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International Council for the
Exploration of the Sea

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REPORT OF THE SUB-GROUP ON METHODOLOGY OF FISH SURVIVAL EXPERIMENTS

Montpellier, France 22-23 April 1994

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International Council for the
Exploration of the Sea

CM 1994/B:8
Fish Capture Committee

ICES WORKING GROUP ON FISH TECHNOLOGY AND FISH BEHAVIOUR

REPORT FROM THE SUB-GROUP ON METHODOLOGY OF FISH SURVIVAL EXPERIMENTS

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1. TERMS OF REFERENCE

According to the resolution (C Res 1993/2:8:2) adopted at the 81st Statutory Meeting 1993, a Sub-group on Methodology of Fish Survival Experiments was to be established under the chairmanship of Mr G Sangster (UK) to meet in Montpellier, France from 22-23 April 1994 to:

a) Review and evaluate data and techniques for survival studies
b) Make proposals for the future direction of research on survival studies

The Sub-group was to report to the Working Group on Fish Technology and Fish Behaviour and to the Working Group on Ecosystem Effects of Fishing Activities.

Participants: (in alphabetical order)

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Å Bjordal	Norway (Institute of Marine Research, Bergen)
A Carr	USA (Division of Marine Fisheries, Massachusetts)
F Chopin	Canada (Marine Institute, St John's, Newfoundland)
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2. INTRODUCTION

On 22 April the Sub-group met during a plenary session to discuss the objectives of the meeting after which they divided into three groups each given a specific task to carry out. This report is the summary of the findings of the Sub-group's two day meeting. The first section provides a general model of fishing mortality and definitions of the various types of mortality used in the model. The second part identifies the problem of unallocated mortality and defines where the main (or most important) problems might occur in the different stages of the capture process. The third section reviews methodology of survival studies. In particular, this focuses on survival experiments in the field, direct observations (*in situ*), and laboratory simulations. Furthermore, two Appendices provide the reader with (1) a review on survival concentrating mainly on fish escapes from trawls and cod-ends and (2) an annotated bibliography of stress, injury and mortality to fish associated with other types of fishing processes.

A draft of this Report was presented to the full Fishing Technology and Fish Behaviour Working Group by the Sub-group chairman and appointed members on 25 April. The draft Report was also sent to ICES Headquarters in Copenhagen and to the chairman of the Working Group on Ecosystem Effects of Fishing Activities. All Groups were asked to consider the draft and to reply to the chairman with comments or constructive criticism by 1 June.

The Working Group on Ecosystem Effects of Fishing Activities commended the survival Sub-group on its efforts and stated that the draft Report was an excellent summary of the available information and was both informative and useful. The Report has made them fully aware that there is an important step from survival experiments to estimates of overall mortalities which have to be considered further.

3. MORTALITY OF FISH ENCOUNTERING FISHING GEARS

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 fisheries is controlled by restricting the use of gears, or elements of gears, that prevent the escape of immature fish. The current intensive trend towards 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 has been subjected to a wide variety of capture stressors and possible damage due to contact with other fish, debris or the gear itself. In commercial fisheries, fish escaping from the gear may die as a direct result of physical damage and stress, or indirectly due to a reduced capacity to escape predators or resist disease.

Generally, fishing mortality is measured in terms of landed catch (accounted mortality), however, there may be a variety of unaccounted mortalities whose magnitude will depend on the size and type of fishing gear, its method of operation and the target species. A more comprehensive model of accounted and unaccounted fishing mortalities is shown in Figure 1, which includes landed catch, discards, drop out mortality and a range of escape and avoidance mortalities associated with predation, injuries, stress, disease and fatigue. With the exception of mortalities associated with disease, these mortalities may be either immediate or time dependent. Time dependent mortalities may be short term (from a few hours to less than two weeks) and/or long term (up to several months).

In general terms, fishing mortality F might be divided into the following components:

$$F = Fc + Fd + Fo + Fe + Fa + Fp$$

where:
Fc is landed catch
Fd is mortality due to discards
Fo is drop out mortality
Fe is mortality after escape and includes disease, fatigue, stress and injury
Fa is avoidance mortality
Fp is mortality by removal by predators

3.1 Definition of Terms

Landed Catch - Fc: Catch landed after being brought on deck.

Discard Mortality - Fd: Mortality of fish actively released by fishermen after capture.

Escape Mortality - Fe: Mortality of fish that escape from a fishing gear after having encountered the gear.

Drop Out Mortality - Fo: Mortality of fish that are captured by the gear, die and drop out or drop off the gear but are not a part of the catch on deck. Examples include fish that are caught in gillnets and drop out in the process of hauling, fish that drops off hooks and dead fish that are washed out of the trawl during haulback.

Avoidance Mortality - Fa: These are mortalities that may be directly or indirectly associated with stress, fatigue and injuries of fish actively avoiding the gear. Some examples include fish that are herded by sweeps and bridles or swim within the net but are not captured by the cod-end. In purse seining fish might be surrounded by the seine but avoid capture by swimming or diving out of the net.

Predation Mortality - Fp: These are gear induced mortalities in which predators take fish directly from the gear or indirectly due to a reduced ability to escape predators after escape.

4. GEAR TYPES/FISHERIES, ENCOUNTERS AND ESCAPEES

4.1 Introduction

The potential for unaccounted mortality is related to the gear type, the fish species, the season, and the local/regional regulations governing minimum fish size and mesh size in the harvesting gear. The principal active harvesting methods employed in the fisheries include towed gears (pelagic and bottom trawls, seines, beam trawls, and dredges). The main passive harvesting methods include the entangling gears (gillnets), hook gears (longlines and jigs) and trap gears (baited pots and weirs). Each gear type operates in a particular manner so as to provide a harvest or catch from which the fisherman ultimately selects the marketable catch and discards the remainder. While the fishing mortality associated with the landed catch can be determined, and the mortality associated with the discarded catch may be available based on observer/sea sampling data, the determination of potential unaccounted fishing mortality associated with each stage of the fish capture process depends on a detailed understanding of the operation of a specific gear type, including the problems involved in estimating the numbers of fish encountering the gear.

4.2 Harvesting Methods and Stages of Capture

It is evident that the numbers of fish which eventually die due to the interaction with a fishing gear depends both on the number of fish which encounter the gear as well as on the probability of dying given encounter. However, the former interaction was outwith the scope of the terms of reference and this Report focuses mainly on the latter.

In general, the trawl and seine gears initially herd or concentrate fish ahead of the mouth of the gear, then filter large volumes of water to separate the fish, and finally sort the catch by size. Ultimate species and size selection is accomplished by the fisherman after the gear is hauled to the surface either alongside or on the deck of the fishing vessel. Potential unaccounted fishing mortality in the capture process is related to the fish that escape and are in diminished condition as a result of the herding and filtration process.

In contrast to trawls and seines, beam trawls and dredges, do not concentrate the resource, but simply rake or harvest the resource that directly enters the mouth of the gear, then filters or separates the catch from the water. When the gear is hauled to the surface, the fisherman makes the final selection of the catch to be landed and the remainder is discarded. Potentially unaccounted fishing mortality in the dredge/beam trawl capture process is related to the animals that escape, but are in diminished condition as a result of physiological stress or injury in the initial raking/sweeping or in the filtration.

The purse seine is set around a school of fish, then the webbing filters the catch from the water. Fisherman's selection occurs at the side of the vessel or on deck in the sorting process. Potential unaccounted mortality occurs if the net bursts in the final stage of the capture process or the fisherman releases the catch prior to bringing it onboard.

The gillnet operates by interrupting the migratory path of fish, and entangling the fish by gilling or wedging. Once the fish has been captured, potential unaccounted mortality occurs when either the fish escape alive, but in diminished condition, or drops out dead from the net on haul back to the boat. Although gillnets are one of the most size selective fishing gears, final selection of both fish size and species is affected by the fisherman on the deck of the fishing vessel.

Pelagic and bottom set longlines operate by attracting fish to the hook with bait, and capturing the fish when the fish attempts to ingest the bait. Escapement from the hook occurs either at fishing depth (*in situ*) or on retrieval of the gear. Potential unaccounted fishing mortality is related to the survival of these escapees. Final selection of both fish size and species is conducted by the fisherman.

Large scale two-dimensional traps also interrupt the migratory path of fishes with their long leaders. They pass through a non-return device and are entrapped, until the net is hauled. At this point, the fish are concentrated and the net is brailed out by the fisherman. Potential unaccounted mortality is related to the survival of fish that are released by the fisherman prior to brailing, due to their unacceptable species, size or condition, or fish escape during this process.

