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Review paper

The condition of fish escaping from fishing gears—a review

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Abstract

The capture of immature fish in many commercial fisheries is controlled by restricting the use of fishing gears or elements of fishing gears that prevent the escape of immature fish. Improving the selective characteristics of fishing gear is based on the assumption that fish escaping are not seriously damaged and able to make a complete recovery. If fish escape and die as a direct result of stress and injuries or indirectly due to disease and predation associated with gear damage, then increasing the opportunity for escape by improving selectivity may result in an increased level of unaccounted fishing mortality. This paper identifies the main fishing gear types used for harvesting marine and freshwater fish, a range of injuries, stress reactions and mortalities that can occur during capture and escape. It is concluded that immediate and delayed mortalities can occur in fish escaping from fishing gears and that the high variation in mortality rates within experiments is associated with a lack of information on how fish condition is affected by various fishing stressors and the type and severity of physical damage received. Improving selectivity without reducing damage or stress incurred during capture and escape may not be the most appropriate way of protecting immature fish.

Keywords: Gear selectivity; Stress

1. Introduction

The species and sizes of fish caught in fishing gears is to a large extent determined by the species and size selective characteristics of the gear. The capture of immature fish in many commercial fisheries is controlled by restricting the use

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of gears or elements of gears that prevent the escape of immature fish. Improving fishing gear selectivity is based on the assumption that fish escaping from fishing gears are not damaged, minimally stressed and able to make a complete recovery after escape. However, in many cases, escape occurs only after the fish have been subjected to a wide variety of capture stressors and possible damage due to contact with other fish, debris or the gear itself.

Damage and stress in fish are recognized as serious problems in aquaculture, recreational catch and release fisheries and fish tagging research because they are known to affect growth, reproductive capacity and survival. In commercial fisheries, fish escaping from fishing gears may die as a direct result of physical damage and stress, or indirectly due to a reduced capacity to escape predators or resist disease. Fish that do not die may have their growth and reproductive capacity impaired.

If there are significant numbers of fish dying after escape from fishing gears the use of traditional gear selectivity measures such as minimum mesh size to protect the pre-spawning biomass may not be appropriate. Hence, this review of literature on the mortality levels of fish escaping from fishing gears has been carried out to determine if the use of some catching technologies result in an "unaccounted" fishing mortality and if there is any need to consider alternative ways of protecting non-target species and sizes of fish.

2. Description of fish catching methods

For the purpose of this review, the basic fishing gear classification system used by Nedelec (1990) has been adopted with the exception that no differentiation has been made between commercial, recreational or research fishing gears. The size and complexity of fishing equipment varies considerably between fisheries and within a fishery. Depending on the system used, catch rates vary from single fish per haul (single hook and lines), through to catches in excess of several hundred tonnes (otter trawls and purse seines). Various authors have produced texts on fish catching methods (Andreev, 1966; Sainsbury, 1975; Baranov, 1976; Von Brandt, 1984). Nedelec (1990) provides a basic definition and classification of fishing gears and detailed examples of net plans and net terminology can be found in catalogues of the Food and Agriculture Organization (FAO, 1978, 1987). Fishing gear terms vary by fishery, by country and no single reference adequately explains the wide variety of terms used. However, Bridger et al. (1981) and the Commission of the European Communities (1992) provide descriptions of fishing gear terms used in European countries. Detailed descriptions of the science and technology associated with commercial fishing gears can be found in Kristjonsson (1959, 1964, 1971), Fridman (1973, 1986) and Baranov (1976). Von Brandt (1984) provides an overview of the vast range of catching methods used in commercial fisheries around the world, Wardle (1983), fish reactions to fishing gears and Nikonorov (1975), the different zones associated with the capture process.

3. Definition of escape from fishing gears

Nikonorov (1975) suggests that fish capture involves fish passing through zones of influence, action and retention. Thus, the range of influence of the gear is not only where the fish are retained, e.g. hook, codend, etc. but also includes parts of the fishing equipment that guide, herd, alarm or scare fish. In this review, escape is defined as the ability of a fish to escape from any one of these zones. The size and species of fish escaping will depend on the selective characteristics of the fishing gear, where selectivity is defined as a measure of the probability of capturing a particular fish species of known size. A general overview of fishing gear selectivity can be found in Margetts (1957), Kipling (1957), Pope et al. (1975) and Baranov (1976).

