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7 Explanatory variables

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The fish capture processes can disturb, stress, and damage an organism which can result in its death. Thereby, any mortality of discards may be influenced by a range of biological (e.g. species, physiology, size, and catch composition), technical (e.g. gear design, deployment duration and speed), and environmental (e.g. temperature, hypoxia, sea state, and availability of light) stressor factors (Figure 2.1; Davis, 2002; Broadhurst *et al.*, 2006; Broadhurst and Uhlmann, 2007). In other words, these factors determine conditions during fishing and influence/affect the stress, injury, and possibly survival of captured and discarded individuals (Davis, 2002). Mortality associated with capture can occur prior to the point of discarding (immediate discard mortality; Braccini *et al.*, 2012) or after the point at which the subject is discarded (delayed discard mortality).

When designing experiments to estimate discard survival, it is important to measure the main factors influencing the stress, injury, and ultimately survival of discards in order to attribute sources of variability. Some of the relevant technical, environmental, and biological variables can be identified by conceptually tracing an organism's pathway from capture, to handling above the water surface, and to the release overboard and, eventual return to its habitat, (path analysis, Figure 2.1). This will include variables which describe an organism's sensitivity to capture and handling, since the ability of an organism to survive the capture and discard pathway will be dependent on its innate capability to tolerate changes in conditions (Davis, 2002; Broadhurst *et al.*, 2006). Individuals which may be able to tolerate certain changes, could be "pushed over the edge" through a combination of stressors. It is also relevant to consider potential stressors caused by the experimental method that was chosen to assess discard mortality. The *a priori* choice of potential and quantifiable explanatory factors will benefit from an organism's "path analysis" (Figure 2.1), and the drafting of data recording sheets (Annex 5). The latter step will assist the process of "thinking through" all relevant stages of data collection, its replicability, and feasibility under experimental conditions. The following section (i) conceptualizes key stressors potentially affecting a captured-and-discarded animal and (ii) reviews the primary literature of experiments that have demonstrated predominant effects.

7.1 Stressor

A stressor can be defined as a factor which induces a stress response. Isolating a single stressor variable is difficult, particularly in field environments, due to the need to control for effects caused by all other variables. Laboratory experiments may be useful for this aim (Section 9; Kennelly *et al.*, 1990; Uhlmann *et al.*, 2009).

There is an array of different stressors experienced by a discarded fish, and these will compound with each other. The compounded effects can lead to the death of the subject. However, the way in which the stressors interact may not be simply additive or multiplicative, but rather synergistic or antagonistic. Unravelling the precise individual and combined influences of multiple stressors is challenging, but as long as survival estimates are based on a range of stressors that reflect the fishery, they can be considered representative. Monitoring the different stressors is therefore essential to determine the representativeness of the discard survival estimates, but they can also be used to inform on potential mitigation measures that may increase survival. The first step in a framework to assess, and potentially mitigate discard

Table 7.1. Count of primary literature (n = number of reviewed studies per gear type) that demonstrated significant effects associated with discard mortality of technical, environmental, and biological factors during demersal trawling and dredging, gillnetting and trapping, hook and line fishing, longlining and jigging, and pelagic purse-seining. The factors are sorted by relevance in descending order.

Effect	Demersal trawls and dredges ($n^1 = 60$)	Gillnets and traps ($n^2 = 85$)	Hook and lines ($n^3 = 102$	Longlines and jigging ($n^4 = 22$)	Purse-seines ($n^5 = 6$)	Count	ns
Gear configuration	1	40	29	20	-	69	21
Handling	8	8	29	6	-	45	6
Deployment duration	17	8	13	9	-	36	11
Body size	10	10	15	12	2	35	14
Water temperature	11	4	22	7	1	35	10
Air exposure	23	5	12	-	-	34	6
Injury	8	9	13	-	3	30	3
Depth	1	6	9	4	-	17	3
Air temperature	14	1	-	1	-	15	1
Gear operation	-	1	6	-	7	13	1
Gear type	-	5	12	-	-	11	6
Physical condition	2	2	3	-	4	10	1
Season	4	3	3	1	-	9	2
Catch volume	8	-	-	-	1	8	1
Depredation	-	10	-	-	-	8	2
Predation	4	-	1	-	1	6	0
Crowding Density	-	-	-	-	4	4	0
Sex	4	1	-	2	1	4	4
Behaviour	1	2	-	-	-	3	0
Dissolved oxygen	-	1	2	-	-	3	0
Light	2	1	-	-	1	3	1
Catch composition	-	1	-	-	1	2	0
Infection	-	2	-	-	-	2	0
Location	-	1	-	1	-	2	0
Catch density	-	1	-	-	-	1	0
Recapture	-	-	1	-	-	1	0
Salinity	1	-	-	-	-	1	0
Sediment type	1	-	-	-	-	1	0
Species	-	1	-	-	-	1	0
Stress	1	1	-	-	-	1	1
Weather	-	-	1	1	-	1	1
Year	-	1	-	-	-	1	0