Pots attract fish with bait. The fish/shellfish are retained in the pot until being hauled aboard the fishing vessel. Some fish escape from the trap on the seabed or as the trap is hauled to the surface, and there is the potential for unaccounted mortality associated with the survival of these escapees.

4.3 Case Studies (see also Fig. 2 and Appendix 1)

Potential unaccounted mortality in different gears should be identified by judging the risk of such mortality in the stages of the catching process. The effect on the fish from encountering the gear are classified as follows:

Reaction/Stress: Degree of response or stress imposed on the fish.

Injury: Physical injury (scale loss, squeezing, bruising, skin laceration etc).

Primary Mortality: Immediate (within few hours) mortality, either by direct predation when fish is in the gear or from causes like swimbladder expansion.

Secondary Mortality: Long term mortality (days-weeks) from stress or injuries leading to disease and/ or reduced predator avoidance.

The problem of identification should also include:

Potential for Recovery after escapement or discard.

Relative Magnitude of escapement or discard to total catch of the species, and finally:

Relative Importance of Unaccounted Mortality (RIUM): the weighted product of potential mortality and the magnitude of escapement or discard.

Identification of this unaccounted mortality should be done for all major fisheries and commercially important species. To illustrate a possible way of identification, some case studies from major fisheries are presented in Tables 1-6. The potential effects are ranked as follows: **0** (none, very low), **1** (low), **2** (medium), **3** (high), and **4** (very high).

5. REVIEW AND EVALUATION OF SURVIVAL STUDIES

This section reviews methodology of survival studies. In particular, this section focuses on survival experiments in the field and direct observations (*in situ*). Laboratory simulation studies are however important. These were discussed and pertinent points recorded, but due to time constraints, discussion concentrated mainly on field studies and direct observations.

The observational methodology of survival experiments in the field consists of the following steps which should be adhered to whenever possible:

1. Choice of experimental design, planning, fish numbers and species

2. Species collection and transportation (if necessary) eg how far from the catching source to the observation/monitoring site?

3. Holding methods (cages or tanks etc) size, design, location and whether feeding is required

4. Monitoring and sampling (eg blood sampling or tissue sampling for physiological assessments) duration, how long/density, environmental parameters, depth

5. Evaluation, analysis and interpretation

   Is there enough data for adequate analysis?
   Choice of analytical method?
   Why mortality?
   What are fish dying of?
   How and by whom will the results be used and/or evaluated.
   Will the results be of value to estimate the consequences at population level?

5.1 Planning the Experiment

Choice of methods will depend on:

a) Species and availability
   Fish (pelagic/demersal)
   Shellfish
b) Fishing gear (moving/fixed/lining)
c) Logistic and financial support

Planning of the Experiment is dependent on:

a) Season (should be conducted when the problem exists)
b) Availability (species and size)
c) Condition of the species under investigation (physical and physiological)

Sample size requirements:

a) Sample size for statistical significance
b) Replication for each category is imperative to show the range of variance
c) Treatment and controls
d) Intended statistical analysis method

5.2 Collection Methods

5.2.1 General

Design should ensure that the method does not bias the results:

a) Ensure adequate replication under commercial conditions, (It is recognised that, at present, certain parts of the protocol cannot match commercial conditions (eg towing duration)
b) Minimise sampling stress and injury to fish during collection. Towing netting cages may cause additional mortality. Shorter trawling tows to minimise fish injury by cover cage attachment methods
c) Obtain reliable controls
d) Ensure consistent handling of controls and escapees

5.2.2 Collection methods and attachment devices for escapees

<u>Attachments</u>

a) Cod-end cover/cage
b) Grid cover/cage
c) Escapee panel cover

<u>(Includes) release methods for the above cover/cage attachments by use of</u>

a) Remote release at depth (acoustic, mechanical)
b) Diver release at depth
c) Surface detached

<u>Collection by divers (shallow water operations)</u>

a) Free diving
b) Diver and towed vehicle

5.2.3 Other collection methods

<u>Collection Traps</u>

Attachments to:

a) Gillnet
b) Set-net
c) Traps
Purse seine trap
Trap for longline

<u>Mobile Collection Devices</u>

Various collecting methods for benthic invertebrates sorted out from a cod-end either during or after trawling

5.3 Transportation of Escapees (Fish)

5.3.1 General

a) If possible, avoid excessive transportation unless extremely confident in the methodology
b) Minimise transport distance, pressure changes, environmental changes, towing speed, towing time, etc
c) Ensure consistent handling of escapees and controls

5.3.2 Methods

a) Towing the cages - with or without divers
b) Towing a transportation device (either the whole cage, or fish transferred to device) made of material to eliminate water flow
c) On board transportation (tank, well) for fish caught near surface. (Avoid sunburn and transportation in strong wave action)
d) Diver transportation (eg in black plastic bags to minimise panic activity)

5.4 Holding Methods

5.4.1 Location

- Controls and escapees treated equally
- Habitat similar to the natural habitat where the fish were caught
- All cages ideally kept under the same environmental conditions (distance between comparing cages not too far)
- Cage proximity to ensure easy monitoring
- Position of the cages in the water column depends on the species under investigation and their habitat - namely

    - Midwater cages for pelagic species
    - Bottom or near bottom cages for demersal species
    - Burrowing species to have bottom substrate
    - Benthic species on sea bed

5.4.2 Design of cages

- Cage size depends on experimental design (species, size and number of fish to monitor)
- Shape (height etc) depends on species - namely: area important to some species (eg flatfish and *Nephrops*) while volume may be important to others, (eg pelagic fish)
- Simple to install and operate
- Material not abrasive to reduce possible damage to fish
- Species of fish determines whether to have a bottom to the cage or natural substratum
- With suitable openings for accessing of feeding and removal of dead fish
- Cage netting materials (colour/contrast) may hinder television observation/ monitoring, but may also contribute to fish damage due to collisions with virtually invisible materials

5.5 Monitoring of the Experiment

5.5.1 Collecting data and monitoring of environmental conditions

This should include:

- Gear characteristics
- Operational details (especially towing speed and tow duration)
- Catch details (species, volume, debris)
- Weather and sea conditions
- Seabed type
- Salinity
- Water depth
- Water/air temperature (including vertical profiles eg using CTD)

Additional information to monitor may be dependent on species and experimental goals. For example, for deck discards survival studies, the following should be collected:

- Air temperature (and temperature on deck)
- Humidity
- In air exposure period of specimens

For *Nephrops*: light intensity and duration of exposure to light; air and water temperature.

5.5.2 Survival/mortality observations

Fish characteristics and condition (trauma classification): Escapees and controls (record time of mortality, escapees or termination of experiment/controls). For discards, record on deck and at time of death or termination of experiment.

- Fish characteristics and conditions - record by using "Trauma Classification Sheet" or by photography

  - Length, weight, girth and degree of body scale damage
  - Eye, gill appearance
  - Oral and cloca inversion or protrusion, degree of extrusion
  - Laceration, abrasion and fin damage, location and degree of damage

- Physiological sampling

  - Tissue
  - Blood chemistry

Additional elements to monitor may be dependent on species and experimental goals.

5.5.3 Observation duration

- Observation durations are an important factor determining the final mortality data
- Some examples of observation monitoring of previous studies have been from a few hours to as many as 60 days
- The termination of a particular experiment may be dependent on the accumulative mortality
- In principle (if possible), the duration of the study should relate to a time period whilst the cumulative mortality curve has a negligible change
- Short term duration's should ideally require a minimum of one week but an extended period may be required
- Attention should be paid to the occurrence of cage mortality which could limit duration of effective experiment (in that case, modification to holding technique may be required for future work)
- Long-term mortality will require monitoring of the experiment for some months

5.6 Evaluation/Analysis/Interpretation of Resultant Data

In any analysis and evaluation of a set of survival experiment data, the following points should be considered which may lead to a better interpretation of the results,

Why do escapees and/or discards die?
What are they dying from?
How and by whom will the results be used?

There will be two main users of the results:

a.) Escapee survival and/or discard survival rates will be used by fisheries managers and stock assessment people to increase the knowledge of the relationship between fish size, gear selectivity and survival and hence, place stock assessment calculations, which need to assume a value for fishing mortality, on a sounder basis.

b) Causes of death due to a specific identifiable mechanism of the trawling process may be used by gear designers to consider modifications to net design which may in turn lead to minimising escapee mortality due to gear induced injuries.