4. Fishing gear mortality estimates

Research on the mortality of fish escaping from fishing gears has been limited to a few fishing methods and has tended to focus on short term studies. Longer term factors such as predation on injured fish and the ability of a fish to fully recover from its injuries or stress are more difficult to monitor and are usually not included in mortality studies. Table 1 lists the mortality of fish escaping or released from commercial, recreational and research fishing gears. Much of the research in this area has been in sports fisheries rather than commercial fisheries where the desires of anglers to continue fishing after they have caught their bag limit have prompted researchers to measure mortality of "catch and release fish". A similar approach has been adopted by scientists engaged in tagging fish to study growth, migration and population dynamics and need to determine whether fish that are subjected to handling and capture stresses and subsequently released have less chances of survival than wild fish. In commercial fisheries where the conditions under which fishing is carried out are more severe, the non commercial mortality estimates might represent the lower end of the mortality scale.

In the Gulf of St. Lawrence, Caddy (1968) noted immediate mortality associated with damage to scallops *Placopecten* sp. in the path of a scallop dredge and subsequent mortalities associated with predation. A more detailed description of the categories of damage and measurement of mortality rates was conducted by Caddy (1973) where he estimated that between 10 and 17% of the scallops died as a result of damage and predation. Medcof and Bourne (1964) and McLoughlin et al. (1991) also observed mortalities associated with dredge damage and suspected that bacterial infection spreading through the residual population were a source of indirect fishing mortality associated with capture stress. In their study extending over 8 months, McLoughlin et al. (1991) estimated indirect mortality (88%) of the scallop *Pecten fumatus* as the total number of scallops in the region minus those caught by the dredge (12%), indicating a massive unaccounted post harvest mortality.

Mortalities of fish escaping from bottom otter trawls have been recorded by

Table 1
Mortalities of fish escaping from fishing gears

Fishing gear	Species	Mortality (%)	Comments	Reference
Surrounding gear	*Scomber* sp.	50–90	Simulated purse seine experiment	Lockwood et al., 1983
Seine nets	Cod, haddock	0, < 10	Fish retrieved at surface	Soldal and Isaksen, 1993
Seine nets	Striped bass	1–17	Beach seine. Mortalities of released fish reduced through improved handling techniques	Dunning et al., 1989
Seine nets	Freshwater drums	84.7	Beach seine. Estimated mortality after release due to stress and injury	Fritz and Johnson, 1987
Trawls	Striped bass	1–16	Otter trawl. Mortalities of released fish reduced through improved handling techniques	
Trawls	Gadoids		Otter trawl and Danish seine; 39–100% surface tagged fish, 12–65% surface non-tagged fish, 0–50% bottom tagged fish, 4–32% bottom non-tagged fish	Hislop and Hemmings, 1971
Trawl	Various	Varied	Discarded fish study in shrimp trawls. Mortality rates depended on time on deck but all fish did not survive 20 min on deck	Wassenberg and Hill, 1989
Trawls	Haddock, whiting	9-27, 10-35	Codend mortality. Figures quoted from tables. Large variation between species and years	Sangster and Lehmann, 1993
Trawls	*Melangogrammus* sp.		Otter trawl. Dead and injured fish found in the wake of the trawl, 163–169 dead fish h^{-1} tow	Zaferman and Serebrov, 1989
Trawls	Gadoids	14–100	Otter trawls. Large variation in mortality between cages, species and years	Main and Sangster, 1990
Trawls	Haddock, whiting	9–27, 10–35	Otter trawl	Anonymous, 1993
Trawls	Cod, haddock	0, 1–32	Otter trawl codend	Soldal et al., 1991
Trawls	King and Tanner crab	21–22	Otter trawl. Non-target catch	Stevens, 1990
Trawls	Lobster	21	Non-target catch. Mortality varied depending on moult condition	Smith and Howell, 1987