. - = not available; ns = not significant; [1] Broadhurst *et al*. (2006); Revill *et al*. (2013); Suuronen and Erickson (2010); [2] Uhlmann and Broadhurst (2015); [3]Arlinghaus *et al*. (2007) (pp. 115–125); Bartholomew and Bohnsack (2005) (pp. 134–136): [4] Web of Science search; [5] Hall and Roman (2013); Marçalo *et al*. (2008, 2010, 2013); Huse and Vold (2010); Tenningen *et al*. (2012); Olsen *et al*. (2012).

mortality, is to describe in detail for the particular fishery and discarded species of interest the pertinent ranges of technical, environmental, and biological conditions and characteristics.

7.2 Literature review identifying key explanatory variables

As part of the development of this guidance, known literature were searched and reviewed to identify explanatory variables that have been linked with a measurable stress, injury, or death of discarded animals. The output from this rapid review is categorized by conventional gear types: (i) trawls and dredges; (ii) gillnets and traps; (iii) hook and line; (iv) longlines and jigging, or (v) pelagic seines and trawls. For each of these gear groups both marine and freshwater fisheries were scanned for cases where a stressor effect was demonstrated or not detected. Primary literature studies for each demonstrable effect indicated their potential relevance across or within gear groups (Table 7.1). For trawls and dredges, existing reviews by Broadhurst *et al.* (2006), Revill *et al.* (2013), and Suuronen and Erickson (2010) were used. For gillnets and traps, the recent review by Uhlmann and Broadhurst (2015) was used. The factors which have been studied for hook-and-line angling gear are based on two reviews that covered both freshwater and marine fisheries, i.e. Bartholomew and Bohnsack (2005, pp. 134–136) and Arlinghaus *et al.* (2007, pp. 115–125), thus excluding studies published after 2007. The factors which have been studied for longlines and jigging machines are based on an online database search (Web of Science). For pelagic seines and trawls, no review existed; therefore, available primary literature studies, mainly on purse-seines, were scanned for relevant factors (Marçalo *et al.*, 2008, 2010, 2013; Huse and Vold, 2010; Olsen *et al.*, 2012; Tenningen *et al.*, 2012; Hall and Roman, 2013).

This rapid review incorporated the findings of published comprehensive reviews but is not considered exhaustive or systematic (Table 7.1, Annex 4 – factors observed to effect discard survival grouped by gear type). Also, it does not encompass why certain factors seemed more relevant to one gear type than another, due to a potential publication bias and the different emphasis of the considered reviews (e.g. mitigation, gear selectivity). This should be addressed in a more critical or systematic review, which was beyond the scope of this exercise. Such a critical and systematic analysis could also identify compounding interactions between factors (as described above) and whether they were appropriately addressed by the design of each study. To this end, and for further reading, the reader is directed to some recent reviews on the mortality, stress and welfare of aquatic animals encountering commercial fishing operations (Veldhuizen, 2017; Cook et al, 2018; Veldhuizen et al, 2018; Breen et al, 2020).

7.2.1 Selection of variables

The rapid review identified that gear configuration, handling, deployment duration, water temperature, and air exposure, were the technical and environmental factors which were most studied and most frequently associated, with discard survival (Table 7.1). Body size was also very important (Table 7.1). For active gears, increasing deployment duration, air exposure, and air temperature reduced survival of many species (Table 7.1). For passive gears, gear materials, gear configuration (i.e. use of selective devices), and physical injury in the organisms were relevant in explaining variation among discard mortality.