5.7 Laboratory Simulations - Survival

The following are guidelines to be considered in any laboratory simulation experiment on survival:

<u>Species</u>

Fish or shellfish

Experimental design and planning

a) Parameters to test
b) Sample size required for the treatment, controls and replication (NB sample size is also dependent on whether the experiment examines just survival or includes stress measurements eg requiring blood chemistry analyses or damage assessments requiring physiological/ histological assay.
c) Monitoring and recording
   Holding tank - environmental parameters
   Trauma classification

Holding design and conditions

- To meet species needs and comfort
- Temperature, density and light intensity
- Feeding requirements

Transportation - from source to laboratory

Maintenance of

- Temperature
- Dissolved oxygen
- Motion stability - either due to sea state or by road

Acclimation of specimens prior to treatment exposure - CRITICAL

- Adequate time period
- Feeding and eating

Treatment

a) Exposure: - single parameter; - multiple parameters (synergism)
b) Controls must be subjected to the same conditions as the treatment specimens, except for experimental exposure
c) Replications
   Identical exposure
   Adequate controls

Adequate post-exposure monitoring

a) Time period or duration
b) Monitoring frequency
c) Stress frequency

Future Research

It is generally understood that survival research is a fairly "new" science and that information is limited to certain gear types and species. However, experimental methodologies are improving with advancing technology. Large gaps in our knowledge on the subject still remain and are in need of more investigation. These include:

A Cause of death - primary, secondary, tertiary factors)
B Stress assessment*
C Relationship of A and B
D Relationship between survival and fish size, age and fitness

6. RECOMMENDATIONS

The Sub-group on fish survival recognises:

- The lack of knowledge of the unaccounted mortalities associated with the fishing processes and their impact on stock assessment and the ecosystem;
- That limited methodologies and results exist for various fishing gears and species

The Sub-group recommends that:

1. The fate of fish that encounter each phase of the fish capture process must be understood
2. Impacts of unaccounted mortality be investigated based on biological and economic consequences
3. Selectivity studies require a complementary understanding of survival
4. Efforts be made on the development of methodologies to obtain results for fisheries of commercial importance
5. More research is needed to identify the factors causing stress** and mortality of fish during the capture process.
6. Research should be aimed at identifying and correcting the damaging mechanisms of fishing gears.

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*Stress assessment may be a tool in the future to assist in determining causal factors of death, and may assist in mitigation- identifying and decreasing mortality.

**Stress assessment is a tool that assists in determining causal factors of mortality and aids in mitigation.

APPENDIX 1

A REVIEW OF THE SURVIVAL OF FISH ESCAPING FROM FISHING GEARS

Graham I Sangster

ABSTRACT

For minimum mesh size regulations to be justified, most of the fish escaping from nets and cod-ends must survive. Since passing through meshes can lead to the fish becoming damaged with possibly fatal effects, survival rates need to be investigated. This paper reviews work in several countries to assess the survival rates of escaping fish: pelagic and demersal. Most of the investigations concentrate on escapes from cod-ends.

INTRODUCTION

Mobile fishing gears (trawls and seines) herd fish into the mouth of the net where most swim until exhausted then drop back to the cod-end. Although some escape through the forward panels of the net, most reach the cod-end, and if small enough in girth, can pass out through the open meshes, either voluntarily or involuntarily. Any fish which has to wriggle or squeeze through the cod-end meshes may be damaged in the process and its chances of survival may be reduced. Since minimum mesh size regulations are imposed in many fisheries to enable small fish to escape from nets and grow to maturity, it is important to know whether the escaping fish survive. If survival rates were low, the mesh regulations would be ill-founded and of little value for conserving stocks.

This report reviews the work which has been done in recent years to investigate the survival rates of fish-pelagic and demersal escaping from nets. the information, up to the present time, from various countries is presented separately.

Scotland

Main and Sangster (1990) described an investigation into the scale damage suffered by young gadoid fish escaping from cod-ends and the survival rates of escapers held in captivity. The work took place from 1985 to 1988. There was no clear relation between scale loss and fish length in the species examined (haddock (*Melanogrammus aeglefinus* (L.) and whiting (*Merlangius merlangus* (L.)) Scale loss was greatest at 70 mm diamond, the smallest cod-end tested and decreased with increasing mesh size (up to 90 mm diamond). There was little difference in the scale damage to haddock escaping from square and diamond mesh cod-ends of similar mesh size. Scale loss tended to increase towards the tail in nearly all fish examined. It was observed that most fish longer than 18 cm suffered some scale loss during escape and that the damage was not due to a single cause.

Haddock escaping from the test cod-ends were caught and held in 17 m^3 cages on the sea bed. Their survival rates were compared with control groups of hand-line caught haddock.

Scale damage is not the only possible cause of death in these captive fish, and to increase confidence in the findings triple experimental groups were used in 1988. The survival rates of the control groups were 97-100%. For 90 mm diamond and square mesh cod-ends, which are not directly comparable as the latter has a larger mean selection length, the survival rates were 67-74% and 92-94%.

Main and Sangster (1991) described further work in 1989 and 1990 on the survival of escaping cod (*Gadus morhua* (L.)), haddock and whiting using similar methodology. Furthermore, they began a physiological investigation into the possible causes of death. The results were inconclusive but the possible causes include loss of osmoregulation (from scale loss), internal organ damage (from squeezing or crushing within the cod-end) and viral or bacterial infections (from skin damage). Triplicated survival data for the three species are presented and analysed for all the cod-ends used. These revealed that of the fish which escaped from a conventional 90 mm diamond cod-end with 120 diamond meshes round the circumference and from a 90 mm diamond cod-end with a square mesh window, 75% and 76% respectively survived. The 95% confidence limits are ±9%. These rates are significantly lower than found with cod-ends of 90 mm diamond with 100 meshes round, 80 mm square mesh and 100 mm diamond with 120 meshes round, which were 94±5%, 91±5% and 91±6% respectively. Some of the lower survival rates found with 90 mm cod-ends were attributed to damage caused to the fish in the cod-end prior to escape by debris swept up by the net and not released.

The aforementioned work by Main and Sangster (1990 and 1991) describes the results of actual experiments set up to specifically investigate fish damage and survival from bottom trawl cod-ends. However, other direct observations by these authors of fish escapes from other parts of fishing gears have been reported and are relevant to be included in this review.

Main and Sangster (1981) described whiting escaping from a bottom trawl in an area of the batings where the cross-sectional diameter was reduced to approximately 2 m. Many of these fish turned here at right angles to the water flow and struck out through the meshes. However, some, depending on their body girth size had to squeeze and wriggle through the meshes to escape. Scale removal was inevitable in these cases. No data is available on their eventual fate. The onset of escape behaviour appeared to be related to the density of packing of individuals in the bating area of the net. The authors also reported that cod were seen to escape under a bobbin type groundgear. As these fish were herded and eventually aggregated just ahead of the groundline, they tired and their steady swimming behaviour changed to a pronounced "kick and glide" action soon to be followed by a fast zig-zagging track between the quarters of the bosom bobbins. Cod then swam very close to the sea-bed and succeeded in escaping under the groundline between the bobbin spacers. Fish interactions with bobbins were not reported during these observations, but collisions with groundgear and subsequent damage cannot be ruled out. No data is available.

Main and Sangster (1983) described possible saithe (*Pollachius virens*) damage during their feeding behaviour in the mouth of a bottom trawl. The saithe appeared to be so intent on the food source that they seemed unconcerned by the presence of the fast approaching trawl. Some were hit by the groundrope; one was stunned and was eventually run over by the net and others were also run over by the footrope and escaped. Some degree of body damage was inevitable, but no data is available as to the eventual fate of the escapees. Saithe and haddock were also observed trying to hold station to avoid a "flapper" just ahead of the cod-end of a bottom trawl. Both juvenile and marketable sizes of fish were squeezed and bumped together as they eventually slid and scraped along the flapper as they dropped back to the rear of the cod-end. There was obvious physical damage due to scale loss to all sizes of fish passing through this area. These observations are evidence that scale damage can occur to all sizes of fish before cod-end mesh selection takes place.

Main and Sangster (1988) described haddock and whiting squeezing and wriggling through the extension of a seine net during the hauling process, at a time when the net was just below the surface. This was due to the "wash out" action which allowed the meshes to fully open and close caused by the surface wave motion. These escapees must have suffered scale losses but no data is available as to their eventual fate. The authors also reported haddock, whiting and cod escaping from a seine net cod-end just below the surface at the end of a 60 minute tow. This occurred during a four minute period while the net was stationary, the bridles were disconnected and the wings transferred on to the powered hauling block. The fish swam the whole length of the net and escaped either through the large belly meshes or out through the net mouth. These fish may have sustained some form of damage during their time in the cod-end but no data is available as to their eventual fate.