Fishing gear	Species	Mortality (%)	Comments	Reference
Trawls	Atlantic halibut	65	65% mortality after 48 h compared with 23% mortality for longline-caught fish	Neilson et al., 1989
Trawls	*Clupea harengus*	85–90, 75–85	Diamond mesh mortality, sorting grid mortality	Suuronen et al., 1993
Trawls	Scup, flounder, cod	0–50, 0–150	Otter trawl	DeAlteris and Reifsteck, 1993
Dredges	*Pecten* sp.	78–88	Boat-operated scallop dredge. Mortality from gear, predation and disease	McLoughlin et al., 1991
Dredges	*Placopecten* sp.	10–17	Boat-operated scallop dredge	Caddy, 1973
Fishing gear	Species	Mortality (%)	Comments	Reference
Gillnets and entangling nets	Pacific salmon	80–100	Cumulative mortality in captive fish	Thompson et al., 1971
Gillnets and entangling nets	Pacific salmon	80	Cumulative mortality due to scale damage and stress	Thompson and Hunter, 1973
Gillnets and entangling nets	*Clupea* sp.	1.9	Actual mortality was v. high but attributed to disease	Hay et al., 1986
Hooks and Lines	*Oncorhynchus* sp.	12–69	Catch and release mortality estimates	Vincent-Lang et al., 1993
Hooks and Lines	*Oncorhynchus* sp.	34–52, 40–86	Coho salmon, Chinook salmon	Parker et al., 1959
Hooks and Lines	*Salmo* sp.	0	No mortalities after 3 days but measurable stress	Wydowski et al., 1976
Hooks and Lines	Rainbow trout	39, 3–5	Hook swallowed corn bait, artificial lure	Barwick, 1985
Hook and Lines	Cutthroat trout	0.3, 3	One time hooked mortality, multiple hooking	Schill et al., 1986
Hooks and Lines	Trout	0–8.6	Angling mortality	Dotson, 1982
Hooks and Lines	Smallmouth bass	0, 11	Artificial lures, live bait	Clapp and Clark, 1989
Hooks and Lines	*Esox* sp.	3	Angling mortality	Schwalme and Mackay, 1985
Hooks and Lines	Chinook salmon	9–32	Trolling, small fish had higher mortalities	Wertheimer, A., 1988
Hooks and Lines	Pacific salmon	41	Trolling, 34% immediate mortality and 7% delayed mortality	Milne and Ball, 1956

various authors and show large variations in individual experiments if not in the pooled data presented in their results. Hislop and Hemmings (1971) measured the mortality of trawl and seine caught fish used in tagging studies. Mortality rates over the 7 year period of study ranged from 39 to 100% for fish brought to the surface and tagged compared with 12–65% for fish brought to the surface but not tagged. In a parallel study of tagged and non-tagged fish caught but not brought to the surface the mortality rates were 0–50% and 4–32% respectively. In a study conducted over 4 years from 1985 to 1988, Main and Sangster (1990) measured mortality rates between 0 and 100% for Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus*. Reasons for the large differences were suspected to be related to fish condition biasing the sample and that no conclusions can be drawn from the year to year variations. Sangster and Lehmann (1993) show the effect of fish size on escapee mortality and give mortality rates of 9–35% for haddock, *Melanogrammus aeglefinus* and whiting *Merlangius merlangus* escaping through codend meshes.

Collisions of fish with the groundgear of otter trawls have been noted by Walsh and Hickey (1993); however, no indication is given as to the types of injury or the fate of the fish. Soldal et al. (1991) noted mortalities of between 1 and 32% for haddock, *Melanogrammus aeglefinus* escaping from the codend or sorting grid of a trawl with mortalities higher in the trawl fitted with a sorting grid. Suuronen et al. (1993) compared mortalities of herring escaping from an otter trawl fitted with a sorting grid and diamond mesh codends and recorded mortalities of 75–85% and 85–90% respectively. Soldal et al. (1991) and DeAlteris and Reifsteck (1993) both suggest that the low mortality rates from their experiments are the basis for validating the use of minimum mesh size in trawls; however, it is not clear whether the fish under investigation were subjected to the full range of stressors and damage that usually occurs in commercial operations. Dunning et al. (1989) noted mortality of 16% and 17% for fish released from trawls and seines respectively but reduced this figure to around 1% with improved handling practices. However, Fritz and Johnson (1987) estimated a mortality of 84.7% of fish released from a seine as a result of forced swimming, struggling and injury. Non-target fish and shellfish are often caught in towed fishing gears. Stevens (1990) estimated the direct and indirect mortality of crabs in the Bering Sea sole fishery at 21% for King crab and 22% for Tanner crab. Similarly, Smith and Howell (1987) estimated the total delayed mortality for lobster resulting from damage from bottom trawls as high as 21%.