Several factors were rarely associated with discard mortality, such as sediment type and salinity (Table 7.1). This could be either because they were measured, but not relevant, or because they were rarely measured or mentioned. Factors such as predation, catch composition, and behaviour fall in the latter category.

7.3 Measurement of variables

The majority of the factors listed in Table 7.1 and Annex 4 can be measured by simple means. This includes observations, time recording, or electronic data logging of water quality parameters such as temperature, dissolved oxygen, or salinity. Different configurations of gear and fishing practices often require specific methods. For example, fishing gear deployment duration may be measured as the period from when (i) the winch starts (e.g. trawlers), (ii) complete submergence of the gear underwater (e.g. gillnets or traps), or (iii) during bottom contact (trawls, traps, or gillnets). Load cells can be used to measure pulling force on trawl wires (drag force, Broadhurst *et al.*, 2013); while acoustic transmitters and receivers record trawl shape and catch size. Remote monitoring may also require specific video technologies to measure and document a species' interaction with specific gear (Bryan *et al.*, 2014; Mallet and Pelletier, 2014). Emerging technologies to remotely monitor fishing operations may provide effective means to record data automatically (Mangi *et al.*, 2013).

The measurement of relevant factors is not limited to natural conditions. Study organisms may also be stressed from research-related handling (e.g. measurement, tagging, or holding in captivity). Thus, animal sensitivities towards stressors found in their natural environment may also extend to artificial conditions. For example, the conditions under which subjects are contained will be an important measure for species sensitive to changes in light.

Once relevant variables have been identified, it will be necessary to consider to what degree of accuracy and precision they should and can be measured, as well as how this can be done. For example, measuring the air exposure time for individual fish accurately with a stopwatch may provide better data than roughly estimating air exposure (as the period between start and end of sorting). In contrast, the accuracy gained from measuring catches using expensive scales instead of volume-based approximations may not contribute much to explaining the variability of mortality.

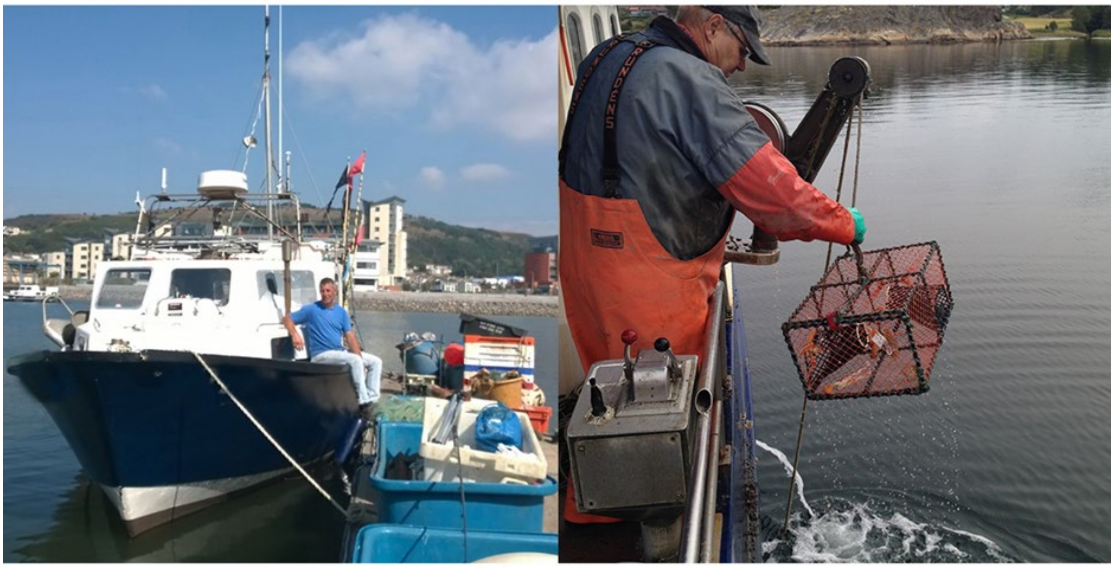

Figure 7.1. Passive fishing techniques: inshore gillnetter [left; credit: Center for environment, fisheries, and aquaculture science (Cefas), UK], Norway lobster creel fishery [right; credit: Swedish university of agricultural sciences (SLU), Sweden].