Sangster and Lehmann (1993) described an investigation into the survival of young haddock and whiting after escape from bottom trawl cod-ends. They used diving techniques to transfer the entire quantity of cod-end escapees into a towed underwater fish transportation container. This 7 m long torpedo-shaped device housed the escapees in a flow free environment and could transfer the fish up to 10 km at a speed of 1.5 ms^{-1}, if necessary. Direct observations by divers showed that the contained fish swam leisurely around the inside of the container and did not display any form of panic behaviour. The fish were transferred to 27 m^3 cages on the sea bed. To increase confidence in the findings, triplicate groups of fish from each cod-end mesh size category were used and their survival rates compared to those of control groups of hand-line caught fish. The survival rates of the controls were 100%. The survival rates for haddock and whiting experimental groups were 73-79% and 65-82% (90 mm cod-end), 74-86% and 68-82% (100 mm cod-end) and 82-91% and 82-90% (110 mm cod-end) respectively.

Sangster and Lehmann (1994) described experiments into the survival of, and damage to haddock and whiting as a result of escape from 70, 90, 100 and 110 mm diamond mesh cod-ends. Cod-end escapees were collected and transferred by divers into 35 m^3 cages on the seabed where their survival against control fish was monitored over a period of 60 days. Triplicated cage experiments showed a range of results for the survival of 15-38 cm haddock and 17-35 cm whiting. The survival rates for the haddock and whiting experimental groups were 48-67% and 52-60% (70 mm cod-end), 79-82% and 73-78% (90 mm cod-end), 73-83% and 67-77% (100 mm cod-end) and 85-89% and 83-86% (110 mm cod-end) respectively. The survival rates of the controls were 100% for both species. These percentages relate only to the numbers of survivors from the total escapees in a particular cod-end mesh size category, regardless of fish length. Further analysis of the data revealed that the survival of the smaller cod-end escapees was much worse than for larger fish of either species. This suggests that survival may be a more complex function of fish length. Furthermore, there was no clear relationship between survival and mesh size for this haddock and whiting population over the diamond mesh range of 70-110 mm. Analysis of the fish body damage, using an image analyser technique revealed that the mean total percentage damage was not dependant on mesh size. The mean damage measured on both flanks of most fish was shown to be distributed equally between the two sides. The proportion of damage appeared to increase towards the tail. There was no apparent difference between the damage seen in either haddock or whiting. The image analysis method produced a more accurate and reproducible method for the assessment of fish skin damage than with previous methods

England

Lockwood *et al.* (1977) investigated the survival of the North Atlantic mackerel (*Scomber scombrus* L.) after escape or release from a purse net. Fish were held at different densities in cages to assess survival rates when prevented from moving freely in the open sea. It was found that 50% of the fish died after 48 hours at a stocking density of 30 fish m^{-3}. Trials with fish densities comparable to those experienced in a "dried up" purse seine prior to "slipping", showed that up to 90% of "slipped" fish died within 48 hours of release. The primary cause of death was probably skin loss, caused by abrasion, although there is some evidence that mackerel have a healing process which can cope with minor skin abrasions. The authors conclude that mackerel held at low density in a relatively large net will suffer some mortality, but when held, even briefly, at high densities have no chance of survival. It was clear from these experiments that the mackerel is an extremely delicate fish.

Kaiser and Spencer (1993) assessed the immediate effects of beam trawling in the Irish Sea on flatfish species in a benthic community. They used a tank system attached to a metal framework which can be bolted on and off ship. The tanks are 4 m long with removable partitions so that compartment size could be altered to suit the animals under investigation. The whole system was supplied with ambient sea water running to waste and was covered with a tarpaulin to eliminate light, heat and disturbance. However, the system was prone to ship's movement, hence severe weather is a limiting factor to experiment duration. However, it was prudent to run such experiments for a least four days so that the effects of delayed mortality became apparent.

Millner *et al.* (1993) carried out tagging and cage survival experiments to estimate the discard mortality of plaice (*Pleuronectes platessa* L.) from small otter trawls, with and without tickler chains. Two separate methods were used to estimate the mortality of plaice. The first involved holding the discarded and control fish in cages and recording their mortality over a period of up to 216 hours. In the second method, discarded plaice were tagged and returned to the sea and their recapture rate compared with a control group of plaice caught by 15-30 minute tows. The results of the cage studies indicate that the short-term survival of discards from the light otter trawl is high (>80%) for the first 100 hours and there was no difference in survival between experimental and control fish. Estimates of longer term survival derived from the recapture of tagged discards confirm that survival is likely to be above 50% and could be substantially better.

Norway

Roald (1980) studied the pathological effects of net mark injuries on Atlantic salmon (*Salmo salar* L.). Healthy and injured fish were transferred from bag nets to floating keep cages in brackish water. During the four months of observation, no mortality occurred. Analysis of the sodium and potassium levels in the serum of severely injured fish showed significant increases in concentration compared to that of control fish. The increases were attributed to skin lesions which in most injured fish had healed after four months.

Engas *et al* (1990) studied in tanks the effect of high swimming activity combined with simulated net mesh injuries on the survival rates of cod and haddock. Four of 27 haddock had died after seven days with secondary infections in their injured skin. One out of 58 cod died after eight days of treatment. All control fish survived. The observation period ended after 14 days. This tank experiment may indicate that haddock are more sensitive to this kind of damage than cod. The mortality was much lower than was observed in a similar experiment with saithe (*Pollachius virens* (L.) held in net pens (Soldal *et al.*, 1989). The authors considered it difficult to relate the findings in these experiments to what would happen to fish escaping from real trawls.

Isaksen (1991) carried out an experiment with a trawl comparing the survival of haddock and cod and (Soldal, 1991), the scale losses of haddock and cod which had escaped from a 135 mm diamond cod-end or a rigid grid. Fish which escaped from the cod-end were guided by an enveloping cover aft to a large framed 20 m^3 cage towed by the net. This was detached and closed by a remotely controlled mechanism. The cage was then either towed to shallow water for survival observation or raised on board the ship for scale loss assessment. When large numbers of fish were collected, the cage was very congested and the death rate was high. Haddock were seen to have suffered significant scale damage when escaping but cod were relatively unharmed. As there were no control groups in the survival experiment, the author advocated caution in drawing any conclusions from these findings. Furthermore, when the cage was towed to the observation zone, water pressure can force the fish against the netting and cause more scale loss. Control groups were used in the scale loss experiment which revealed less than 1% scale removal of the body surface for treated and control cod larger than 30 cm. There was an indication of a higher scale loss in smaller cod, but as only five specimens were analysed, it was difficult to draw any conclusion. Scale loss of haddock was substantially higher and highly dependent on fish size. The scale loss of mesh selected haddock below 40 cm was significantly higher than that of grid sorted fish. The smallest length groups of control fish also showed significant scale loss and there was little difference between controls and grid selected haddock. This could indicate that the experimental methodology caused unwanted damage, particularly to small haddock.

Soldal *et al.* (1991 and 1993) reported on further survival experiments on cod and haddock. These results produced survival estimates for cod of 100% and 93.5 to 99% for mesh (135 mm diamond) selected and 89.5 to 94.5% for grid selected haddock. These results agreed well with their small scale experiments as well as to results from their Danish seine net (135 mm diamond mesh) experiments where a 100% survival of cod and a 93.2-96.8% survival of haddock was found.

Soldal *et al.* (unpublished) studied the survival of one year old cod and haddock in the shrimp trawl fisheries using techniques similar to those used by the Norwegians in their earlier experiments with demersal trawls. The experiments are not finished as yet, and survival data is not available. Soldal *et al.* (unpublished) investigated whether cod that have escaped from a trawl and are damage or fatigued are more easily eaten by a predator than undisturbed fish. Simulated trawling experiments were performed in circular tanks on groups of 0-group cod (10-12 cm) at different towing speeds. Fish passing through the 70 mm cod-end meshes were released along with controls into an aquarium housing large cod (30-40 cm). Numbers of fish eaten by the predators from each group were recorded. The results are not yet available but the authors realise the problem of assessing the results from simulated experiments with what occurs in nature.

Misund and Beltestad (1992) investigated their herring purse seine fishery where incidental fishing mortality may occur after net bursts or during storage of live herring in netpens. They simulated two net bursts by pulling up netpens until they split by the weight of the herring. In both cases, the experimental group suffered more than the control group and few herring exposed to a simulated net burst survived more than 120 hours. These authors also quantified the mortality of herring that were captured by purse seine, transferred to netpens, and towed inshore for storing. This study indicated that survival was primarily determined by the size of the netpens, since the survival percentage was low in small netpens and high in large ones. Beltested and Misund (1993, 1994) studied the survival of mackerel after sorting from a purse seine by a metal grid. The results showed 36% survival for the Experimental group and 56% for the control. However, the fish had been towed in a net pen for 15 hours before the selection experiment and in doing so, may have increased mortality considerably. Further, similar experiments on grid sorting of mackerel in purse seine fisheries showed mortality rates of 1.6, 0.5 and 1.1% in three parallel experimental groups, while the triplicate control results showed 1.1, 1.8 and 0.7% mortality rates. The fish in this latter experiment were small and they passed through the sorting grid without skin contact with the metal bars.

