaller sharks and, depending on the height of the net, there can also be incidental catch of

TABLE II. Summary of studies examining at-vessel mortality (AVM) and other elements of discard survival of elasmobranchs by gear. Data for AVM in parentheses relate to small sample sizes

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
Trawl (excluding beam trawl)						
Indian Ocean; Natal (Fennessy, 1994)						
Commercial prawn trawl (otter trawl, 38 mm stretched mesh codend, $3{\cdot}7–5{\cdot}6\,\mathrm{km\,h^{-1}}$ trawl speed; fishing depths of 20–45 m)	AVM		Squatinidae	*Squatina africana* (*n* = 10)	60	
			Stegostomatidae	*Stegostoma fasciatum* (*n* = 1)	(0)	
			Scyliorhinidae	*Halaelurus lineatus* (*n* = 47)	19·2	
			Triakidae	*Mustelus mosis* (*n* = 14)	28·6	
			Carcharhinidae	*Carcharhinus amboinensis* (*n* = 1)	–	
				Carcharhinus brevipinna (*n* = 25)	56	
				Carcharhinus obscurus (*n* = 8)	(12·5)	
				Carcharhinus plumbeus (*n* = 6)	(33·3)	
				Rhizoprionodon acutus (*n* = 24)	29·2	
			Sphyrnidae	*Sphyrna lewini* (*n* = 169)	97·6	
			Rhinidae and Rhinobatidae	*Rhina ancyclostoma* (*n* = 1)	–	AVM = 32·5% for rhinobatoids (all species combined)
				Rhynchobatus djiddensis (*n* = 11)	18·2	
				Rhinobatus annulatus (*n* = 9)	(11·1)	
				Rhinobatus leucospilus (*n* = 19)	52·6	
			Torpedinidae	*Torpedo sinuspersici* (*n* = 5)	(40)	
			Rajidae	*Raja miraletus* (*n* = 2)	(0)	
			Dasyatidae	*Dasyatis chrysonata* (*n* = 34)	17·7	
				Dasyatis thetidis (*n* = 10)	70	
				Himantura gerrardi (*n* = 47)	42·6	
				Himantura uarnak (*n* = 16)	25	
			Gymnuridae	*Gymnura natalensis* (*n* = 84)	46·4	AVM was lower in tows of <2 h duration; AVM higher in larger catches
			Myliobatidae	*Aetobatus narinari* (*n* = 3)	(0·0)	AVM = 27·3% for myliobatids (all species combined)
				Myliobatis aquila (*n* = 4)	(50·0)	
				Pteromylaeus bovinus (*n* = 4)	(25·0)	
Northern Australia (Stobutzki *et al.*, 2002)						
Commercial prawn trawl (research surveys and observer data)	AVM	Elasmobranchs categorized as live or dead	Carcharhinidae	*Carcharhinus dussumieri* (*n* = 321)	52	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
				Carcharhinus sorrah ($n = 23$)	65	
				Carcharhinus tilstoni ($n = 73$)	82	
				Rhizoprionodon acutus ($n = 116$)	82	
			Hemigaleidae	*Hemigaleus microstoma* ($n = 68$)	62	
			Rhinidae	*Rhynchobatus djiddensis* ($n = 59$)	10	
			Dasyatidae	*Dasyatis leylandi* ($n = 41$)	59	
				Himantura toshi ($n = 58$)	53	
			Gymnuridae	*Gymnura australis* ($n = 34$)	41	
SW Atlantic; Falkland Islands (Laptikhovsky, 2004)						
Bottom trawl squid fishery (codend mesh size of 110 mm; 3·8–4·2 km trawl speed; 80–190 m fishing depth)	Short-term survival	Random sample of skates placed in on-board tanks to assess health over periods of up to 2·3 h	Arhynchobatidae	*Bathyraja albomaculata* ($n = 14$) *Bathyraja brachyurops* ($n = 11$) *Bathyraja griseocauda* ($n = 3$) *Bathyraja macloviana* ($n = 2$) *Bathyraja magellanica* ($n = 5$) *Bathyraja* sp. ($n = 16$) *Psammobatis* 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%)
NE Atlantic Ocean; Cantabrian Sea (Rodríguez-Cabello *et al.*, 2005)						
Otter (baca) trawl with codend liner deployed from research vessel (0·5 h tow duration)	Short-term survival	Specimens left on deck for known periods to simulate catch processing time, then maintained in a tank for 1 h before categorization as alive or dead	Scyliorhinidae	*Scyliorhinus canicula*	–	Mean survival rate was 90%, ranging from 60 to 100%. Survival decreased with increased sorting time
Otter (baca) trawl deployed from commercial vessels (3–6 h tow duration)		As described above	Scyliorhinidae	*Scyliorhinus canicula*	–	Mean survival rate was 78%, ranging from 47 to 98%. Suggestion of reduced survival with increased depth and increased sorting time, but results not significant

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NW Atlantic Ocean (Mandelman & Farrington, 2007*a*)						
Danish otter trawl deployed from commercial vessel (0·75 h haul duration)	Short-term survival and blood sampling	Spurdog caught, transported ashore and held in captivity ($n = 34$)	Squalidae	*Squalus acanthias*	–	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
NW Atlantic Ocean (Mandelman & Farrington, 2007*b*)						
Danish otter trawl deployed from commercial vessel (codend of 152 mm mesh size; 0·75–1·0 h haul duration; 60–72 water depth)	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 was sampled with hook-and-line (46–56 m depth)	Squalidae	*Squalus acanthias*	–	AVM not reported, but no immediate post-capture mortality observed in sub-samples examined. Trawl-caught fish exhibited 29% mortality over 72 h. No at-vessel mortality for fish caught by hook-and-line, with this control group showing 24% mortality over 72 h. Catch mass in the trawl found to be an important factor affecting survival, with catches >200 kg leading to higher 72 h mortality estimates
NW Atlantic Ocean (Rulifson, 2007)						
Trawl (101 mm stretch mesh; 0·5–1·5 h haul duration)	AVM and short-term survival	Immediate post-capture mortality recorded, live fish maintained in sea cages for 48 h	Squalidae	*Squalus acanthias*	0	All spurdog ($n = 635$) that were captured were alive; all specimens maintained in sea cages ($n = 480$) survived for 48 h. 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

Table II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NE Atlantic Ocean; southern North Sea (Ellis *et al.*, 2008*a*)						
Demersal trawls deployed from commercial inshore vessels. The tow durations (*c*. 0·5–1·5 h), were as normal practice for this fishery	AVM and tagging	Health state recorded on a three-point scale (lively, sluggish, dead) and fish tagged and released	Rajidae	*Raja clavata* ($n = 3822$)	0·6	Overall, 86·9% were categorized 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 probably increase if fish remained on deck whilst catch processed
NE Atlantic Ocean; Bristol Channel (Enever *et al.*, 2009)						
Demersal twin-rig otter trawl	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. Codend mass estimated	Rajidae	Various skates, including: *Leucoraja naevus*, *Raja brachyura*, *Raja clavata*, *Raja microocellata*, *Raja montagui*	–	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%, respectively Skates deemed of good health in commercial tows ranged from 3 to 6% (*R. brachyura*, *R. microocellata* and *R. montagui*) to 35% (*R. clavata*). A greater percentage of skates (18–69%) were considered to be in good condition in shorter tows. Catch mass, species and sex all found to be important factors influencing health state

TABLE II. continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NE Atlantic Ocean; Bristol Channel (Enever *et al.*, 2010)						
Trawls with different designs of codend (80 and 100 mm diamond mesh and 100 mm square mesh)	Vitality	Health state assessed visually for vitality (poor health = 1, moderate health = 2; good health = 3)	Rajidae	Various skates, including: *Leucoraja naevus*, *Raja brachyura*, *Raja clavata*, *Raja microocellata*, *Raja montagui*	–	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
	Short-term survival	Survival in onboard holding tanks (to >48 h)	Rajidae	*Raja microocellata*	–	The percentage of individuals that survived >48 h were 55–57% (80 mm codend), 59% (100 mm diamond) and 67% (100 mm square mesh)
NW Atlantic Ocean; Gulf of St Lawrence (Benoît *et al.*, 2010*a*)						
Trawl and line fisheries	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: *Amblyraja radiata*, *Leucoraja ocellata*, *Malacoraja senta*	–	>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)
NW Atlantic Ocean; Canada (Benoît *et al.*, 2012)						
Bottom trawl (5·1 km h^{-1} tow speed; tow duration of 1–2 h)	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: *Amblyraja radiata*, *Leucoraja ocellata*, *Malacoraja senta*	13·75	75·6% survived capture and holding, and 10·6% died whilst being held in tanks

TABLE II. continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NW Atlantic Ocean; Massachusetts and New Hampshire (Mandelman *et al.*, 2012)						
Trawl (165 mm diamond mesh codend) 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	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: *Amblyraja radiata*, *Leucoraja erinacea*, *Leucoraja ocellata*, *Malacoraja senta*	<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)
Western Mediterranean Sea (Saygu & Deval, 2014)						
Research trawl (17 m ground rope; 44 mm codend mesh; 4·33–5·0 km h^{-1} trawl speed). Tow duration either control (1 h) or commercial (3 h)	AVM and short-term survival	Catch processed, skates left on deck for 10–20 min and then placed in holding tanks. Health state recorded on a four-point scale (0 = dead; 1 = poor health; 2 = moderate health; 3 = good health). Short-term survival checked over 48 h	Rajidae	*Raja clavata* ($n = 120$)	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 percentage alive after 48 h was 80·8%
				Raja miraletus ($n = 68$)	26·5	Only 42·6% of specimens were in moderate or good health. The overall percentage alive after 48 h was 20·6%
Australia (Jaiteh *et al.*, 2014)						
Pilbara trawl fishery (trawl depths of 50–100 m, tow durations of *c.* 2·5 h)	AVM		–	Sharks (aggregated, $n = 66$)	90·9	Data reported for higher taxonomic groups only
			–	Batoids (aggregated, $n = 53$)	66	
Beam trawl and dredge						
NE Atlantic Ocean; Irish Sea (Kaiser & Spencer, 1995)						
Beam trawl (4 m beam, chain mat, 80 mm diamond mesh codend; 0·5 h tows)	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	*Leucoraja naevus* ($n = 32$)	0	No AVM, but 41 dead after 5 days
			Scyliorhinidae	*Scyliorhinus canicula* ($n = 42$)	0–3	90–94% of fish survived periods of 120 h