A more detailed description of the key factors, their effects, and how some of these can be measured are given in Section 7.2 and Annex 4. Factors are discussed in order, according to when they are in association with an organism during the three different phases of capture, handling on board, and release (Figure 2.1). Not all factors are pertinent to all fisheries; and some may be more important than others for a particular gear type (described in detail Section 7.2 and in Annex 4). For example, towing speed does not apply to passive gillnet fisheries, while crowding and herding are phenomena pertinent to seines and trawls.

Factors have been classified individually in Table 7.1, but intercorrelations may exist among them. Such relationships between factors are difficult to account for, unless a rigorous, well-replicated design is chosen in a controlled setting. For example, the way in which catches are handled on board may also determine the period of air exposure. A similar correlative relationship among factors exists where a given environmental or technical factor provokes a measurable response from the organism. One example is the depth of fishing which determines the occurrence and severity of barotrauma injuries among species with swimbladders. Another example is in pelagic purse-seines, where depleted dissolved oxygen concentrations during crowding and herding may trigger an evasion response which causes fatigue. In this example, there is a potential to measure either the cause or the effect.

7.4 Conceptually identifying key variables

Conceptualizing factors that could affect the survival of a captured and discarded animal is a useful method to identify key stressors. Relevant technical, environmental, and biological variables can be identified by tracing an organism's pathway through capture, handling above the water surface, release overboard, and eventual return to its habitat.

7.4.1 Capture phase

7.4.1.1 Technical stressors

The configuration of the fishing gear plays an important role in how animals are caught, how they interact with gear, with what components they come into contact, and the intensity of this contact. In trawl fisheries, the interaction starts with a stimulus by the gear, such as otter boards and sweeps (Wardle, 1993), tickler chains (van Beek *et al.*, 1990; Kaiser and Spencer, 1995), and groundgear (for trawls), which can cause physical contact and possible injury (Chapman, 1981; Suuronen and Erikson, 2010; Winger *et al.*, 2010). Next, the animals pass through the gear towards the codend. During that process, further physical contact can occur, resulting in injuries such as abrasion. The characteristics of the netting material (i.e. stiffness, yarn surface, knot thickness, mesh shape) are important in that process (ICES, 1993; Evans *et al.*, 1994). Physical barriers in the net, such as guiding panels, can inflict additional injury (Lundin *et al.*, 2012). In hook-and-line fisheries, the design of the hook has an effect on survival (Cooke and Suski, 2005; Grixti *et al.*, 2007) and the type of lure can be important (Annex 4; Arlinghaus *et al.*, 2008). In static-net fisheries, the design of net is important. For example, fish are more likely to get entangled in trammelnets than in single layered gillnets (Uhlmann and Broadhurst, 2015).

A negative relationship typically exists between deployment duration and survival. The longer gears are deployed, the longer animals are exposed to the capture process, whereby crushing and injury may confound exhaustion effects. It is not necessarily the duration *per se*, but the increasing interactions with the gear and/or other parts of the catch. For example, both Wassenberg *et al.* (2001) and Uhlmann and Broadhurst (2007) showed that in penaeid prawn trawls, survival probabilities for discarded organisms decreased with longer tow duration (Annex 4). Deleterious effects from beam trawl capture may be exacerbated by adverse weather conditions (high waves), causing the heavy gear to lift off the bottom repetitively (Uhlmann *et al.*, 2016). In trap fisheries, discard species may be trapped and are not able to feed or move as needed (Barber and Cobb, 2007). For hook-and-line fisheries, longer fighting times have been shown to increase the occurrence of sublethal effects and post-release mortalities (Tomasso *et al.*, 1996; Meka and McCormick, 2005).

Towing speed is another technical factor which may influence discard mortality, although not identified by any of the reviewed studies (Table 7.1). Higher towing speeds can lead to exhaustion and increased risk of injury due to increased likelihood and intensity of contact with the gear and other components of the catch. The type and likelihood of injuries to captured organisms can be affected by the movement of the fishing gear, as determined by its design, the nature of the seabed, depth range (Milliken *et al.,* 2009; Benoît *et al.,* 2013), and currents.

The process of hauling of fishing gear on board, the movement of parts of the fishing gear containing the catch, physical interactions with hard parts of the vessel (which can be exacerbated by poor weather conditions), size and composition of the catch, and the time before emptying the catch, can all affect animal vitality in the catch. Speed of hauling will also affect how quickly gases in the animal's body expand and how it can cope with this physical change (see barotrauma below).