Finland

Suuronen (1991) reported preliminary studies on the size selection and survival rates of herring (*Clupea harengus* L.) escaping through a grating and a square mesh netting panel. The grating was of stainless steel with a bar spacing of 14 mm. The mesh size of the square mesh netting was 35 mm. Both devices were tested in the front upper panel of the extension piece in pelagic trawls. Control groups were obtained by removing the device under test and allowing fish to pass through the gap. Escaping fish were retained in a hooped cage which was detached from the net when enough fish had entered and kept at the same depth. After 1-12 days, the cages were raised to the surface and both dead and live fish were counted and measured. Survival rates varied considerably, but averaged 60% for both experimental systems and were higher for the controls (60-94%). Mortality increased with time in the cage and decreased with increasing fish size. Further experiments were carried out by Suuronen *et al.* (1993) using similar techniques with a 12 mm grid bar spacing and 36 mm diamond mesh cod-ends. Most deaths in the retaining cages occurred during 3-8 days after escape and mortality was negligible after 10-12 days. The average survival of cod-end escapees (length 8-17 cm) after two weeks caging was 10-15%, and that of fish escaped through the sorting grid around 10-15% higher. In the grid selected herring there was a slightly decreasing trend in the survival rates towards the smaller fish groups, but in cod-end selected herring, no size-dependent long-term mortality was observed. However, the mortality rate among the smallest individuals was higher during the first days after escape. Control fish caught by hook and line suffered little mortality during a three weeks caging period. It was assumed that the main part of the mortality found in escaping herring was attributed to contacts with the trawl.

Turunen *et al.* (1994) studied trawling stress and mortality in undersized brown trout (*Salmo trutta* L). This species was examined at open-water seasons on the big lakes in Eastern Finland. It was generally assumed that undersized trout freed after being caught in trawls do not survive. Blood lactate and glucose concentrations and plasma chloride concentrations were measured from blood samples taken immediately after trawling. The recovery of the fish from trawling stress was also monitored by blood sampling and following the mortality of fish caged for seven days after capture. Trout were considerably stressed by trawling. Abundant catch and high water temperature increased stress of the trout. These variables and the duration of trawling as well as the cod-end emptying technique explained 72% of the increase of blood lactate. The indicators of stress did not return to control values by four hours post-capture, but blood lactate showed an abrupt decrease over two hours. Plasma chloride concentration was, however, still decreasing four hours after the end of trawling. The percentage of caged fish which survived a week was 85.5%. Lifting of the cod-end to the vessel clearly increased the mortality of trout. Without the extra stress connected with caging, the proportion of surviving fish would probably have been greater. On the basis of the results it was concluded that if the undersized trout were freed immediately by emptying the cod-end in small portions directly in the water, trawling would not cause them considerable mortality.

Faroe Islands

Jacobsen *et al.* (1992) carried out a pilot study to estimate the survival of saithe (*Pollachius virens* L) after escape through 145 mm diamond cod-end trawl meshes. This work continued in 1993 (Jacobsen, 1994). Escaped fish were collected in fine meshed net cages (supported on 2 x 2 x 5 m aluminium frame) mounted aft on a cod-end cover. After one hour trawling between 150-250 m depth, the cages were released by means of an acoustic release system and slowly hauled up to 40 m below the sea surface for television observations. The cages drifted freely in the open sea and were located by radio tracking buoys. No mortality was observed for cod and the results indicate that saithe can withstand almost the same cod-end mesh sorting as cod with high survival (96-100%). Haddock was more vulnerable with 15% mortality, and the results for whiting indicated 7% mortality. The results for *Sebastes viviparus* indicated high survival (94-100%).

Canada

Black (1958) reviewed research into hyperactivity as a lethal factor in fish mortality. This included preliminary studies by Von Buddenbrock (1938) on cod and plaice (*Pleuronectes platessa* (L.)) in sea water, Secondat and Diaz (1942) on tench (*Tinca tinca*) in fresh water, Litt (1954) on striped bass (*Roccus* sp.) in fresh water, Black (1957) and Parker and Black (1957) on sockeye and chinook salmon (*Oncorhynchus* sp.) in sea water. These studies investigated the effects on these species of captivity, vigorous chasing, maintaining position in turbulent flow and struggling in nets and troll lines. Deaths occured under varying conditions following intense muscular activity but the precise causes of death was not determined. However, it was suggested that the severe disturbance to the acid-base relationships following the large increase of lactic acid liberated from muscle glycogen may be the principal cause of death. All workers concluded that hyperactivity in fish, as a possible lethal condition, should be considered in the study of fish biology and fisheries.

Beamish (1966) studied muscular fatigue and mortality in haddock caught by otter trawls and in 1967 the same author studied cod fatigue and mortality in the Atlantic cod using an exercise chamber. Haddock mortality ranged between 7 and 78%. No mortalities attributed to muscular fatigue occurred among cod.

Hoag (1975) investigated the survival of the Pacific halibut (*Hippoglossus stenolpis*) after capture by trawls. The physical condition of over 2,000 halibut caught and released by trawlers was assessed, and fish were placed in one of five categories based on their external injuries and physical activity. Fish condition was positively corelated with size and negatively with time on deck and total catch weight. Most of the fish were tagged, and the recovery rate declined with poorer condition. The criteria for judging condition were not entirely accurate as some of the fish that were considered dead subsequently recovered. The survival rate of fish was estimated from the number of tags recovered, expected rates of fishing mortality and other losses. The average survival of halibut in all conditions was estimated as 28% for those smaller than 80 cm and 55% for those larger than 80 cm. The survival of the smaller fish was probably underestimated and the author suggests that the survival for all sizes was about 50%.

Neilson *et al.* (1989) assessed the effectiveness of a proposed 81 cm minimum landing size limit for Atlantic halibut (*Hyppoglossus hippoglossus*) in Canadian waters. They examined the survival of small fish caught by longline and bottom trawl gear and held in tanks, firstly on board a research vessel and subsequently, in a shore laboratory. Of halibut less than the proposed size limit, 35% of the otter trawl catch and 77% of the longline catch survived more than 48 hours. Factors potentially influencing halibut survival (handling time, total catch, fish length, maximum depth fished and trawl duration) were examined using proportional hazard models. On the basis of the analyses, it was concluded that in bottom trawl hauls of the duration normal in the commercial fishery (at least two hours) higher survival times were associated with shorter handling time, larger fish size and smaller total catch weight. Supplementary information on the condition of trawl caught halibut was also obtained from observers on board commercial trawlers.

USA

Reifsteck and DeAlteris (1990) described investigations during 1988 and 1989 into the escapement of juvenile scup (*Stenotomous chrysops*) and winter flounder (*Pleuronectidae* sp.) from diamond (60 mm) and square (60 mm) mesh cod-ends using a simulation apparatus. The validity of the methodology used for investigating the behaviour of bottom trawl cod-end escapees is discussed and critically evaluated. After escape from the cod-end into the cover, the fish were eventually transferred to a cage on the sea bed where they were monitored for mortality. Results of the 1988 scup experiments indicated that there was a 95% survival of the control fish. The mean survivability of square and diamond mesh escapees was 94 and 50% respectively; and these were significantly different (p=0.05) from each other. In the 1989 scup trials, control fish survival was 100%. Square mesh and diamond mesh treatment survival was 100 and 97% respectively. No significant difference (p=0.05) was found between square mesh, diamond mesh and the control treatments. The flounder trial resulted in high survival of control fish and variable survival of experimental fish.