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NE Atlantic Ocean; Western English Channel (Revill *et al.*, 2005)						
8 m Beam trawl with chain mat and 80 mm codend mesh	Short-term survival	Specimens maintained in on-board survival tanks for periods of 36–60 h	Scyliorhinidae	*Scyliorhinus canicula*	–	Mean survival rate of 98%
NW Atlantic Ocean; Gulf of St Lawrence (Benoît *et al.*, 2010*b*)						
Scallop dredge (commercial fishery and experimental)	Vitality	Health state assessed visually for vitality (1–4) and degree of injury (1–3)	Rajidae	*Leucoraja ocellata* (*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
NE Atlantic Ocean; North Sea (Depestele *et al.*, 2014)						
Beam trawls deployed from research vessel	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
NW Atlantic Ocean (Rudders *et al.*, 2015)						
Scallop dredges (commercial vessels with standard fishing operations; 15–15·5 commercial scallop dredges with 4″ (100 mm) rings and 10″ (250 mm) square-mesh top; 0·17–1·5 h tows)	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	*Leucoraja erinacea* (*n* = 2634 for condition of which 179 for post-release mortality)	–	The percentage of fish with minor, moderate and extensive injuries were 22, 49 and 29%, respectively. Post-release mortality estimated at 49·1% over 72 h
				Leucoraja ocellata (*n* = 1313–116)	–	The percentage of fish with minor, moderate and extensive injuries were 19, 52 and 29%, respectively. Post-release mortality estimated at 65·2% over 72 h
				Dipturus laevis (*n* = 269–239)	–	The percentage of fish with minor, moderate and extensive injuries were 11, 58 and 31%, respectively

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
Gillnet and tangle net						
Australia; New South Wales (Reid & Krogh, 1992)						
Protective nets set off beaches. Soak times generally 12–48 h	AVM	Information on the percentage alive recorded, but no specific information in relation to soak time	Hexanchidae	*Notorynchus cepedianus* (*n* = 54)	85·1	Values relate to the percentage recovered dead from protective shark nets, which is analogous to AVM
			Squatinidae	*Squatina australis* (*n* = 651)	34·4	
			Heterodontidae	*Heterodontus* spp. (*n* = 60)	3·3	
			Orectolobidae	*Orectolobus* spp. (*n* = 13)	15·4	
			Odontaspididae	*Carcharias taurus* (*n* = 62)	41·3	
			Alopiidae	*Alopias* spp. (*n* = 22)	90·9	
			Lamnidae	*Carcharodon carcharias* (*n* = 185)	49·2	
				Isurus spp. (*n* = 17)	90·9	
			Carcharhinidae	*Carcharhinus* spp. (*n* = 724)	61	
				Galeocerdo cuvier (*n* = 177)	76·7	
			Sphyrnidae	*Sphyrna* spp. (*n* = 2031)	98·3	
Bahamas (Gruber *et al.*, 2001)						
Scientific fishing with gillnet (10 cm stretch mesh, soak time *c.* 12 h, but nets checked every 0·25 h)	AVM	Mortality recorded after capture, handling, tagging and maintenance in a pen	Carcharhinidae	*Negaprion brevirostris* (*n* = 655)	0–11·1	Overall, handling mortality (including capture) of juvenile lemon sharks was 3·5% (ranging from 0 to 11·1% for the various study sites and years reported)
NW Atlantic Ocean; South-west Florida (Manire *et al.*, 2001)						
Gillnet (11·75–15·25 mm stretched mesh size; 0·75–1·0 h soak time; depth <3 m)	AVM and blood sampling	Sharks sampled in research programme, with blood samples taken and condition recorded (five-point scale)	Carcharhinidae	*Carcharhinus limbatus* (*n* = 33)	24·2	39·4% in Good or fair condition and 36·4% in poor or very poor condition
				Carcharhinus leucas (*n* = 27)	18·5	74·1% in Good or fair condition and 7·4% in poor condition
			Sphyrnidae	*Sphyrna tiburo* (*n* = 39)	30·8	35·9% in Good or fair condition and 33·3% in poor or very poor condition
SW Pacific Ocean; New South Wales (Gray, 2002)						
Commercial gillnets (>80 mm stretched mesh) set overnight	AVM	Commercial catches examined and percentage of fish discarded alive recorded	Dasyatidae	*Dasyatis* sp. (*n* = 112)	7·2	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
South Australia (Walker *et al.*, 2005)						
Commercial gillnets 6–6·5″ (150–160 mm) mesh; mean soak time of 8·2 h; fishing depths of 17–130 m (mostly <80 m)	AVM	AVM recorded for two fishing grounds (Bass Strait and South Australia)	Hexanchidae	*Notorynchus cepedianus* (*n* = 83)	79–83	
			Squalidae	*Squalus megalops* (*n* = 325)	0–6	
				Squalus acanthias (*n* = 1)	(0)	
			Heterodontidae	*Heterodontus portusjacksoni* (*n* = 778)	0	
			Squatinidae	*Squatina australis* (*n* = 43)	11–33	
			Orectolobidae	*Orectolobus maculatus* (*n* = 4)	(0)	
			Alopiidae	*Alopias vulpinus* (*n* = 20)	60	
			Lamnidae	*Isurus oxyrinchus* (*n* = 4)	(75)	
			Pristiophoridae	*Pristiophorus cirratus* (*n* = 1051)	7–23	
				Pristiophorus nudipinnis (*n* = 250)	22–33	
			Scyliorhinidae	*Cephaloscyllium laticeps* (*n* = 1034)	0	
			Triakidae	*Furgaleus macki* (*n* = 1)	–	
				Galeorhinus galeus (*n* = 187)	2–70	
				Mustelus antarcticus (*n* = 4625)	53–60	
			Carcharhinidae	*Carcharhinus brachyurus* (*n* = 42)	0	
			Sphyrnidae	*Sphyrna zygaena* (*n* = 77)	3	
			Rhinobatidae	*Aptychotrema vincentiana* (*n* = 6)	(16·6)	
			Rajidae	Rajidae indet (*n* = 5)	(0)	
			Urolophidae	*Urolophus paucimaculatus* (*n* = 43)	23–50	AVM ranged from 23% (*n* = 41) to 50% (*n* = 2) in the two fishing areas studied
			Myliobatidae	*Myliobatis australis* (*n* = 94)	9–21	
			Callorhinchidae	*Callorhinchus milii* (*n* = 763)	23–29	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NW Atlantic Ocean; Gulf of Mexico (Hueter *et al.*, 2006)						
Scientific gillnet surveys, soak times usually 1 h	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	*Carcharhinus limbatus*	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%)
			Sphyrnidae	*Sphyrna tiburo*	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%)
NW Atlantic Ocean (Rulifson, 2007)						
Gillnet (101–165 mm mesh sizes; 19·5–23·5 h soak time)	AVM and short-term survival	Immediate post-capture mortality recorded, live fish maintained in sea cages for 48 h	Squalidae	*Squalus acanthias* ($n = 2284$)	17·5	The majority of captured specimens had evident damage from gillnets, but a lower percentage had other damage (*cf*. 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%
NW Atlantic Ocean; North Carolina (Thorpe & Frierson, 2009)						
Experimental fishing with gillnets in inshore waters. Soak times not specified	AVM	Sharks caught recorded as live or dead	Carcharhinidae	*Carcharhinus acronotus*	81·3	Study primarily looking at gillnet selectivity, with observations on mortality rates given
				Carcharhinus limbatus	90·5	
				Rhizoprionodon terraenovae	80·4	
			Sphyrnidae	*Sphyrna tiburo*	71·5	
NE Atlantic Ocean; southern North Sea (Ellis *et al.*, 2008*a*)						
Gillnets deployed from commercial inshore vessels. Fixed tangle nets were soaked overnight; drift trammel nets fished for 1–3 h	AVM and tagging	Health state recorded on a three-point scale (lively, sluggish, dead) and fish tagged and released	Rajidae	*Raja clavata* ($n = 975$)	0–2	AVM = 2% for the vessel with overnight soak times. No-mortality observed in drift trammel nets with short soak times