Figure 7.2. Passive fishing techniques: freshwater fyke fishers in the Dutch IJsselmeer (credit: B. Griffioen, Wageningen Marine Research, The Netherlands.

7.4.1.2 Environmental stressors

The effects of temperature changes from ambient temperature at deeper depth to surface/air temperature, are well known for some freshwater and marine fish (Brett, 1970; Fry, 1971; Schreck *et al.*, 1997; Davis *et al.*, 2001). A series of experiments on marine fish demonstrated species-specific differences in mortality associated with temperature change (Barton and Iwama, 1991; Muoneke and Childress, 1994; Ross and Hokenson, 1997). Swimming performance and the ability of fish to maintain position in the net can be influenced by temperature change, thus influencing the likelihood of physical injury through contact with the gear or the catch (Beamish, 1966; He and Wardle, 1988; Winger *et al.*, 1999; Breen *et al*., 2004).

Over a longer time-scale, temperature changes may contribute to observed seasonal effects on mortality, although few studies have taken seasonality into account (Gale *et al*., 2013). Other more crucial parameters may be "masked" by seasonality, but strongly correlated to it, such as ambient temperature and spawning. ICES (2010) demonstrated significant seasonal differences in the mortality rates of little skates (*Leucoraja erinacea*) captured between February and July, mostly associated with variations in surface water temperature. Revill *et al.* (2013) found differences in the survival of plaice in different seasons. Mediterranean swordfish (*Xiphias gladius*) also demonstrated lower vitality during the post-spawning season compared to prespawning, a finding attributed to the poor health condition of the spawners (de Metrio *et al.*, 2001; Damalas and Megalofonou, 2009).

With increasing depth, natural light levels are reduced through attenuation (Johnsen, 2012), which can also influence behaviour during the capture process. Observations and measurements of fish behaviour under conditions of low light and darkness have been carried out both in the field and in the laboratory, confirming that effects of light are species-specific (Batty, 1983; Olla and Davis, 1990; Ryer and Olla, 1998; Olla *et al.*, 2000). In some trawl fisheries, certain fish species under low light conditions swam less, passed along the trawl faster, and did not orient themselves to the long axis of the trawl resulting in more injury and mortality. At very low light intensities, fish do not detect an approaching net (Wardle, 1993). At the other extreme, bright surface light may cause disorientation and bleaching of sensory pigments in the eye, reducing the animals' ability to make avoidance responses if released at sea (Pascoe, 1990). For some species, short-term or permanent blindness may also occur (Frank and Widder, 1994).

Differences in salinity result in varying osmotic pressures, which require aquatic species to regulate their body water. Marine stenohaline species (e.g. *Nephrops norvegicus)* may suffer haemodilution and rapid mass gain, even after a brief exposure to non-preferred salinity ranges (Harris and Ulmestrand, 2004). Another relevant environmental factor during the capture phase is water depth (Table 7.1). The negative effect of a change in depth on fish vitality is mainly due to the rapid decrease of hydrostatic pressure (see next section).

7.4.1.3 Biological stressors

Significant variation in discard mortalities for some species has been documented not only between studies, but also within studies (Frick *et al*., 2010; Revill, 2012). In general, sedentary species and those lacking a swimbladder (e.g. flatfish, sharks, and rays) have a higher likelihood of survival (Benoît *et al.,* 2013). Several crustacean species (crabs, lobsters) and bivalve molluscs (scallops) are relatively robust and are likely to survive when discarded (Mesnil, 1996).

(Round) fish that are captured, brought to the surface, and discarded, experience depressurization (barotrauma; Stewart, 2008), which can cause mortality (Nichol and Chilton, 2006; Campbell *et al*., 2010a; Hochhalter and Reed, 2011; Rudershausen *et al*., 2014). The presence and type of swimbladder is an important biological determinant for survival (Benoît *et al.*, 2013; Rudershausen *et al.,* 2014). The most frequently observed barotrauma symptom in fish is an overinflated or ruptured swimbladder, with associated gas release into the body cavity. However, swimbladder healing after a short period of time has been described for some species, such as the Atlantic cod (*Gadus morhua;* Midling *et al.,* 2012).