Robinson, Carr and Harris (1993) investigated the survivability of the juvenile bycatch (deck discards) and cod-end escapees of Atlantic cod (*Gadus morhua*), American plaice (*Hippoglossoides platessoides*) and yellowtail flounder (*Pleoronectes ferrugineus*). Survival rates were determined by placing the "discarded" fish in large cages and returning them to the tow depth for a period of about 24 hours. Results varied with fishing season. Spring survival rates were 51% for cod (N=99), 66% for plaice (N=114) and 77% for yellowfin flounder (N=144). Summer survival rates produced 9% for cod (N=244), 40% for plaice (n=182) and 66% for flounder (N=36). Winter fishing figures were 36% for cod (N=47), 0% for plaice (N=37) and 50% for flouder (N=15). The primary factors that were determined to influence survival were air temperature, decktime, fish length, tow duration and tow weight. Air temperature, deck time, fish length and tow duration were most critical to plaice survival. Tow duration and deck time affect the survival of yellowtail flounder. Cod, yellowtail and plaice blood samples were taken from a sub-sample of landed fish and analysed for haematocrit, protein, lactate, chloride, glucose, sodium, potassium, total osmolality and cortisol. With the exception of glucose, all measured parameters for cod bycatch were generally elevated above control values, even in those fish sampled within three minutes of landing on deck. Yellowtail, in, contrast, generally exhibited elevations in all parameters except for cortisol. No control American plaice data were available for comparison. Lactate was the only blood parameter that continued to rise in all three species as time on deck was extended. Cod also exhibited increases in protein, haematocrit, K and cortisol. Total osmolality increased as time on deck elapsed for both yellowtail and plaice (as well as chloride in yellowtail; glucose, K and haematocrit in plaice). These data demonstrate that cod and yellowtail had been considerably stressed prior to landing. Although fish were subjected to highly stressful conditions on deck, this additional stress was less than that which the fish experienced prior to being landed. Atlantic cod bycatch, caged bycatch and cod-end escapees all exhibited perturbations of osmotic balance and elevations in several of the other non-osmotically-linked blood parameters. In general, cod-end escapees were less stressed than the caged bycatch, which in turn were less stressed than the deck-processed bycatch.

Netherlands

Bergman *et al.* (1989) investigated the effects of beam trawling on densities of fish in a 2 x 2 nautical miles area 25 nm off the Dutch coast. They stated that direct effects of beam trawling on the densities of various fish species in the area were not found. Most small fish apparently escaped through the meshes of the commercial trawl fairly undamaged. At least 56% of dab (*Limanda limanda* (L.)), 85% of plaice, 100% of sole (*Solea solea*) and 68% of dragonet (*Callionymidae* sp.) and solenette (*Microchirus boscanion*) which escaped from the cod-end into a cover survived the first 24 hours after capture.

Van Beek *et al.* (1989) studied the survival of undersized plaice and sole caught in the otter trawl and beam trawl fisheries of the North Sea. They also investigated the survival of soles that escaped through the cod-end meshes in covered cod-end experiments. In the commercial beam trawl fishery, the survival of both undersized plaice and sole was estimated to be less than 10%. The survival of soles that escape through the meshes was estimated at 60%. Deaths were attributed to the fishing process, through the action of the tickler chains and the injuries inflicted during the stay in the net. The present day commercial practice of processing the catch on deck would be likely to increase the mortality of the small fish which are discarded.

Germany

Berghahn *et al.* (1992) investigated the mortality of various species of fish bycatch from shrimp trawlers that utilise automated sieving devices to grade shrimp. Mortalities increased considerably after the catch passed the sorting sieve. 100% mortality was detected for whiting (*Merlangius merlangius*) and 10% for sculpin (*Myxocephalus scopious*), hooknose (*Agonus cataphractus*) and eelpout (*Zoarces viviparus*) in the discard groups. Survival of flatfish depended strongly on the species, the size of the specimens as well as the catch and catch processing conditions, and ranged from 17-100%. No differences were detected in the survival after sorting on different machines. They concluded that clearly the sorting methods had an important influence on the mortality of discards, especially when mechanical devices were used. However, due to better sorting efficiency, the rotary sieve may reduce mortality of fish in the bycatch.

Von Kelle (1976) reported on the survival rates of undersized flatfish (*Plueronectes, Limanda* and *Solea* species) in the German shrimp fishery. The relationships between mortality rate and haul duration, catch quantity, catch composition, fish size and treatment on board were analysed. There was a direct relationship between towing time, total catch weight and survival of small sole, dab and plaice. The survival rate of undersized flatfish was 51% for plaice, 57% for sole, and 26% for dab. Cyanea and Pleurobrachia showed a positive influence by decreasing the survival rates of fish when they appeared in the by-catch in large amounts.

USSR

Treschev *et al.* (1975) carried out experiments on the mortality of Baltic Sea herring escaping from a 32 mm diamond mesh cod-end. They compared the survival of control and test fish held in sea-bed cages. Mortality did not exceed 3% on average, however, mortality was increased to 12.6% with large by-catches of spiny fishes.

Borisov and Efanov (1981) conducted experiments on the mortality of Baltic herring escaping from 28 and 32 mm diamond mesh cod-ends which gave survival figures of 85% and 90% respectively. A study of the physiological condition of escaping herring revealed that mortality could be higher in fish with a low energy level and that smaller fish (less than 9 cm) suffered the most.

Efanov and Istomin (1988) carried out experiments on the survival of Alaskan pollack which had passed through a 50 mm diamond mesh cod-end and were collected in a small mesh "container" during trawling. The container was slowly raised to the surface allowing the captive fish to decompress. Mortality of these fish ranged from 2.3 to 7.7%.

Zaferman and Serebrov (1989) used an underwater submersible to make bottom trawling observations in the Barents Sea of cod and haddock escapes from a 100 mm diamond mesh cod-end. After hauling the fishing gear, observations along the trawl path revealed that dead haddock were frequently seen lying on the sea bed. Their size range and numbers were similar to haddock caught in the same area using a small mesh covered cod-end technique. Dead cod were also seen lying on the bottom, but in much fewer numbers. The sizes of these cod were similar to 60-80% of cod retained in the cod-end.

Australia

Hill and Wassenberg (1990) made a study on the fate of teleosts, non commercial crustaceans and cephalopods discarded from trawlers in Torres Strait. These groups take up about 80% of the discards by weight, have a high mortality rate and are therefore the most likely animals to be eaten by scavengers. The remaining 20% of discards consists of animals such as turtles, sharks, bivalves and sponges, which are caught in low numbers and appear to have a low mortality from trawling. Fish made up 78%, non-commercial crustaceans 18%, and cephalopods 3% by weight of the material studied. Nearly all fish were dead when discarded and about half sank. About half of the non-commercial crustaceans were alive when discarded and all sank when discarded. Few cephalopods (2%) were alive when discarded and around 75% sank. Sharks and dolphins were the most common scavengers of floating discards at night. Birds (common and crested terns, and lesser and greater frigates) scavenged only during the day. Discards that sank did so rapidly, taking less than 5 mins to reach 25 m depth. Sharks and teleosts (nemipterids) ate most of the material that reached the bottom; scavenging by invertibrates was negligible. In an adjacent area that had not been trawled for eight years, no dolphins and fewer birds were seen scavenging floating discards but there were more sharks. In this area, significantly fewer fish were attracted to a bait on the bottom at night compared with the trawled area. The cause of the difference in scavenging observed between the two areas is not known; while it may reflect learned behaviour by some scavengers such as birds and dolphins, there may also be intrinsic differences between the two areas unrelated to trawling. Discarding from trawlers had the effect of transferring large quantities of biological material from the bottom to the surface. This made available to scavengers food that would otherwise be inaccessible.

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Turunen, T., Kakela, A. and Hyvarinen, H. 1994. Trawling stress and mortality in undersized (<40 cm) brown trout (*Salmo trutta* L.). *Fisheries Research,* **19**, 51-64.

van Beek, F.A. *et al.* 1989. On the survivalof plaice and sole discards in the otter trawl and beam trawl fisheries in the North Sea. ICES CM 1989/G:46.

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APPENDIX 2

AN ANNOTATED BIBLIOGRAPHY OF STRESS, INJURY AND MORTALITY OF FISH ASSOCIATED WITH FISHING PROCESSES

Pingguo He

INTRODUCTION

Studies on capture related stress, injury and mortality of fish can be classified into five broad categories according to their purposes and applications:

a) Causes of mortality associated with exercise and fish capture processes
b) Capture and tagging mortality of fish in tag and recovery experiments
c) Survival of fish in catch-and-release sports fisheries
d) Survival of fish caught by fishing gears and discarded
e) Survival of fish escaped from fishing gears

Causes of Mortality Associated with Exercise and Capture Processes

Basic research into the cause of death in fish involved measurements of biochemical changes of blood or muscle following capture or simulated capture processes such as exercise. The purpose was to determine how death occurred under various conditions in reference to biochemical changes. Various parameters of blood and muscle were measured including lactic acid, cortisol, glucose, ATP and related products. Earlier works included those of the Canadian scientist E Black and his colleagues (Black, 1958; Parker and Black, 1959; Parker, Black and Larkin, 1959) and more recently others (Bouck and Ball, 1966; Bourke *et al.*, 1987; Caillouet, 1971; Wood *et al.*, 1983; Xu *et al.*, 1993). While some researchers contributed exercise or capture related death to severe acidosis (Black, 1958; Caulouet, 1971; Wood *et al.*, 1983), others discounted this and attributed the cause to excessive haemodilution (Bourke *et al.*, 1987).