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NE Atlantic Ocean; Celtic Sea (Bendall *et al.*, 2012)						
Chartered surveys on board two commercial gillnetters; commercial trammel nets and gillnets deployed for different soak times	AVM	Vitality scored on a five-point scale (lively, sluggish, very sluggish, dead and scavenged)	Squalidae	*Squalus acanthias* ($n = 388$)	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
			Lamnidae	*Lamna nasus* ($n = 20$)	80	AVM for 11–26 h soak time
			Rajidae	*Dipturus batis*-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)
SE Australia (Braccini *et al.*, 2012)						
Gillnet fishery (2·4–20·6 h soak times)	AVM	Vitality scored according to activity, presence of wounds and skin damage and any damage by sea lice	Hexanchidae	*Notorynchus cepedianus* ($n = 202$)	33·2	
			Squalidae	*Squalus acanthias* ($n = 52$)	13·5	
				Squalus chloroculus ($n = 5$)	(40)	
				Squalus megalops ($n = 1178$)	10·3	
			Pristiophoridae	*Pristiophorus cirratus* ($n = 562$)	24·7	
				Pristiophorus nudipinnis ($n = 113$)	41·6	
			Squatinidae	*Squatina australis* ($n = 56$)	25	
			Heterodontidae	*Heterodontus portusjacksoni* ($n = 1452$)	0·8	
			Parascyllidae	*Parascyllium ferrugineum* ($n = 24$)	12·5	
				Parascyllium variolatum ($n = 5$)	(20)	
			Orectolobidae	*Orectolobus maculatus* ($n = 5$)	(0)	
				Sutorectus tentaculatus ($n = 6$)	(0)	
			Alopiidae	*Alopias vulpinus* ($n = 9$)	(66·7)	
			Lamnidae	*Isurus oxyrinchus* ($n = 8$)	(37·5)	
			Scyliorhinidae	*Cephaloscyllium laticeps* ($n = 1977$)	0·5	
			Triakidae	*Furgaleus macki* ($n = 223$)	92·8	
				Galeorhinus galeus ($n = 1361$)	72·7	
				Mustelus antarcticus ($n = 3726$)	56·9	
			Carcharhinidae	*Carcharhinus brachyurus* ($n = 152$)	36·2	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
			Sphyrnidae	*Sphyrna zygaena* ($n = 122$)	89·3	
			Urolophidae	*Urolophus paucimaculatus* ($n = 26$)	3·8	
				Urolophus viridis ($n = 15$)	0	
			Myliobatidae	*Myliobatis australis* ($n = 133$)	5·3	
Eastern Pacific Ocean; California (Lyons *et al.*, 2013)						
Commercial gillnets, including set gillnets (>89 mm; variable soak times) and drift gillnets (89–150 mm; 4–12 h soak times)	AVM and PRM	PRM quantified from satellite and acoustic tags	Lamnidae	*Carcharodon carcharias*	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%
Australia; Tasmania (Lyle *et al.*, 2014)						
Commercial and recreational gillnets (graball nets of 114 mm mesh size; mullet nets of 64 mm mesh size). Soak time ranged from 2 to 24 h	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	*Squalus acanthias* ($n = 502$)	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%
			Scyliorhinidae	*Cephaloscyllium laticeps* ($n = 990$)	0	No AVM ($n = 990$) and no delayed mortality ($n = 71$). Post-release survival estimated at 100%
			Triakidae	*Mustelus antarcticus* ($n = 67$)	24	Usually alive but damaged. AVM = 24% (all data combined), and whilst 57% only had minor or moderate damage (conditions 1–3), 19% were in poor condition Post-release survival estimated at 58·7%
			Rajidae	*Zearaja maugeana* ($n = 177$) and *Raja whitleyi* ($n = 61$)	0–9	No AVM observed for either *Z. maugeana* ($n = 50$) or *R. whitleyi* ($n = 61$) when soak times were short, with 98% of specimens rated as lively or with only minor damage. Overnight sets resulted in 80% of *Z. maugeana* ($n = 127$) being lively or with only minor damage, and AVM was 9%. Post-release survival was estimated at >87·2%

Table II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
			Urolophidae	*Urolophus cruciatus* ($n = 30$) and *U. paucimaculatus* ($n = 33$)	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
			Callorhinchidae	*Callorhinchus milii* ($n = 314$)	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 AVM would increase estimates to 10 and 40. Delayed mortality ranged from 8·3% (conditions 1 and 2; $n = 24$) to 33·3% (conditions 3 and 4; $n = 6$). Post-release survival estimated at 74–82%
Longline						
Pacific Ocean; Hawaii (Boggs, 1992)						
Longline deployed from research vessel (soak times <12 h)	AVM		Alopiidae	*Alopias* spp. ($n = 6$)	(40)	
			Carcharhinidae	*Carcharhinus longimanus* ($n = 26$)	15	
				Prionace glauca ($n = 21$)	0	
			Dasyatidae	*Pteroplatytrygon violacea* ($n = 8$)	(12)	
New Zealand (Francis *et al.*, 2001)						
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)	AVM	AVM recorded by observers	Lamnidae	*Isurus oxyrinchus* ($n = 299$)	28·4	
				Lamna nasus ($n = 2370$)	39·2	
			Carcharhinidae	*Prionace glauca* ($n = 7838$)	13·5	AVM lower for domestic fleet (8·3%) than observed in foreign-licensed and foreign-chartered fleets (13·9%)
Mediterranean Sea (Megalofonou *et al.*, 2005)						
Commercial longlines targeting swordfish, albacore or blue-fin tuna. Limited data for commercial driftnet	AVM	Vitality and AVM recorded (1 = good; 2 = fair; 3 = poor; 4 = dead or no response to stimuli)	Hexanchidae	*Hexanchus griseus* ($n = 3$)	(0)	
			Lamnidae	*Isurus oxyrinchus* ($n = 31$)	16	Most fish in fair or poor condition (32 and 29%), and only 22·6% in good condition

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
			Alopiidae	*Alopias superciliosus* ($n = 1$) and *A. vulpinus* ($n = 16$)	5·9	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
			Triakidae	*Galeorhinus galeus* ($n = 5$)	(0)	
			Carcharhinidae	*Carcharhinus plumbeus* ($n = 2$)	(0)	
				Prionace glauca ($n = 513$)	4·5	71% of fish in good condition
NW Atlantic Ocean; south-eastern coast of the U.S.A. (Beerkircher *et al.*, 2004)						
Pelagic longline fishery (hooks of 7/0 to 11/0; hook depths usually 35–60 m)		Condition of captured sharks recorded by observers	Alopiidae	*Alopias superciliosus* ($n = 82$)	53·7	
			Lamnidae	*Isurus oxyrinchus* ($n = 80$)	35·0	
			Carcharhinidae	*Carcharhinus falciformis* ($n = 1446$)	66·3	
				Carcharhinus longimanus ($n = 131$)	27·5	
				Carcharhinus obscurus ($n = 679$)	48·7	
				Carcharhinus plumbeus ($n = 112$)	26·8	
				Carcharhinus signatus ($n = 572$)	80·8	
				Galeocerdo cuvier ($n = 263$)	3	
				Prionace glauca ($n = 434$)	12·2	
			Sphyrnidae	*Sphyrna lewini* ($n = 199$)	61·0	
			Dasyatidae and Mobulidae	Unidentified batoids ($n = 113$)	0	
SW Atlantic Ocean; South Georgia (Endicott & Agnew, 2004)						
Deep-water longlines (746–1913 m depth)	Short-term survival	Skates randomly selected and placed in deck tanks (one skate per tank) for 12 h	Rajidae	*Amblyraja* 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

Table II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NW Atlantic Ocean (Diaz & Serafy, 2005)						
Commercial longline targeting swordfish and tuna	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	*Prionace glauca*	31	Overall, 69% of records were for discarded alive. The percentage released alive increased with increasing fish length and decreasing soak time
Pacific Ocean; Hawaii (Moyes *et al.*, 2006)						
Longline deployed from research vessel (10–18 h soak time)	AVM	Health assessed, with 23 individuals tagged with PSATs and selected sharks also examined for blood chemistry	Carcharhinidae	*Prionace glauca*	*c.* 5·2	Only nine of 172 blue sharks were assessed as moribund (5·2%)
NW Atlantic Ocean; Gulf of Mexico (Morgan & Burgess, 2007)						
Commercial longline fisheries with observer coverage	AVM	AVM assessed visually (alive–dead)	Carcharhinidae	*Carcharhinus limbatus* ($n = 1982$)	88	
				Carcharhinus obscurus ($n = 662$)	81	
				Carcharhinus plumbeus ($n = 8583$)	36	
				Galeocerdo cuvier ($n = 2466$)	8·5	
			Sphyrnidae	*Sphyrna lewini* ($n = 455$)	91·4	
				Sphyrna mokarran ($n = 178$)	93·8	
NE Atlantic Ocean; southern North Sea (Ellis *et al.*, 2008*a*)						
Bottom longlines deployed from commercial inshore vessels. Soak times of *c.* 2–4 h	AVM	Vitality recorded on a three-point scale (lively, sluggish, dead) and fish tagged and released	Rajidae	*Raja clavata* ($n = 817$)	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

Table II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NW Atlantic Ocean (Campana *et al.*, 2009*a*, *b*, 2011)						
Commercial longline targeting swordfish and tuna	AVM and PRM	Estimates of both AVM (scientific observers) and PRM (electronic tagging of healthy and injured fish)	Carcharhinidae	*Prionace glauca*	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
NW Atlantic Ocean (Carruthers *et al.*, 2009)						
Commercial longline targeting swordfish and tuna	AVM	Observer data (2001–2004) for fish recorded as alive or dead analysed in relation to hook type, soak time and fish size	Lamnidae	*Isurus oxyrinchus* and *Lamna nasus*	–	*I. oxyrinchus* of larger size had increased probability of surviving
			Carcharhinidae	*Prionace glauca*	–	Improved survival for *P. glauca* caught on circle hooks than J-hooks
			Dasyatidae	*Pteroplatytrygon violacea*	–	AVM low for both J-hooks (10%) and circle hooks (2%)
Australia; Victoria (Frick *et al.*, 2010*a*)						
Commercial longline (demersal sets; 5/0 hooks; 2–2·5 h soak time)	AVM and blood sampling	Sharks taken for blood sampling; AVM also reported	Triakidae	*Mustelus antarcticus* (*n* = 93)	2·2	
NW Atlantic Ocean; Gulf of Mexico (Morgan & Carlson, 2010)						
Research longline fishing from commercial vessels, soak times ranging from 4 to 6 h (day) and 6 to 10 h (night), 18/0 circle hooks	AVM	AVM assessed visually (alive–dead). Hook timers used to assess the time each shark had been hooked	Carcharhinidae	*Carcharhinus acronotus*	77	Mortality generally increased with time the shark was hooked. In the case of *C. plumbeus*, larger individuals typically had a higher mortality case of *C. plumbeus*, larger individuals typically had a higher mortality
				Carcharhinus leucas	15	
				Carcharhinus limbatus	85	
				Carcharhinus plumbeus	21	
				Rhizoprionodon terraenovae	91	