In the Pacific salmon fishery, Parker et al. (1959) estimated a delayed mortality of 40–86% for chinook salmon and 34–52% for coho salmon caught by trolling while Thompson et al. (1971) recorded a mortality between 80 and 100% for gillnet escapes. Thompson and Hunter (1973) were able to separate scale damage mortalities from mortalities associated with combined physical injuries and physiological stress. Scale damage alone resulted in mortalities of 40%, while scale damage and stress accounted for 80% mortalities for salmon escaping from gillnets (see Ricker, 1976 for a detailed review of indirect mortalities). Wertheimer (1988) measured the mortality of chinook salmon released from commercial trollers, noting fish length (mortality rates of 20–29% for fish less than 66 cm and 9–32% for larger fish), injury location and lure type as three factors influencing mortality rates.

Fish mortality after escape from other fishing gears is not well documented with the exception of papers on recreational catch and release fisheries, fishing gears used in tagging and releasing live fish. Catch and release hook caught fish suffer a range of mortalities depending on the species, bait type and size, length of fish and water temperature. Clapp and Clark (1989) showed that mortality was associated with the site and depth of hook penetration and showed an 11% mortality for fish caught on live bait and swallowing the hook but 0% mortality for fish caught with artificial lures and hooked in the mouth. They also showed that growth was affected owing to capture stress. However, Barwick (1985) recorded a mortality of 39% for fish caught on corn pieces owing to hook swallowing but only 3–5% mortality using artificial lures. Dotson (1982) observed hook-caught fish for a period of 30 days after release and recorded mortalities between 0 and 8.6%, observing that mortalities increased with temperature. It is clear from the broad range of studies that fish escaping or released from fishing gears suffer immediate as well as delayed mortalities owing to physical injury, predation and disease. Neilson et al. (1989) compared the survival of Atlantic halibut (*Hippoglossus hippoglossus*) in otter trawls and longlines and found that 65% of trawl-caught and 23% of longline-caught halibut died within 48 h of capture.

5. Escape models

Few authors have adequately explained the full range of mortalities that can occur when fish escape from fishing gears. By far the most detailed description of escape mortalities is presented by Ricker (1976). Ricker considers the problems of indirect or unaccounted fishing mortalities in the Pacific salmon fishery in depth and describes a comprehensive model for fishing mortality based on catch data and estimates of indirect fishing mortality . He classifies losses (escapes) into six types and includes indirect fishing mortality with fishing mortality. Mortalities of coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*Oncorhynchus tshawytscha*) escaping from gillnets, trollers and longlines are estimated at one fish killed for every two boated. Several models describing the capture process also contain some details on fish that are not caught (Ferno et al., 1986; Dickson, 1988; Arimoto, 1989). Arimoto describes a wide range of escape possibilities, including mis-hooking, fish dropping off the line and the holding effectiveness of the hook and lines, but no catch data are presented to validate the model.

6. Considerations

In many commercial fisheries, protection of immature fish is believed to occur by restricting the use of certain types of fishing equipment or elements of the fishing gear which are known to catch immature fish. In most cases, such as cod-end minimum mesh size, management regulations are designed to increase the opportunities for the fish to escape from fishing gears rather than preventing or reducing their chance of encountering the fishing gear. Thus, rather than develop techniques that enable fish to avoid fishing gear, the simpler approach of providing an escape avenue through the meshes, escape chutes etc. from conventional fishing gear is used. In this way, the fish is subjected to all the capture stressors and physical injuries due to contact with other fish, debris or the fishing gear during their encounter with the fishing gear (Sangster and Lehmann, 1993) as well as the additional injuries and stressors associated with escape. In all cases, design modifications to improve selectivity are based on the assumption that fish escaping from fishing gears are undamaged, minimally stressed and able to make a complete recovery from the encounter. Several authors (Stringer, 1967; Hislop and Hemmings, 1971; Thompson and Hunter, 1973; Warner, 1979; Smith and Howell, 1987; Wertheimer, 1988; Stevens, 1990) have shown that physical damage incurred during capture can result in significant mortalities of fish. The location and degree of injury as well as size of fish are all significant factors in whether the fish survive or die (Barwick, 1985; Wertheimer, 1988; Clapp and Clark, 1989). In fishing gears where fish must pass through the net meshes (gill-nets, seines, trawls, etc.), damage is likely to be incurred when the fish passing through the mesh has an opercular circumference the same size or larger than the mesh opening and there is a high probability that the fish may become wedged. Thus regulations set up to protect pre-spawning juveniles such as minimum mesh size, may in fact be responsible for causing the highest levels of escape injury in fish closest to spawning size. However, in the absence of any data on the mortality of 0 and 1 group fish passing through the net, it is not possible to determine which size group is most affected by mesh penetration.