The size and structure of the swimbladder varies considerably in different teleosts. Some taxa, particularly those living in the deep sea or benthic habitats, have lost the swimbladder altogether (McCune and Carlson, 2004). Physoclistous (i.e. closed bladder) fish are most susceptible to the effects of barotrauma (Broadhurst *et al.*, 2006). Physostomous (i.e. open bladder) fish can more readily regulate the amount of gas in their swimbladders by venting it, but may be more susceptible to barotraumatic effects than fish lacking a gas bladder (Benoît *et al.,* 2013). This may account for the proportionally higher survival frequently observed for discarded elasmobranchs and some benthic teleosts that lack closed gas bladders (Laptikhovsky, 2004; Enever *et al.,* 2009; Depestele *et al.,* 2014). A list of marine fish with physoclistous (closed) or physostomous (open) swimbladders is given in Benoît *et al.* (2013).

The composition and size of the catch (Robinson *et al.,* 1993) will determine the severity of the interaction between different animals in the catch for the duration of the fishing operation. They thereby can influence the nature and severity of injuries and the associated mortality (note: there can be a potential correlation with gear deployment duration). For example, Mandelmann and Farrington (2007) observed that larger catch volumes caused greater mortalities among discarded spiny dogfish (*Squalus acanthias,* Annex 4). Moreover, the crowding density of the catch prior to release (e.g. during slipping in purse-seines; Annex 4; Tenningen *et al.,* 2012), and the herding effect, that may lead to exhaustion of the fish, can result in lower survival (ICES, 1975a; Berghahn *et al.,* 1992; Robinson *et al*., 1993; Wardle, 1993; Colura and Bumguardner, 2001). It has been suggested that abrasive objects such as spiny fish may cause scale loss among teleosts confined in a codend (Pranovi *et al.,* 2001; Broadhurst *et al.,* 2006), and stinging jellyfish that cannot be excluded from the catch can potentially cause harm (Uhlmann and Broadhurst, 2015). Catch size and composition can also affect handling practices and duration, which, in turn, affects survival (Section 7.4.2).

Finally, depredation is the killing and total/partial removal of an animal (or bait) from a fishing gear by a predator. It has been recognized as an influential factor, especially in gillnets and traps (Uhlmann and Broadhurst, 2015). When partial removal of an individual has occurred, the remainder will often be discarded. The inclusion of these individuals in estimating a discard survival rate will depend on whether they are being classified as discards.

7.4.2 Handling phase

7.4.2.1 Technical stressors

Once the catch is brought on deck, the handling phase will influence discard survival. The path of the catch through the infrastructure of the vessel, after removal from the fishing gear, can have some effect on the survival of fish (Berghahn *et al.,* 1992). Different methods exist to haul individual fish on board. Animal vitality in the catch will be affected by whether the catch is released into a hopper, pumped, or gaffed, and the speed, technique, and conditions of handling. Since exposure to air affects survival (Castro *et al.,* 2003), a quick sorting of the catch generally improves survival (Breen et al, 2020). Therefore, the design of the vessel and the skill and number of individual crew members on the processing line will, have an influence. Dehooking and removing from static nets is easier and faster for experienced fishers. Discards can be temporarily stored on deck and can be released through a tube above or under the water. This can affect the exposure time to air, altered temperature, and light as well as exposure to seabird predation (Chapman, 1981; Cook *et al*., 2018; Breen *et al*., 2020).

7.4.2.2 Environmental stressors

Many aquatic organisms suffer from hypoxia during air exposure or during confinement (e.g. Chapman, 1981; Cook *et al*., 2018; Breen *et al*., 2020). The time of air exposure is typically measured as the period between pulling the catch out of the water and discarding back to the water (Annex 4). By sorting the catch in water, Macbeth *et al.* (2006) demonstrated that minimizing air exposure reduced discard mortality of undersized prawns (*Metapenaeus macleayi*) (Annex 4). Hypoxia effects can be confounded with temperature changes to negatively affect survival (e.g. van Beek *et al.,* 1990; Gamito and Cabral, 2003; Giomi *et al*., 2008; Hyvärinen *et al.,* 2008). Irrespective of gear type, species-specific and size-dependent tolerances to hypoxia are important biological factors in determining susceptibility to discard survival (Barber and Cobb, 2007; Gisbert and López, 2008; Stewart, 2008). Effects of air exposure may be exacerbated by simultaneous exposure to direct sunlight, which can lead to heating and rapid dehydration. Exposure to wind or freezing temperatures may also increase dehydration.