Table II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
Indian Ocean; Réunion Island (Poisson *et al.*, 2010)						
Longline fishery targeting swordfish	AVM	AVM data (and percentage alive after 8 h hooking)	Carcharhinidae	*Carcharhinus longimanus* (*n* = 17)	58·9	
				Prionace glauca (*n* = 92)	51·1	
			Dasyatidae	*Pteroplatytrygon violacea* (*n* = 12)	58·8	
SW Atlantic Ocean; Brazil (Afonso *et al.*, 2011)						
Research longline (pelagic) with 18/0 circle hooks and 9/0 J-hooks	AVM	Catch rates and AVM compared between hook types	Ginglymostomidae	*Ginglymostoma cirratum* (*n* = 6)	(0)	No AVM observed
			Lamnidae	*Isurus oxyrinchus* (*n* = 6)	–	Sample size limited, but AVM was 20% (circle hooks) and 100% (J-hooks)
			Carcharhinidae	*Carcharhinus falciformis* (*n* = 14)	–	Lower AVM reported for circle hooks (22·2%) than J-hooks (80%)
				Carcharhinus leucas (*n* = 2)	(50)	
				Carcharhinus longimanus (*n* = 12)	–	Lower AVM reported for circle hooks (22·2%) than J-hooks (66·5%)
				Carcharhinus obscurus (*n* = 10)	–	Lower AVM reported for circle hooks (28·5%) than J-hooks (100%)
				Carcharhinus signatus (*n* = 33)	100	AVM was 100% for both hook types
				Galeocerdo cuvier (*n* = 8)	–	Lower AVM reported for circle hooks (16·6%) than J-hooks (50%)
				Prionace glauca (*n* = 32)	–	Lower AVM reported for circle hooks (27·2%) than J-hooks (70%)
			Sphyrnidae	*Sphyrna lewini* (*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)	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	*Ginglymostoma cirratum* (*n* = 14)	0	No AVM observed

Table II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
			Carcharhinidae	*Carcharhinus acronotus* (*n* = 41)	23–74	AVM ranged from 23% (circle hooks) to 74% (J-hooks)
			Dasyatidae	*Dasyatis americana* (*n* = 43)	0	No AVM observed
Atlantic & Indian Oceans (Coelho *et al.*, 2011)						
Commercial longliners targeting swordfish	AVM	AVM recorded	Alopiidae	*Alopias superciliosus*	48·6–68·4	AVM ranged from 48·6% (*n* = 849; Atlantic) to 68·4% (*n* = 19; Indian Ocean)
			Lamnidae	*Isurus oxyrinchus*	32·8–56·0	AVM ranged from 32·8% (*n* = 1004; Atlantic) to 56·0% (*n* = 430; Indian Ocean)
			Carcharhinidae	*Carcharhinus falciformis*	55·1–74·2	AVM ranged from 55·1% (*n* = 296; Atlantic) to 74·2% (*n* = 31; Indian Ocean)
				Prionace glauca	12·7–24·7	AVM ranged from 12·7% (*n* = 22 887; Atlantic) to 24·7% (*n* = 2358; Indian Ocean)
			Sphyrnidae	*Sphyrna zygaena*	70·1–84·0	AVM ranged from 70·1% (*n* = 338; Atlantic) to 84·0% (*n* = 25; Indian Ocean)
			Dasyatidae	*Pteroplatytrygon violacea*	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)
Pacific Ocean (Musyl *et al.*, 2011)						
Longline fishery targeting swordfish	AVM	AVM recorded	Pseudocarchariidae	*Pseudocarcharias kamoharai* (*n* = 3)	66·7	
			Alopiidae	*Alopias pelagicus* (*n* = 28)	35·7	
				Alopias superciliosus (*n* = 12)	25	
			Lamnidae	*Isurus oxyrinchus* (*n* = 8)	0	No AVM observed
			Carcharhinidae	*Carcharhinus falciformis* (*n* = 35)	11·4	
				Carcharhinus longimanus (*n* = 19)	5·3	
				Prionace glauca (*n* = 203)	5·9	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
Gulf of Mexico (Scott-Denton *et al.*, 2011)						
Bottom longline fishery for reef fish. Average fishing depth = 94 m. Most hooks were 13/0 but ranged from 12/0 to 15/0. Mean soak time was 5·1 h (range = 0·9–32·2 h)	AVM	Condition and fate recorded by observers, (but data lacking for some specimens and estimates of AVM are given here)	Hexanchidae	*Heptranchias perlo* (*n* = 33)	24·2	
			Squalidae	*Squalus cubensis* (*n* = 49)	10·2	
				Squalus sp. (*n* = 92)	0	Of the live-caught fish that were subsequently discarded, 42·2% were dead
			Centrophoridae	*Centrophorus granulosus* (*n* = 35)	0	Of the live-caught fish that were subsequently discarded, 14·3% were dead
			Ginglymostomidae	*Ginglymostoma cirratum* (*n* = 163)	NA	AVM not estimated, but 87·1% released alive
			Triakidae	*Mustelus canis* (*n* = 1279)	0·8	
				Mustelus sp. (*n* = 72)	0	Of the live-caught fish that were subsequently discarded, 1·4% were dead
			Carcharhinidae	*Carcharhinus acronotus* (*n* = 801)	8·0	
				Carcharhinus brevipinna (*n* = 26)	3·8	Of the live-caught fish that were subsequently discarded, 34·8% were dead
				Carcharhinus falciformis (*n* = 94)	26·6	
				Carcharhinus leucas (*n* = 43)	2·3	
				Carcharhinus limbatus (*n* = 87)	23·0	
				Carcharhinus plumbeus (*n* = 59)	3·4	
				Carcharhinus porosus (*n* = 48)	0	
				Galeocerdo cuvier (*n* = 102)	0·9	
				Negaprion brevirostris (*n* = 157)	1·9	
				Rhizoprionodon terraenovae (*n* = 2090)	19·1	
			Sphyrnidae	*Sphyrna lewini* (*n* = 73)	19·2	
			Rajidae	*Leucoraja eglanteria* (*n* = 50)	4	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
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)	AVM	Condition and fate recorded by observers, (but data lacking for some specimens and estimates of AVM are given here)	Ginglymostomidae	*Ginglymostoma cirratum* ($n = 33$)	0	Whilst no AVM was reported, 6·1% of the specimens subsequently discarded were dead
			Triakidae	*Mustelus canis* ($n = 35$)	0	Whilst no AVM was reported, 12·5% of the specimens subsequently discarded were dead
			Carcharhinidae	*Carcharhinus acronotus* ($n = 32$)	3·1	Of those specimens caught alive, 12·9% were subsequently discarded dead
				Carcharhinus falciformis ($n = 71$)	0	Whilst no AVM was reported, 1·4% of the specimens subsequently discarded were dead
				Carcharhinus limbatus ($n = 39$)	0	Whilst no AVM was reported, 15·8% of the specimens subsequently discarded were dead
				Rhizoprionodon terraenovae ($n = 83$)	0	Whilst no AVM was reported, 7·6% of the specimens subsequently discarded were dead
SW Atlantic Ocean; Brazil (Afonso *et al.*, 2012)						
Research fishing from a commercial longline vessel (pelagic), with combinations of wire and monofilament leaders, and circle and J-hooks	AVM	AVM recorded; catch rates and bite-offs recorded	Pseudocarchariidae	*Pseudocarcharias kamoharai* ($n = 11$)	91	
			Alopiidae	*Alopias* spp. ($n = 9$)	89	
			Lamnidae	*Isurus* spp. ($n = 4$)	75	
			Carcharhinidae	*Carcharhinus falciformis* ($n = 24$)	75	
				Carcharhinus longimanus ($n = 11$)	82	
				Galeocerdo cuvier ($n = 3$)	(67)	
				Prionace glauca ($n = 77$)	31	
			Sphyrnidae	*Sphyrna* spp. ($n = 3$)	100	
			Dasyatidae	*Pteroplatytrygon violacea* ($n = 40$)	5	
Pacific Ocean (Bromhead *et al.*, 2012)						
Commercial longline fishery	AVM	AVM recorded from observer coverage	Pseudocarchariidae	*Pseudocarcharias kamoharai* ($n = 139$)	38·7	
			Alopiidae	*Alopias pelagicus* ($n = 1353$)	63·8	
				Alopias superciliosus ($n = 1636$)	50·0	
				Alopias vulpinus ($n = 87$)	52·9	
			Lamnidae	*Isurus oxyrinchus* ($n = 171$)	50·3	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
			Carcharhinidae	*Carcharhinus albimarginatus* ($n = 20$)	15·0	
				Carcharhinus amblyrhynchos ($n = 4$)	(50·0)	
				Carcharhinus brachyurus ($n = 19$)	5·6	
				Carcharhinus falciformis ($n = 3242$)	26·5	
				Carcharhinus galapagensis ($n = 8$)	(25·0)	
				Carcharhinus limbatus ($n = 10$)	60·0	
				Carcharhinus longimanus ($n = 917$)	30·6	
				Carcharhinus plumbeus ($n = 1$)	(0)	
				Galeocerdo cuvier ($n = 5$)	(60·0)	
				Prionace glauca ($n = 3452$)	19·6	
			Sphyrnidae	*Sphyrna lewini* ($n = 5$) and *S. mokarran* ($n = 3$)	(75)	Although data were limited, AVM was 75% for this genus
			Dasyatidae	*Pteroplatytrygon violacea* ($n = 501$)	18·5	
Atlantic Ocean (Coelho *et al.*, 2012)						
Pelagic longline	AVM	AVM recorded by observers on commercial vessels	Pseudocarchariidae	*Pseudocarcharias kamoharai* ($n = 1621$)	13·3	
			Alopiidae	*Alopias superciliosus* ($n = 1061$)	50·6	
				Alopias vulpinus ($n = 3$)	(66·7)	
			Lamnidae	*Isurus oxyrinchus* ($n = 1414$)	35·6	
				Isurus paucus ($n = 168$)	30·7	
				Lamna nasus ($n = 10$)	30·0	
			Triakidae	*Galeorhinus galeus* ($n = 25$)	0	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
			Carcharhinidae	*Carcharhinus altimus* (*n* = 11)	60·0	
				Carcharhinus falciformis (*n* = 310)	55·8	
				Carcharhinus longimanus (*n* = 281)	34·2	
				Galeocerdo cuvier (*n* = 36)	2·9	
				Prionace glauca (*n* = 30 168)	14·3	
			Sphyrnidae	*Sphyrna lewini* (*n* = 21)	57·1	Whilst no AVM was observed for *S. mokarran*, this was based on a small sample size
				Sphyrna mokarran (*n* = 3)	(0)	
				Sphyrna zygaena (*n* = 372)	71	
			Dasyatidae	*Pteroplatytrygon violacea* (*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
NW Atlantic Ocean; Grand Banks (Epperly *et al.*, 2012)						
Pelagic longline	AVM	Observers recorded condition of fish brought aboard 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)	Lamnidae	*Isurus oxyrinchus* (*n* = 543)	21·3–26·5	AVM of *I. oxyrinchus* was 26·5% (9/0 J-hook), falling to 21·3 and 23·7% for 18/0 circle hooks with no and 10° offset, respectively. AVM of *L. nasus* was similar (29·5–31·6%) for all hook types
				Lamna nasus (*n* = 866)	29·5–31·6	
			Carcharhinidae	*Prionace glauca* (*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