Much of the research on fish mortality has been short term because of the difficulty in observing fish for extended periods of time. However, McLoughlin et al. (1991) have shown that long term mortalities can be extremely high as evidenced by their observations of damage, disease and predation of scallops after dredging activities. Their studies estimated that the number of live scallops on the seabed 14 days after dredging was greater than 30%, reducing to less than 1% after 300 days and 0.1% after 400 days. Post harvest mortalities were also noted by Gwyther and McShane (in McLoughlin et al., 1991) who estimated scallop mortalities on fished beds 9-15 times higher than on unfished beds.

Although the reviewed literature shows quite clearly that damage resulting from capture can produce significant levels of mortality, the effects of stress on fish survival are not so clear. Stress response is a mechanism which enables fish to avoid or overcome potentially threatening, noxious or harmful situations (Pickering, 1993). How a fish reacts to a particular stressor will depend on the species, the type of stressor and its severity (Wedeymeyer et al., 1990). Most of the research associated with how fish react to various stressors has been conducted in the aquaculture industry where fish held in confinement may suffer chronic stress due to overcrowding (Wedeymeyer, 1976), confinement (Barton et al., 1980), and handling (Strange et al., 1977). Pickering (1993), describes in depth the effect chronic stress may have on salmonids which include an increased susceptibility to naturally occurring pathogens, suppression of reproductive endocrinology and maturation processes. The type of stressors fish are subjected to during capture by commercial fishing gears will depend on the fishing method but include confinement, overcrowding, and severe exercise. For example, drying up a purse seine or trap will subject fish to confinement, overcrowding and handling stressors, while fish swimming in the codend of trawl or caught on a hook and line will be subject to severe exercise. Various authors have shown that capture and confinement in fishing gears results in increased levels of stress (Parker et al., 1959; Wardle, 1971; Wydoski et al., 1976; Swift, 1983; Wells et al., 1984, 1987; Hopkins and Cech, 1992; Pankhurst and Sharples, 1992). Hopkins and Cech (1992) showed that gillnetting was more physiologically deleterious than trapping as evidenced by hyperglycaemia, severe acidosis and erythrocytic swelling in gillnet caught fish but did not measure mortality. Pankhurst and Sharples (1992) showed that capture stress resulted in changes in plasma cortisol concentrations and suggested that this may result in depression of gonadal steroids and immune response and increased sensitivity to pathogens. Disease outbreaks during fish mortality experiments have been noted by Hay et al. (1986) and Main and Sangster (1990) but were not attributed to stress associated with capture.

With respect to the literature reviewed, there are several important features that emerge from mortality studies many of which are inter-related. The large variation in mortalities within and between experiments suggest the need for a standard experimental protocol for setting up, conducting and monitoring survival experiments which should include some index of fish condition prior to capture so that comparisons can be made between wild fish and experimental fish. Although injury type and location are recorded by most authors a classification system should be set up to record the causes and severity of damages incurred. Detailed autopsies should be also be considered to determine the cause(s) of death. The same approach should be taken with respect to identifying the range and severity of stressors fish may be subjected to during capture and escape. Longer term studies should be aimed at measuring the individual and cumulative effects of stressors on fish condition. The lack of comprehensive escape models for most fish catching methods should also be considered as a severe limitation in determining how and how many fish die after escape. The value of modelling the escape process is evidenced in Ricker (1976) who included escape mortalities with catch data to determine total fishing mortality.

In conclusion the main requirement for determining the fate of fish after escape should be in the commercial fishing sector where the problems of excess fishing pressure on both domestic and high seas fish resources and the decline in fish stocks continues to be a global problem. The use of gear selectivity as a fishery management tool without adequate research into the fate of fish encountering the fishing gear but not caught should be a cause for concern in any fishery but especially those that are either fully or over exploited. The research conducted on fish escaping from fishing gears indicates that some of the escapees incur physical injuries which result in mortalities. Further, mortalities occurring after escapement have been attributed to stress associated with various capture stressors. It is therefore likely that any attempts to increase the numbers of fish escaping from fishing gears will result in an increase in the levels of mortality and injury to escapees. In this respect, regulatory measures to increase the escape of immature fish by increasing codend mesh size, using square mesh etc., might also result in increased levels of mortality. Thus, using fishing gear selectivity as a fisheries management tool without adequate research into the condition of fish escaping from fishing gear may not be the most effective way to protect immature fish.

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