7.4.2.3 Biological stressors

Within species, size matters, with larger fish generally showing higher survival (Neilson *et al.*, 1989; Sangster *et al*., 1996; Milliken *et al.*, 1999). Increased sensitivity of smaller fish is attributed to greater mass-specific respiration demands (Benoît *et al.,* 2013), to fatigue from swimming during capture (Wardle, 1993), and to a reduced ability to avoid injurious contact with the gear and catch (Suuronen *et al.*, 1995, 1996; Sangster *et al.,* 1996; Wileman *et al.*, 1999; Breen *et al.,* 2007). In addition, body core temperature increases faster in smaller fish (Davis *et al.*, 2001; Davis and Olla, 2001, 2002). An inverse relationship between the rate of body core temperature increase and fish size has been documented (Spigarelli *et al.*, 1977). The mechanisms behind the sensitivity towards changing temperatures have not yet been resolved for many species. For example, while flatfish can tolerate both hypoxia and temperature change; sablefish (*Anoplopoma fimbria*) tolerate hypoxia, but are sensitive towards changes in temperature (M. Davis, pers. com.). Salmonids are very sensitive towards temperature changes (Gale *et al.*, 2013), as are clupeids (Lundin *et al.,* 2012).

Injuries will influence survival during the handling phase. For example, removing fish from hooks has a high potential of inflicting tears or punctures to mouthparts or the oesophagus.

Figure 7.3. Modifications to catch handling and sorting procedures on board a Dutch beam trawler: hopper with different sized opening gates to apportion quantities transfered to the conveyor belt (top left); extra aeration of a water-filled hopper (top right); batten with multiple holes to discharge unwanted small-sized individuals (bottom left); extra lid to keep the water inside the hopper from spilling over during rough seas (bottom right). Credit: Wageningen Marine Research, The Netherlands.

As discussed above, the extent of physiological responses to air exposure is species-specific (Benoît *et al*., 2013). The lack of gas exchange during hypoxia triggers a cascade of metabolic products that can be measured in the haemolymph, blood, and tissue (McMahon, 2001; Davis, 2002). Owing to different respiratory mechanisms, crustaceans are favourably adapted to tolerate anoxic conditions when compared to teleost fish. Benoît *et al*. (2013) identified some biological traits, such as the presence of deciduous scales, mucus production, body softness, and presence of sedentary lifestyles, which are indicative of hypoxia sensitivity (Annex 4). The degree to which such biological resilience occurs may be very specific and associated with certain biological traits (Table 7.2). To illustrate the relationship between stressors and stress responses for discarded organisms, Table 7.2 lists sensitivities and measurable responses towards anoxic conditions, and changes in temperature and water depth (here: decompression).

Table 7.2. List of biological traits and measurable effects associated with sensitivity to hypoxia, changes in temperature, and decompression.

Sensitivity	Traits	Effect	Species	Reference
Hypoxia	Presence of deciduous scales	Fish with soft scales are sensitive towards desiccation	Atlantic herring, capelin, rainbow smelt	Suuronen *et al.* (1996); Benoît *et al.* (2012)
	High mucus production	Mechanism to prevent desiccation	Hagfish, eel	Benoît *et al.* (2012)
	Body softness or fragility	Measured with a durometer	Atlantic halibut, mackerel	MacDonald *et al.* (1996); Benoît *et al.* (2012)
	Sedentariness	Signs of low metabolic activity (e.g. anaerobic)	Shorthorn sculpin, hagfish	MacCormack and Driedzic (2004); Cox *et al.* (2011); Benoît *et al.* (2012)
Temperature	Ventilation rate	Fish under temperature stress breathe faster	Salmonids, Clupeids, Percidae	Gale *et al.* (2013); Lundin *et al.* (2012)
	Metabolic rate	Fish below thermal optimum have a reduced metabolism		
Decompression	Presence and type of gas bladder	Fish with a closed gas bladder are more sensitive towards pressure changes	Ling, redfish (*Sebastes*), haddock, whiting	Benoît *et al.* (2013); Breen *et al.* (2007)

7.4.3 Release phase

7.4.3.1 Technical stressors

The mechanisms by which individuals are released into the water will influence survival. To reduce adverse affects from discarding, release chutes or recovery boxes may facilitate a less stressful release process (Annex 4). Allowing species to recover prior to being released has been shown to reduce predation (Farrell *et al.*, 2001).