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NW Atlantic Ocean (Serafy *et al.*, 2012)						
Pelagic longline	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	*Prionace glauca* ($n = 10977$)	10–11	AVM did not change between the two periods
				Carcharhinus falciformis ($n = 2071$)	44–59	AVM decreased from 59 to 44% after the introduction of circle hook regulations
Tropical NE Atlantic Ocean (Fernandez-Carvalho *et al.*, 2015)						
Pelagic longline	AVM	Fate recorded for sharks taken on different hook types (J, circle and offset circle hooks) and baits (squid and mackerel)	Pseudocarchariidae	*Pseudocarcharias kamoharai* ($n = 664$)	4·7–9·1	AVM = 4·7% (J-hooks, $n = 190$), 8·1% (circle hooks, $n = 211$) and 9·1% (offset circle hooks, $n = 263$)
			Alopiidae	*Alopias superciliosus* ($n = 815$)	49·6–58·5	AVM = 49·6% (offset circle hooks, $n = 248$) and 49·8% (J-hooks, $n = 295$), but 58·5% with circle hooks ($n = 272$)
			Carcharhinidae	*Carcharhinus longimanus* ($n = 152$)	11·1–28·4	AVM = 28·4% (offset circle hooks, $n = 81$) and 22·7% (J-hooks, $n = 44$), but 11·1% with circle hooks ($n = 27$)
			Sphyrnidae	*Sphyrna zygaena* ($n = 203$)	62·0–62·9	AVM was higher for this species (62·0–62·9% for the three hook types)
SW Atlantic Ocean; Brazil (Afonso & Hazin, 2014)						
Demersal longline (scientific) with 14–15 h soak time	PRM	Satellite tags used to evaluate PRM; dead specimens landed	Carcharhinidae	*Galeocerdo cuvier*	–	AVM not reported. Healthy specimens released with satellite tags. Data available for 19 specimens, no PVM reported. Sharks handled with a higher degree of care than would be expected in commercial fisheries

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NW Atlantic Ocean (Gallagher *et al.*, 2014*a*)						
Pelagic longline (targeting tuna or swordfish)	AVM	AVM data collected by observers (1995–2012). Data used for fish classed as alive and dead (those reported as damaged were excluded from analysis). Mean survival given for tuna and swordfish longline fisheries	Alopiidae	*Alopias superciliosus* (*n* = 367)	51·7	
			Lamnidae	*Isurus oxyrinchus* (*n* = 2126)	28·6	
				Isurus paucus (*n* = 139)	51·1	
				Lamna nasus (*n* = 255)	21·4	
			Carcharhinidae	*Carcharhinus falciformis* (*n* = 1090)	42·2	
				Carcharhinus longimanus (*n* = 213)	25·7	
				Carcharhinus obscurus (*n* = 274)	27·9	
				Carcharhinus plumbeus (*n* = 189)	26·7	
				Carcharhinus signatus (*n* = 1141)	67	
				Galeocerdo cuvier (*n* = 1348)	3·2	
				Prionace glauca (*n* = 17 780)	15·1	
			Sphyrnidae	*Sphyrna lewini* (*n* = 727)	54·1	
NW Atlantic Ocean; Florida (Gallagher *et al.*, 2014*b*)						
Experimental drumline, (soak time of 1 h, circle hooks)	PRM and blood sampling	Satellite tags used to examine PRM Blood chemistry examined	Carcharhinidae	*Carcharhinus leucas* (*n* = 27) *Galeocerdo cuvier* (*n* = 28)	–	Based on data from satellite tags, 26% of *C. leucas* (and no *G. cuvier*) were thought to have died within 2 weeks of release
			Sphyrnidae	*Sphyrna mokarran* (*n* = 28)	–	Based on data from satellite tags, 43% were thought to have died within 2 weeks of release
NW Atlantic Ocean; Bahamas (Brooks *et al.*, 2015)						
Demersal longline survey (10/0 to 16/0 hooks; 472–1024 m water depth; 4 h soak time)	AVM	AVM reported for scientific fishing	Hexanchidae	*Hexanchus griseus* (*n* = 8)	0	Specimens caught at depths of 504–791 m