Post-capture and Tagging Mortality of Fish in Tag and Recovery Experiments

Another important issue in fish survival study is the mortality associated with capture and tagging processes. Tag and recovery experiments have been used in abundance and migration studies in both fresh water and marine species. Unaccounted delayed mortality in tagged and released fish can affect the recapture ratio. Examples of work on this aspect include Rutecki and Meyers (1992) and Pierce and Tomcko (1993).

Survival of Fish in Catch-and-release Sports Fishing

Sports fishing is becoming more and more important and in many areas catch-and-release is practiced to conserve the resource and allow more people to participate. In the catch-and-release management practice, a large proportion of the released fish are assumed to stay alive and become a source for the next fisherman or they become available as a part of the spawning biomass. A great number of papers are available on this topic, but only a few are included in this bibliography. The readers are referred to Barhart and Roelofs (1977) for further references.

Survival of Fish Caught by Fishing Gears and Discarded

Fish caught and landed on board may be above legal size target species, undersized target species (discarded), non-target by-catch species (kept or discarded). Discard survival is the key to the minimum landing size and species-specific quota regulations. Many management regulations require that undersized animal and non-target species be released with the assumption that they will survive the capture and landing process, and contribute to the fishery or fisheries of other species in future years. Many researchers concentrated on the level of by-catch and discards, and the rate of survival of discarded animals. Some important references include that of Veen *et al.* (1975), Kelle (1976), Neilson *et al.* (1989), Beek *et al.* (1990), Steven *et al.* (1990), Wassenberg and Hill (1989, 1993), Hill and Wassenberg (1990) and Berghahn *et al.* (1992).

Survival of Fish Escaped from Fishing Gears

Minimum mesh size regulations and the usage of various grids and sorters are based on the assumptions that fish escaping from fishing gears and selection devices will live a normal life after the escapement and contribute to the spawning biomass or exploitable biomass in other fisheries. Study of escapee survival involves collection of live fish escaped from fishing gears for survival observation. The technique of live fish collection is critical, as post-escape handling and husbandry mortality can often overshadow the mortality of fish resulting from fishing and escape processes. Some important references in this area include Hay *et al.* (1986), Main and Sangster (1990), Sangster and Lenhmann (1993), Soldal *et al.* (1993) and Suuronen *et al.* (1993).

ANNOTATED BIBLIOGRAPHY

In the annotations of the following bibliography, great attention is paid to the experimental methodology. Fishing gears and operational methods, handling methods, live fish transportation equipment, survival tank, and duration of observation are some of the key points of interests. Results are summarised according to species if possible. Detailed annotations are made on those papers more relevant to commercial marine fisheries, while less detailed annotations on those less important or sports fisheries. No annotations were made on indirectly related papers or on those papers which were not available to the author at the time of compilation of the bibliography.

Beamish, F.W.H. (1968). Glycogen and lactic acid concentrations in Atlantic cod (*Gadus morhua*) in relation to exercise. *J. Fish. Res. Bd Can.*, **25**, 837-851.

Cod (around 40 cm long) were caught by otter trawl towed at three knots for 30 min at depths between 45 and 55 m. After capture, they were transferred to an onboard tank and then to a 2 m diameter, 1.3 m high holding tank. Fish were kept there for at least four weeks before the experiment. Fish were exercised in one of two swimming flumes at different speeds and for different durations. At various points of exercise, blood and muscle samples were taken madand blood and muscle lactic acid and muscle glycogen reserve were analysed. Muscle glycogen levels were reduced by 50% after swimming at 35 cm/s for 15 min, but by as much as 80% after swimming at 130 cm/s for 15 min.

Muscle glycogen had not yet returned to the pre-exercise level after eight hours recovery. Both muscle and blood lactic concentrations were low at lower swimming speeds (<90 cm/s). But at higher speeds, lactic acid concentration was built up significantly. Muscle lactic remained high one hour after exercise, but returned to pre-exercise level after eight hours resting. No fish died due to exercise at various speeds for various durations, although small mortality occurred in serial sampling which may have caused death.

Beltestad, A.K. and Misund, O.A. (1989). Is unaccounted fishing mortality a problem in purse seining? *ICES Fish Capt. Comm. FTFB WG Meeting*, 9pp.

Mortality of herring in purse seine net burst situations was discussed. No experimental work was included in this informal paper.

Bendock, T. and Alexandersdottir, M. (1993). Hooking mortality of Chinook salmon released in the Kenai River, Alaska. *N. Am. J. Fish. Manag.*, **13**, 540-549.

Fish were caught by anglers using single hooks with artificial lures. Captured fish were transferred to a tagging boat and tagged with a radio transmitter on the right side of each fish beneath the dorsal fin. The fish were kept in water at all times during tagging and transfer, and were released after tagging. Fish were tracked using telemetry methods. Five day mortality was 7.6% ranging from 4.1% in 1991 to 10.6% in 1989. Mortality was highest in small male (<75 cm mid-eye length) compared with large males and all females. Survival was significantly reduced in fish hooked in gills and bleeding. Most mortality occurred within 72 hours after release.

BEON. (1990). Effects of beamtrawl fishery on the bottom fauna in the North Sea. *BEON Report*, **8**, 57pp.

To study the escapee survival, a small mesh cover (2 cm in the body and 1 cm in the cod-end) collected animals escaping from the 9 cm mesh beamtrawl on short (1 min) tows. Animals were collected into a water filled tub and kept for observation for one day in either 60 x 40 x 12 cm (deep) tank or 55 cm dia 35 deep round tub. Survival for some species were: dab 56%, plaice 85%, sole 100%, dragonet 68%, solenette 68%, starfish, brittle stars and swimming crabs >98%. In the second experiment, the survival of discards were studied. The beamtrawl was towed at six knots for two hours. Animals were put into the above mentioned tanks during the sorting of catches. Mortality was observed for two days. The results of survival rate were: dab 0%, plaice 10%, starfish 80%, astropecten 70%, brittle star 60%, crabs 60-70%, hermit crab 100%.

BEON. (1991). Effects of beamtrawl fishery on the bottom fauna in the North Sea. II - The 1990 studies. *BEON Report*, **13**, 85pp.

This report covers three aspects: 1) penetration depth of beamtrawl; 2) survival of benthos and fish caught and escaped from trawl; and 3) long term effect of beamtrawling on the seabed. Equipment used includes a side scanning sonar (able to detect trawl tracks), a computer-controlled precise positioning system and a ROV. The result shows that the

beamtrawl tracks were visible for up to 12 hours at wind force 4Bf. Fish escaping through the mesh had 80-90% survival rate. Fish in commercial catches had a very low survival rate, probably 0% (discards). Sole and plaice may have 10% discard survival rate. Survival rates of discards of benthos are: mollusc and crab 40% at best, starfish 70-80%, whelks and hermit crabs approximately 100%.

BEON. (1992). Effects of beamtrawl fishery on the bottom fauna in the North Sea. III - The 1991 studies. *BEON Report*, **16**, 27pp.

As in the previous BEON Report (1991), samples of beamtrawl catches (towed at 2.8-3.3 knots for 1.5 hours) during sorting were placed into tanks with running waters, and mortality was observed over two days. Survivability of 58% for plaice and 23% for dab was recorded.

Bjordal, A. (1989). Fish escapement from longlines and methods to study escapement and survival. *ICES Fish Capt. Comm. FTFB WG Meeting*, 6pp.

The author believed that escapement during hauling of traditional longline gear might be as much as 15-30% of the fish that were actually hooked. To evaluate the survival of the escaped fish, an echo sound to monitor the hooked fish while they are lifted during retrieval. No substantial results have been obtained.

Bouck, G.R. and Ball, R.C. (1966). Influence of capture methods on blood characteristics and mortality in the rainbow trout (*Salmo gairdneri*). *Trans. Am. Fish. Soc.*, **95**, 170-176.

Blood characteristics and mortality of rainbow trout caught (from tank) by angling using lures, electroshocking and seining were compared. Fish caught by angling was simulated to that practiced by fishermen, eg fish were exhausted when landed. Captured fish were either killed for blood analysis or placed in a 200 gallon tank for a mortality study. Mortality was negligible in shocked (~10%) and seined fish (0%), but 87% in angled fish. The majority of mortality in angled fish occurred during 3-5 days after a simulated capture process.

Bourke, R.E., Brock, J. and Nakamura, R.M. (1987). A study of delayed capture mortality syndrome in skipjack tuna, *Katsuwonus pelamis* (L). *J. Fish Dis.*, **10**, 275-287.