7.4.3.2 Biological stressors

Successfully evading predation depends on the responsiveness of the prey (Fuiman *et al.*, 2006). If reflex responses are impaired (e.g. reduced swimming speed, loss of orientation), then responsiveness will be reduced (Ryer, 2004; Raby *et al.*, 2013). Injuries can affect not only a fish`s ability to evade predators (see following section), but also its shelter seeking and feeding abilities. Open wounds can facilitate infections by pathogens, particularly in fish already stressed by their interaction with the fishing gear. This can be a direct cause of mortality or result in an increased probability of predation.

7.4.3.3 Environmental stressors

The environment into which individuals are discarded and the distance from their natural habitat (displacement) will also affect survival chances. Predation rates of discarded fish also depend on variables such as the type of predators present, predator density (Cooke and Philipp, 2004), and predator avidity (Campbell, 2008). Vulnerability to predators is species- and size-specific, e.g. large pelagic sharks are shown to have substantial survival rates (> 90%) due to their robust nature, their ability to recover quickly from exhaustion, and the low probability of being attacked by larger predators (Megalofonou *et al.*, 2005; McLoughlin and Eliason, 2008).

7.5 Explanatory variables: conclusions

Once a fishery and species have been selected for survival assessment, it is important to identify the relevant stressors to which the organisms will be subjected. This will help ensure that the resultant survival estimates are representative of the fishery, and that the main influencing factors on survival are identified. The latter point may be useful in developing mitigation tools. The stressors can be categorized as either technical, environmental, or biological.

The rapid review presented here identified that, among the technical and environmental factors, gear type and configuration, handling, deployment duration, water temperature, water depth, and air exposure, frequently influenced discard survival levels (Table 7.1). Body size and physical injury were also relevant in explaining variation among discard survival estimates. It should be noted that some important stressors and factors may not have been measured in previous studies (or if studied, were not published). For many stressors, taking measurements is straightforward. However, some are more difficult to measure and, consequently, have been less studied, e.g. physical condition, predator abundance, or distance from suitable habitat.

There are many variables that can be measured. Therefore, the investigator must make a choice as to which variables will be measured and the accuracy to which they need to be measured, based on the benefits that will be gained. The frequency with which variables are shown to effect discard survival is an indication of their relative importance. However, this approach needs to be viewed with caution, given the caveats of a potential publication bias and the lack of critical evaluation of potential compounding effects.

7.6 Summary and recommendations

Potential explanatory variables of discard survival can be categorized as either technical, environmental, or biological. Two approaches are suggested to identify relevant explanatory variables or stressors for a survival assessment: (i) conceptually tracing an organism's pathway through capture, handled above the water surface, release overboard and eventually return to its habitat; and (ii) conduct a literature search of relevant material.

Once relevant variables have been identified, the method of measurement, and the required degree of accuracy need to be considered.

The rapid review presented here identified common potential explanatory variables of discard survival. As examples:

- Technical: gear type and configuration, handling, deployment duration,
- Environmental: water temperature, depth change, air exposure,
- Biological: body size and physical injury.

It is important to remember that intercorrelations may exist between potential explanatory variables, which are difficult to account for unless a rigorous, well-replicated design is conducted in a more controlled setting.

Recommended questions for practitioners/researchers

With respect to assessing the effect of explanatory variables, the researcher should ask themselves the following questions when planning a discard survival assessment:

- Have pathway analysis and literature reviews been used to identify the most likely potential explanatory variables to be considered in an experimental design?
- Will the most common potential explanatory variables be considered as part of experimental design?
  - Technical: gear type and configuration, handling, deployment duration.
  - Environmental: water temperature, depth change, air exposure.
  - Biological: body size and physical injury.
- To what degree of accuracy and precision should, and can, the potential explanatory variable be measured, and how can this be done?
- Has the potential for intercorrelations between explanatory variables been considered?
- How will the potential explanatory variables, and any inter-correlations, be addressed by a well-controlled and replicated design?