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
				Hexanchus nakamurai (*n* = 14)	7·1	
			Centrophoridae	*Centrophorus* sp. (*n* = 51)	29·4	Specimens caught at depths of 580–830 m
			Somniosidae	*Centroscymnus owstoni* (*n* = 5)	80	Specimens caught at depths of 841–1024 m
			Squalidae	*Squalus cubensis* (*n* = 55)	9·1	Specimens caught at depths of 472–730 m
			Scyliorhinidae	*Galeus springeri* (*n* = 3)	66·7	Specimens caught at depths of 630–807 m
			Pseudotriakidae	*Pseudotriakis microdon* (*n* = 1)	–	No AVM, but based on a single specimen caught at 790 m depth
			Triakidae	*Mustelus canis* (*n* = 7)	0	Specimens caught at depths of 504–651 m
Australia; New South Wales (Butcher *et al.*, 2015)						
Demersal longline with nylon trace and 16/0 non-offset circle hook (water depths 50–100 m; 7–14 h soak times; hook timers used)	AVM and blood sampling	Survival and condition examined in relation to hooking time. Blood samples also collected	Orectolobidae	*Orectolobus halei* (*n* = 3)	0	No AVM for soak times up to 14 h
				Orectolobus maculatus (*n* = 10)	0	
				Orectolobus ornatus (*n* = 5)	0	
			Odontaspididae	*Carcharias taurus* (*n* = 12)	0	No AVM for soak times up to 14 h
			Triakidae	*Mustelus antarcticus* (*n* = 22)	20–25	AVM for soak times up to 14 h
			Carcharhinidae	*Carcharhinus brachyurus* (*n* = 6)	(66·7)	Higher estimates of AVM for 14 h soak times, lower estimates for 7 h soak times
				Carcharhinus brevipinna (*n* = 50)	94·4–96·9	
				Carcharhinus leucas (*n* = 1)	(0)	
				Carcharhinus limbatus (*n* = 113)	86–95·5	
				Carcharhinus obscurus (*n* = 74)	53·3–79·5	
				Carcharhinus plumbeus (*n* = 160)	43–62·7	
				Galeocerdo cuvier (*n* = 123)	4·3–6·6	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
			Sphyrnidae	*Sphyrna lewini* ($n = 52$)	87·5–90·1	Higher AVM with longer soak time
				Sphyrna.zygaena ($n = 2$)	(100)	
				Sphyrna mokarran ($n = 11$)	100	
			Rhinidae	*Rhynchobatus australiae* ($n = 8$)	0–25	AVM increased from 0% (7 h) to 25% (14 h)
			Rhinobatidae	*Aptychotrema rostrata* ($n = 2$)	(0)	No AVM recorded
			Dasyatidae	*Dasyatis brevicaudata* ($n = 18$)	0	No AVM recorded
Pacific Ocean; Palau (Gilman *et al.*, 2015)						
Pelagic longline fishery for tuna	AVM	AVM data collected by observers	Squatinidae	*Squatina tergocellatoides* ($n = 1$)	(0)	Sample size limited
			Pseudocarchariidae	*Pseudocarcharias kamoharai* ($n = 2$)	(0)	Sample size limited
			Alopiidae	*Alopias superciliosus* ($n = 41$)	34·2	
				Alopias vulpinus ($n = 16$)	18·75	
				Alopias pelagicus ($n = 22$)	36·4	
			Lamnidae	*Isurus oxyrinchus* ($n = 19$)	5·3	
				Isurus paucus ($n = 10$)	40·0	
			Carcharhinidae	*Carcharhinus altimus* ($n = 2$)	(0)	Data available for nine carcharhinid sharks, but data limited for most species
				Carcharhinus brachyurus ($n = 10$)	0	
				Carcharhinus falciformis ($n = 368$)	29·1	
				Carcharhinus galapagensis ($n = 1$)	(0)	
				Carcharhinus longimanus ($n = 4$)	(0)	
				Carcharhinus melanopterus ($n = 5$)	(0)	
				Carcharhinus plumbeus ($n = 6$)	(50)	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
				Galeocerdo cuvier ($n = 8$)	(0)	
				Prionace glauca ($n = 215$)	15·35	
			Sphyrnidae	*Sphyrna mokarran* ($n = 1$) and *S. lewini* ($n = 1$)	(100)	Data limited, but AVM = 100%
			Dasyatidae	*Pteroplatytrygon violacea* ($n = 372$)	29·1	
			Mobulidae	*Mobula japanica* ($n = 1$)	(0)	Data limited, but no AVM recorded
NE Atlantic Ocean and Gulf of Mexico; North Carolina to Louisiana (Gulak *et al.*, 2015)						
Bottom longlines deployed from chartered fishing vessels (soak times of 1·5–22·6 h; 16/0, 18/0, 20/0 circle hooks and 12/0 J hooks)	AVM	AVM data recorded; hook timers deployed	Ginglymostomidae	*Ginglymostoma cirratum* ($n = 311$)	0·3	
			Odontaspididae	*Carcharias taurus* ($n = 13$)	0·0	
			Carcharhinidae	*Carcharhinus acronotus* ($n = 110$)	66·4	
				Carcharhinus brevipinna ($n = 32$)	81·3	
				Carcharhinus falciformis ($n = 35$)	57·1	
				Carcharhinus leucas ($n = 122$)	2·5	
				Carcharhinus limbatus ($n = 902$)	70·8	
				Carcharhinus obscurus ($n = 104$)	70·2	
				Carcharhinus plumbeus ($n = 933$)	16·9	
				Galeocerdo cuvier ($n = 270$)	8·9	
				Negaprion brevirostris ($n = 24$)	4·2	
				Rhizoprionodon terraenovae ($n = 902$)	89·4	
			Sphyrnidae	*Sphyrna lewini* ($n = 175$)	62·9	
				Sphyrna mokarran ($n = 75$)	56	

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
NW Atlantic Ocean (Marshall *et al.*, 2015)						
Demersal longline deployed from research vessel (18/0 circle hooks with 10° offset; soak times of 0·5–12·5 h)	AVM and PRM	AVM data recorded (alive, dead, moribund). PSATs deployed to estimate PRM	Carcharhinidae	*Carcharhinus obscurus* ($n = 50$)	22	A further 18% of specimens were moribund. PRM estimated at 28·6% from PSAT data ($n = 21$)
				Carcharhinus plumbeus ($n = 119$)	5	A further 2% of specimens were moribund. PRM estimated at 20% from PSAT data ($n = 10$)
SW Atlantic; Uruguay (Mas *et al.*, 2015)						
Pelagic longline fishery targeting tuna, swordfish and blue shark	AVM		Mobulidae	Mobulidae ($n = 191$ with fate information, 10 lost during hauling)	5·2	Of those specimens identified to species, most were *Mobula japanica* or *M. thurstoni*
NW Atlantic Ocean (Campana *et al.*, 2016)						
Commercial pelagic longline targeting swordfish and tuna	AVM and PRM	Fish condition (healthy, injured, dead, unknown) scored at unhooking; PRM studied using pop-up satellite archival tags	Lamnidae	*Isurus oxyrinchus* [$n = 520$ (vitality) and $n = 26$ (PSATs)]	26·2	Specimens of 80–229 cm 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
				Lamna nasus [$n = 683$ (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	*Prionace glauca* [$n = 15\,592$ (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%

Table II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
Purse seine fisheries						
NW Atlantic Ocean: Gulf of Mexico (De Silva *et al.*, 2001)						
Commercial purse seine targeting gulf menhaden *Brevoortia patronus*	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 *Carcharhinus limbatus*, *C. brevipinna*, *C. obscurus*, *C. leucas*, *C. falciformis*, *C. plumbeus*, *C. isodon*, *C. acronotus* and *Rhizoprionodon terraenovae* (Carcharhinidae). A small number of *Sphyrna tiburo* also caught	–	Most fish were dead and either discarded ($n = 50$) or retained on board ($n = 24$). Some live fish were released in either a disorientated ($n = 12$) or healthy ($n = 8$) condition. Fate of six unknown
West-central Indian Ocean and East-central Atlantic Ocean (Capietto *et al.*, 2014)						
Tuna purse seine fishery	AVM	Analyses of observer data (where fate recorded)	Rhincodontidae	*Rhincodon typus*	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%)
Indian Ocean (Poisson *et al.*, 2014*a*)						
Tuna purse seine fishery	AVM and PRM	Health state of sharks recorded (four-point scale); selected sharks tagged with PSATs and released	Carcharhinidae	*Carcharhinus falciformis* ($n = 202$)	69	AVM = 69% (but lower for the small number that were entangled in the meshes compared to those that were brailed). 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 (25·85) tags did not give conclusive results. Overall mortality estimated at 81%

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
West-central Pacific Ocean (Hutchinson *et al.*, 2015)						
Tuna purse seine fishery	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	*Carcharhinus falciformis* ($n = 295$ 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%
Eastern Pacific Ocean (Eddy *et al.*, 2016)						
Tuna purse seine fishery. Work undertaken on commercial fishing vessel, fishing operations of 1–2 h and catch brailed on board	AVM and PRM	Vitality (1–5 scale) and AVM data recorded; PRM assessed with PSATs	Lamnidae	*Isurus oxyrinchus* ($n = 1$)	–	Single fish in moderate condition
			Carcharhinidae	*Carcharhinus falciformis* ($n = 53$)	58·5	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
			Sphyrnidae	*Sphyrna* 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
New Zealand (Francis & Jones, 2016)						
Commercial purse seine fishery for skipjack tuna	PRM	Pop-up archival transmitting tags attached to commercially caught fish	Mobulidae	*Mobula japanica* ($n = 9$)	–	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.

TABLE II. Continued

Fishery	Approach	Details	Family	Species	AVM (%)	Key findings
Recreational fisheries						
Bahamas (Danylchuk *et al.*, 2014)						
Recreational gears	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 min	Carcharhinidae	*Negaprion brevirostris* ($n = 32$)	–	Post-release mortality (monitored for 0·25 h post-release) of 12·5%
SE Australia (French *et al.*, 2015)						
Recreational gears (either circle or J-hooks; fight times of 1–513 min, but most samples were for fight times ≤1 h)	AVM and PRM	Catch condition recorded, and survivorship pop-up archival transmitting (sPAT) tags deployed	Lamnidae	*Isurus oxyrinchus*	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%
California (Sepulveda *et al.*, 2015)						
Recreational gears	AVM and PRM	Satellite tagging of sharks that were hooked by the mouth ($n = 7$) or caudal fin ($n = 9$)	Alopiidae	*Alopias vulpinus*	0	Specimens hooked by the mouth (125–187 cm L_F; fight time = 9–25 min) all survived release. Nearly 78% of specimens hooked by the caudal fin (111–175 cm L_F; fight time = 10–25 min) died

L_F, fork length; PRM, post-release mortality; PSAT, pop-up satellite archival tag.

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, catch composition and mass, 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, 2007*a*, *b*). Rodríguez-Cabello *et al.* (2005) examined the survival of *S. canicula* caught in a Spanish baca type otter 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 20–60 min (research vessel) and 20–85 min (commercial vessel). The mean survival rates from research surveys and commercial trawlers were 90 and 78% respectively.

Skates (Arhynchobatidae) are a by-catch in the Falkland Island trawl fishery targeting squid and Laptikhovsky (2004) 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.*, 2010*a*).

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 by-catch 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 sharks *Sphyrna lewini* (Griffith & Smith 1834).

Although there has been extensive work on by-catch mitigation for some species taken incidentally in trawls (*e.g.* sea turtles), there has been less work undertaken on reducing by-catch or improving survivorship of elasmobranchs (Griffiths *et al.*, 2006). Indeed, many studies on the efficacy of grids and other by-catch 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 by-catch 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 (TED) and by-catch reduction devices (BRD). This study reported that nets with TEDs or combined TED–BRDs successfully reduced shark and ray by-catch, 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 by-catch 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 by-catch 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 codend (Chosid *et al.*, 2012). The 50 mm bar spacing used in this study allowed commercial quantities of the target species still to be caught, but 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 batoid mortality can be influenced by the mass 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 codend 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, but Enever *et al.* (2010) indicated that changing from 80 mm diamond to 100 mm square mesh in the codend 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 fishes, in this instance anglerfish *Lophius* spp. and so such measures are not always be popular with the fishing industry.

Whilst several studies have examined the AVM and short-terms survival of trawl-caught elasmobranchs, most studies have presumably focused on those specimens that have been retained in the codend 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 with those that have passed to the codend 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 5 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; 7·4–9·3 km h^{-1} (4–5 knots) trawl speed; waters of 60–80 m depth].

Skates may also be an occasional by-catch in dredge fisheries for scallops. For example, *L. naevus* is a frequent by-catch species in European dredge fisheries for scallop *Pecten maximus* and queen scallop *Aequipecten opercularis*, with a high proportion of these immature (Craven *et al.*, 2013). Whilst discard survival information is not available for northern European dredge fisheries, there are some data from elsewhere in the world. Benoît *et al.* (2010*b*) 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 by-catch 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 fishes 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 fishes, emphasizing the greater physiological effect 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 & 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

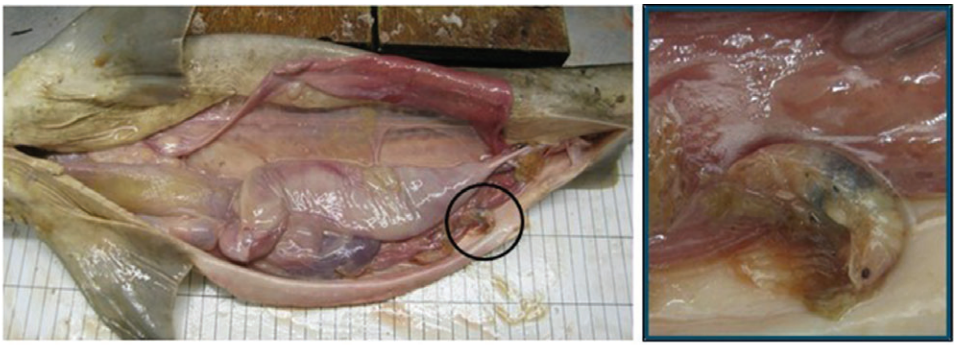

FIG. 1. Gillnet-caught *Squalus acanthias* in which the internal organs have been partially eaten by scavenging isopods (inset).

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 by-catch 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 fishes 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 *Isurus* spp. and 98% in *Sphyrna* spp.).

Potential by-catch mitigation measures in gillnet fisheries could include spatial and 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). There have been few such studies to date, however, 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 by-catch and 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* L. 1758. The lower height of the tie-down gillnet reduced the catch of *S. acanthias*, but the catch of skates increased four-fold and catches of *G. morhua* also decreased.

Whilst a proportion of fishes can survive capture and release from gillnets, some individuals escaping from such gears may retain monofilament around parts of the body (Schwartz, 1984; Seitz & 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 fishes 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* (L. 1758), *Lophius* spp. and skates taken in gillnets in the Georges

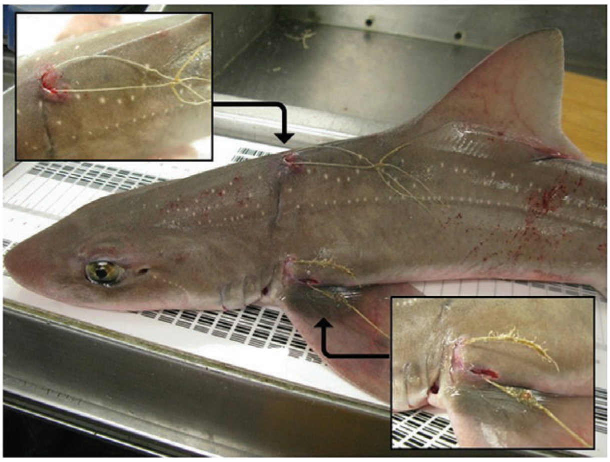

FIG. 2. Trawl-caught *Mustelus asterias* showing evidence of prior capture by gillnet.

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 *Tursiops tursiops*. 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 by-catch 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, Megalofonou *et al.* (2005) reported the health state for sharks caught in *X. gladius* and *Thunnus* spp. 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 *X. gladius* longline fisheries (82–97%) than in longline fisheries targeting albacore *Thunnus alalunga* (Bonnaterre 1788) (69%). Diaz & Serafy (2005) reported that *c.* 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 4·0–5·7% mortality reported (Walsh *et al.*, 2009). In contrast, Campana *et al.* (2009*a*) 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 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.*, 2010*a*), with >80% categorized as in 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*, although these fisheries no longer operate given the E.U. zero TAC currently in place for these species. Currently, most of the longline effort conducted by the U.K. 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.*, 2008*b*). 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* (L. 1758)]. Soak times in this fishery are normally 2–4 h and most fishes are lively and unwanted elasmobranchs can be returned to the sea (Ellis *et al.*, 2008*b*). In other areas, longlines may be set overnight (24 h soak time) and whereas the elasmobranchs caught are also generally lively, these fishes 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 & Agnew (2004) examined the survival of skates taken as a by-catch in the South Georgia toothfish fishery, with longlines fished at 746–1913 m depth. 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.

By-catch 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 by-catch, 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

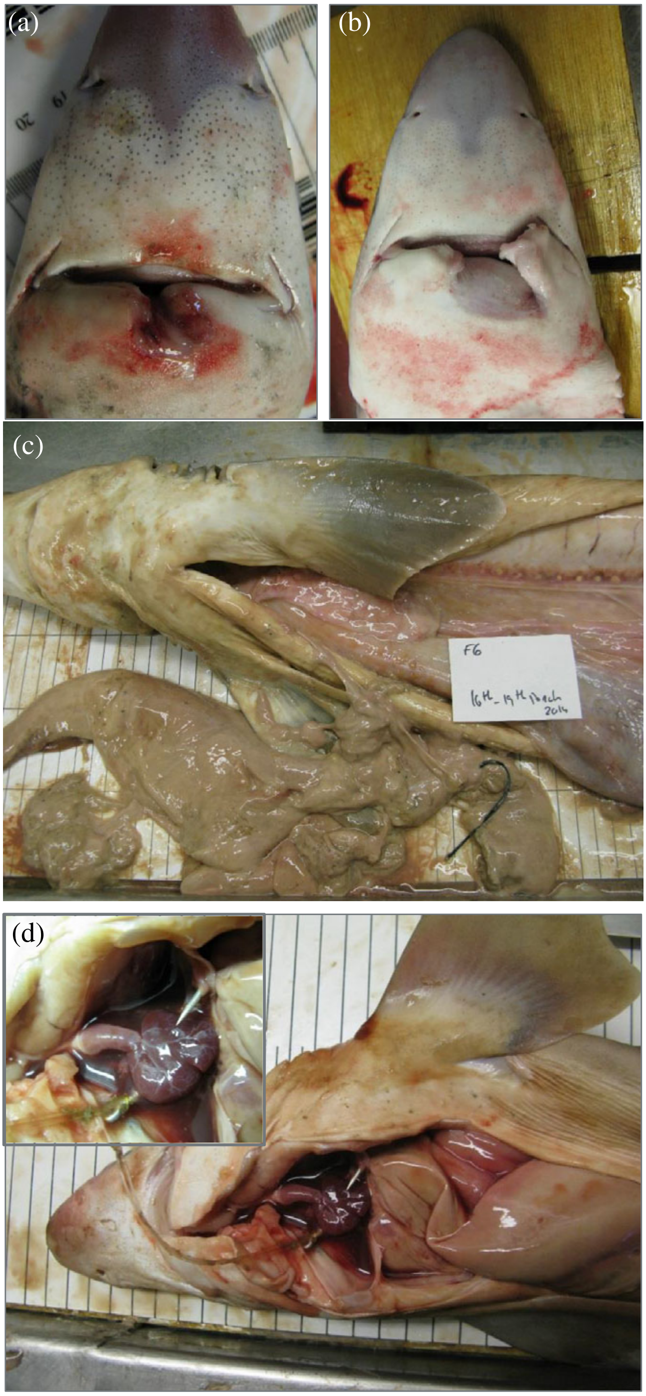

FIG. 3. Trawl or gillnet-caught *Squalus acanthias* showing evidence of prior capture by longline (a) and (b) showing various stages of healing of jaws; (c) hook in body cavity (N.B. the poor state of the liver may be an artefact of freezing and thawing); (d) hook that has penetrated into the pericardial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

mortality of sharks with different longline configurations have indicated circle hooks may not have such a great benefit (Yokota *et al.*, 2006; Afonso *et al.*, 2012; Amorim *et al.*, 2015). 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 rather 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. It cannot be assumed, however, 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 *S. tiburo* were caught after sunrise and suggested that setting lines only during the night could potentially reduce by-catch of this group. Determining the utility and efficacy of mitigation measures for any longline fishery clearly requires detailed investigations as to the likely effects 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 prey on, or aggregate with, schooling teleosts; consequently, there is often a shark by-catch associated with fisheries for small pelagic fishes. 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 by-catch in purse-seine fisheries for tuna reported AVM of 58·5–69·0% and, when considering post-release mortality through studies with PSATs, estimated overall mortality rates of 81–89% (Poisson *et al.*, 2014*a*; 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 mass 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 fishes (including free-swimming *C. falciformis* within the purse seine prior to brailing), with these fishes generally surviving capture and release (Filmalter *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 by-catch mitigation (Poisson *et al.*, 2014*b*).

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 by-catch. 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 by-catch of sharks [including great hammerhead *Sphyrna mokarran* (Rüppell 1837), smooth hammerhead *Sphyrna zygaena* (L. 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 summarized preliminary findings from incorporating an escape tunnel along the bottom of the trawl, which was suggested to have reduced elasmobranch by-catch.

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 fare better than obligate ram-ventilators.

The potential effect of recreational fisheries on coastal elasmobranchs that are considered endangered has attracted some attention (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 and 1·5–7 min, respectively (total duration of event 4–11·5 min). One individual was thought to have died within an hour of release, but the remaining nine sharks were tracked for periods of 0·85–5·90 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 s) and visually tracked these individuals for 15 min 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

Elasmobranchs display a broad diversity in size, shape and skin structure, as well as their habitats (*e.g.* demersal, pelagic and 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.*, 2005). 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 Ocean have shown low AVM for trawl and line-caught *S. acanthias*, with 6–29% mortality over the short term (Mandelman & Farrington, 2007*a*, *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 *c.* 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 by-catch in existing deep-water commercial fisheries are currently lacking.

PRISTIOPHORIFORMES

Sawsharks occur in the Indo-Pacific and parts of the Atlantic Oceans, but not in the north-east Atlantic Ocean. 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 by-catch 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 by-catch in protective nets and *c.* 15% are recovered dead (Reid & Krogh, 1992). Nurse shark *Ginglymostoma cirratum* (Bonnaterre 1788) is an occasional by-catch 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 Odontaspididae, 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 by-catch 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 by-catch in European trawl and set-net fisheries, but data are available for European longline fisheries (Megalofonou *et al.*, 2005). In general, *Alopias* spp. exhibit a relatively high mortality, with *c.* 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 a 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; Coelho *et al.*, 2011, 2012; Bromhead *et al.*, 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 by-catch in some gillnet fisheries and as an incidental catch in trawl fisheries. *Carcharadon carcharias* and *I. oxyrinchus* have been shown to exhibit 44·0 and 37·5–75·0% AVM in gillnet fisheries, respectively (Walker *et al.*, 2005; Braccini *et al.*, 2012; Lyons *et al.*, 2013). Within European waters, *L. nasus* taken as a by-catch in bottom-set gillnets in the Celtic Sea have shown 80% AVM (Bendall *et al.*, 2012). Given the occasional (or seasonal) nature of such by-catch, 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 & Krogh, 1992).

More data are available for longline fisheries, especially with regard to *I. oxyrinchus* and *L. nasus*. Reported AVM of the former may be as low as *c.* 5–30% (Megalofonou *et al.*, 2005; Epperly *et al.*, 2012; Gallagher *et al.*, 2014*a*; Campana *et al.*, 2016;

Gilman *et al.*, 2015), 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.*, 2014*a*; 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 SCYLIORHINIDAE

Catsharks are a frequent by-catch 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 to 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 to 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 with 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.* (2010*a*). Lower AVM, of up to 25%, has been reported for various triakids captured by longline (Frick *et al.*, 2010*a*; Coelho *et al.*, 2012; Brooks *et al.*, 2015; Butcher *et al.*, 2015), but these data are either based on small sample sizes 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 (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.*, 2014*a*; Butcher *et al.*, 2015; Gulak *et al.*, 2015), with high post-release survival also reported (Afonso & Hazin, 2014; Gallagher *et al.*, 2014*b*).

Similarly, *P. glauca*, which is a frequent by-catch of pelagic longline fisheries and one of the most studied pelagic sharks, typically exhibits an AVM of <25% (Boggs, 1992; Beerkircher *et al.*, 2004; Megalofonou *et al.*, 2005; Moyes *et al.*, 2006; Campana *et al.*, 2009*a*, *b*, 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.*, 2014*a*; Gilman *et al.*, 2015). There is, however, some post-release mortality (Campana *et al.*, 2016) and some other field studies (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, 1992; Beerkircher *et al.*, 2004; Bromhead *et al.*, 2012; Coelho *et al.*, 2012; Gallagher *et al.*, 2014*a*; Fernandez-Carvalho *et al.*, 2015), with those studies reporting either a higher or lower AVM (Poisson *et al.*, 2010; Musyl *et al.*, 2011; 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 to 81% in the former and typically 42 to 75% in the latter (Beerkircher *et al.*, 2004; Coelho *et al.*, 2011, 2012; Serafy *et al.*, 2012; Gallagher *et al.*, 2014*a*). Interestingly, two studies have reported AVM of *C. falciformis* when caught by longline to be <30% (Musyl *et al.*, 2011; Gilman *et al.*, 2015). *Carcharhinus falciformis* is also by-catch in purse-seine fisheries, where AVM and PRM can result in >80% total mortality (Poisson *et al.*, 2014*a*; 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 effects 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 [*e.g.* 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 & Krogh, 1992).

CARCHARHINIFORMES: FAMILY SPHYRNIDAE

Hammerhead sharks *Sphyrna* spp. appear to be particularly vulnerable to the effects of capture in commercial gears. High AVM for *Sphyrna* spp. has been reported in trawls (97·6%; Fennessy, 1994), protective nets (98·3%; Reid & Krogh, 1992) and commercial gillnets (71·5–89·3%; Thorpe & Frierson, 2009; Braccini *et al.*, 2012).

Even capture in gillnets set for short periods (≤1 h) during scientific studies can result in an AVM of 31–37% (Manire *et al.*, 2001; Hueter *et al.*, 2006). Furthermore, estimates of overall mortality in the latter study, using mark–recapture data from fishes at different categories of vitality, suggested mortality of 62%. Within commercial longline fisheries, although some studies have indicated AVM of 54–71% (Beerkircher *et al.*, 2004; Coelho *et al.*, 2012; Gallagher *et al.*, 2014*a*; Fernandez-Carvalho *et al.*, 2015), higher estimates (AVM = 70–90% or more) have also been reported widely (Morgan & Burgess, 2007; Coelho *et al.*, 2011; Bromhead *et al.*, 2012; Butcher *et al.*, 2015). Afonso *et al.* (2011) noted a higher mortality when *Sphyrna* spp. were caught by J-hooks in comparison with circle hooks, but this was based on a low sample size. There have been fewer studies on PRM of *Sphyrna* spp. Gallagher *et al.* (2014*b*) noted that 43% of *S. mokarran* tagged were thought to have died within 2 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 by-catch 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 to 25%, depending on the time they were hooked for (Butcher *et al.*, 2015).

TORPEDINIFORMES

Electric rays are an occasional by-catch 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 by-catch, 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.*, 2008*b*) and similarly low rates of AVM also reported for some other fisheries (Mandelman *et al.*, 2012; Lyle *et al.*, 2014; Saygu & Deval, 2014). AVM is higher on more offshore grounds where tow durations and soak times are greater (Bendall *et al.*, 2012), but there is less information from fisheries that catch skates from deeper water (Endicott & Agnew, 2004; Laptikhovsky, 2004).

Studies using on-board survival tanks have shown survival of *c.* 40–72% over various time periods, typically over 2–5 days (Kaiser & Spencer, 1995; Laptikhovsky, 2004; Enever *et al.*, 2009, 2010; Benoît *et al.*, 2010*a*; Depestele *et al.*, 2014), but some of these studies have combined data across the species-complex taken in the fishery and it should be recognized that there may be important species-specific differences in survival (Mandelman *et al.*, 2012). 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 by-catch 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 to 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 by-catch 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.*, 2015), 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 to 46% (prawn trawl; Fennessy, 1994; Stobutzki *et al.*, 2002).

Eagle rays (Myliobatidae) are only an infrequent by-catch 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 by-catch in various pelagic fisheries in tropical and sub-tropical waters. Reported AVM ranges from *c.* 1·4 to 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.*, 2016) 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 elasmobranchs in recent decades and consequently there has been a notable increase in discard survival studies over the past 10 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 co-ordination to collect standardized data on AVM for other fisheries could usefully be considered.

The various studies that have collected data on the vitality of fishes after capture have used a range of scales, ranging from five-point scales to a simpler binary (live or dead) scoring system. Those studies using three to five-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 (Rodríguez-Cabello *et al.*, 2005; Mandelman & Farrington, 2007*b*; Lyle *et al.*, 2014), or from using electronic tags (Gallagher *et al.*, 2014*b*; 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 co-ordination 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 prioritization 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 species that are prohibited or not to be retained; discarding of unmarketable by-catch species, especially if the discarded species are considered vulnerable taxa; 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); 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 fishes and shellfish, specific analyses for elasmobranchs (and other vulnerable taxa) should be considered.

Within European waters, several elasmobranch stocks, including rajiforms and *S. acanthias*, will potentially be included within the landing obligation, unless there is an appropriate body of scientific evidence to demonstrate high survival. In relation to *S. acanthias*, 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 (Mandelman & Farrington, 2007*a*, *b*; Rulifson, 2007; Braccini *et al.*, 2012; Lyle *et al.*, 2014), but these studies will not reflect the range of fishing operations catching *S. acanthias* in European seas.

There have been several studies examining discard survival of skates, both in European seas (Kaiser & Spencer, 1995; Ellis *et al.*, 2008*b*; Enever *et al.*, 2009, 2010; Bendall *et al.*, 2012; Depestele *et al.*, 2014) and elsewhere (Fennessy, 1994; Endicott & Agnew, 2004; Laptikhovsky, 2004; Benoît *et al.*, 2010*a*, *b*, 2012; Mandelman *et al.*, 2012; 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 fishes, whether through spatial management (*e.g.* closures or gear restrictions in nursery grounds) or through a minimum landing size. Additionally, smaller fishes are often of lower market value and so may be more likely to be discarded by fishers. Some studies have confirmed that smaller fishes may display higher capture mortality (Diaz & Serafy, 2005; Ellis *et al.*, 2008*b*) and smaller individuals are intuitively more likely to be preyed 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 by-catch of juveniles.

Several studies have indicated that females of some elasmobranch species may survive better than males (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 (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 maximize 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 are listed as species that should not be retained in some fisheries. Studies to date have generally indicated that AVM and 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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