Skipjack tuna were captured for research purposes using live bait and barbless hooks. Of 244 skipjacks delivered to NMFS Kewalo Research Facility, 65% died on second or third day after capture. Morphological measurements and biochemical analysis of blood were made at capture and at various times up to >500 hours after capture to determine the cause of delayed mortality. The authors discounted anoxia, disseminated intravascular coagulation, lactic acidosis, capture myopathy or infection as the cause of mortality. They suggested that post-capture haemodilution may be the major factor causing delayed capture mortality in skipjack. Excessive haemodilution could cause death due to: a) inability to control acid-based balance due to low serum protein; b) decrease in

the oxygen and metabolite carrying capacity of the blood; or c) impairment of metabolite transfer through tissue membrane.

Caillouet, C.W., Jr. (1971). Lactate acidosis as a cause of mortality in captured sharks: an hypothesis. *Trans. Am. Fish. Soc.*, **1**, 139-140.

The author supported the theory of lactate acidosis as a cause of mortality in fish as put forward by Black *et al.* (1961) and assumed that the mortality of captured sharks is caused by accumulation of lactate acid in the blood following strenuous activity. The author suggested a possible treatment by employing lactate acidosis therapy through injecting agents such as sodium lactate to reduce mortality in captured shark.

Carr, H.A., Robinson, W.E., Sullivan, P.A., Caruso, P. and Cruse, J. (1992). Survival of juvenile Atlantic cod and American plaice in the northeastern Atlantic trawl fishery. *Proc. Mar. Tech. Soc*, **1**, 316-321.

Charuau, A., Morizur, Y. and Rivoalen, J.J. (1993). Survival of *Nephrops norvegicus* rejects in the Gulf of Gascony (Bay of Biscay) and Celtic Sea. *Scot. Fish. Res. Trans*, **90**, 1-8.

The experimental *Nephrops* were from undersized commercial rejects (discards) just before they were returned to the sea. They were instead put into cages which were then sunk to the seabed. After 36 to 72 hours, the cages were retrieved and animals were counted as dead (including dying), and live. The result showed a survival rate of 19 to 31% of these commercially discarded *Nephrops*. No mention of cage size and the depth where the cages were located were made. other lacking information included towing speed, duration and the amount of catch. (Original in French, ICES CM 1982/B:13).

Chopin, F.S. and Arimoto, T. (1994). The condition of fish escaping from fishing gears - a review. *Fish. Res.*, (in press).

A comprehensive review of stress, fatigue, injury and survival of fish escaping from various fishing gears. The paper proposed a model of various mortalities associated with capture processes. It contains useful references and a summary table of unaccounted mortalities from various sources.

Christensen, S. (1994). Potential bioeconomic impact of reduced mortality of cod-end escapees in the shrimp fishery in Davis Strait. *Presented at the ICES Fish Capt. Comm. FTFB WG Meeting, Montpellier, France.*

A bioeconomic model was developed to explore the benefit of reducing mortality of escaped small shrimps from shrimp trawls. This is a very useful attempt linking the unaccounted mortality issue with potential future yield and economics.

Clapp, D.F. and Clark, R.D., Jr. (1989). Hooking mortality of smallmouth bass caught on live minnows and artificial spinners. *N. Am. J. Fish. Manag,*, **9**, 81-85.

Smallmouth bass 6.3 to 12.6" long were collected from the wild using electrofishing, angling and traps. They were individually tagged and divided into two groups, and kept in artificial channels (15′ wide x 120′ long, 1 to 4" deep). After one week, one channel was fished with live minnow and No 6 hook and another using Mepps No 1 spinner. The fish caught were unhooked by hand and released back to the channel. Fishing was stopped before the channels were drained for checking of dead fish. Mortality of minnow-fished bass were 11% compared with 0% of spinner-fished bass and 4% for those not hooked.

DeAlteris, J.T. and Reifsteck, D.M. (1993). Escapement and survival of fish from the cod-end of a demersal trawl. *ICES Mar. Sci. Symp.*, **196**, 128-131.

A towed cod-end simulation apparatus was developed to investigate the survival of scup (16.5-17.5 cm), winter flounder (16.4-17.7 cm) and Atlantic cod (40.8-44.4 cm) (all previously captured by handlining and hold in tanks or pens before being released at the mouth of the towed apparatus) escaped from diamond (120 mm) and square mesh (126 mm) cod-ends towed at 1.28 m.s for 30 min. Escapees and control were first kept in onboard tanks then transferred to seabed cages at 5-10 m water depth and the survival rate was observed for 10 days. The survival of cod was 100%, winter flounder 85-100%, and scup 50-100%. There was no significant difference between the experimental fish and the control. In addition, escape time and swimming time were analysed. The size of the onboard tanks and the seabed cages, and the duration the fish kept in the tank was not stated in the paper.

Dunning, D.J., Ross, Q.E., Mattson, M.T. and Geoghegan, P. (1989). Reducing mortality of striped bass captured in seines and trawls. *N. Am. J. Fish. Manag.*, **9**, 171-176.

Mortality of striped bass with two transferring methods were investigated. The first (old) method transferred fish by lifting the cod-end out of the water and into onboard tanks while the second (modified) method, transferred fish by emptying the cod-end into a partially submerged tank (2.4 m long x 0.9 m x 0.9m), then lifting the tank out of the water and transferred to tanks of the same size as in the old method. Immediate mortality using the old method was 16.1% in seine-caught and 17.7% in trawl-caught fish compared with 1.2% in seine-caught and 1.0% in trawl caught fish using the modified method. In addition, using the old methods, higher mortality was associated with higher water temperature (12-16°C) and larger (>500 mm TL) fish in both seine and trawl caught fish.

Efanov, S.F. (1981). Herring of the Gulf of Riga: the problem of escapement and mechanical impact of the trawl. ICES CM 1981/J:7, 16pp.

Herring escaping from a cod-end towed at 2.7 to 3.1 knots were retained in a cod-end cover. As the cover rose to the surface, but still remained in the water, the dead and live fish were separated. The live ones were transferred to a container and then a trap. The controls were taken from cod-end cover without a cod-end (open trawl) towed at 2.1 knots for 10-15 min. The cod-end escapees and the controls were observed for 10 days. The size of the trap and whether it was on the surface or at depth was not mentioned in the paper. Mortality of herring escaping from 24.0, 28.0, and 32.0 mm mesh was 35.3%, 15.6% and 10.1% respectively. Traumatic death was related to the degree of scale loss. In addition, herring and sprat were observed swimming at towing speed of 2.7 knots for 25-30 min before tiring and becoming pressed against the side netting. Absolute catchability of herring by pelagic trawl in summer was 36%, whereas fishing large concentrations at 200 m in front of the trawl mouth, the catchability was reduced to 15%.

Fritz, K., Fleet, S.V., Johnson, D.L. and Reutter, J.M. (1980). Induced mortality of unmarketable fishes due to capture in Ohio commercial fishing gear. *NOAA, Final Report CRFD 3-301-R-2. Columbus, Ohio.*

Fritz, K.R. and Johnson, D.L. (1987). Survival of fresh water drum released from Lake Erie commercial shore seines. *N. Am. J. Fish. Manag.*, **7**, 293-298.

Beach seines operated in Lake Erie have a length of 1,500 m and it takes three hours to haul the net to the beach. Their target species is white bass, but they may catch as much as 50-75% of fresh water drum as a by-catch. The survival of the drum released into the lake was studied to determine the percentage of fish that survived and the factors affecting their survival. Samples of water (for water quality analysis) and fish (for survival test) were made when the seine was "bagged" and at 7, 15, 24, 48 and 70 min (exposure time) thereafter. Sampled fish were transported to 2 x 2 x 2 m holding net with 60-L tanks and observed for 20-24 hours. After that time, fish were classified as active (live), moribund (floated, and not able to maintain equilibrium) and dead. Dissolved oxygen (DO) level was measured from the water samples. It was found that dissolved oxygen reduced as the exposure time was increased and with a larger catch. Lower survival was associated with longer exposure time and larger catch size when oxygen concentration became lower. A mortality (dead and moribund) of 37 to 64% for fish exposed for 10 and 20 min with reduced DO level. Any fish remaining in the bag for more than 100 min had very low survival probability. DO is the key factor affecting survival in seined fish. Other factor affecting survival included length of fish; larger fish had a higher survival rate than the small ones.

Harman, B.J. (1978). Effect of capture by shore seine on survival of Lake Erie fresh water drum. Columbus: Master's Thesis, Ohio State University.

Hay, D.E., Cooke, K.D. and Gissing, C.V. (1986). Experimental studies of Pacific herring gillnets. *Fish. Res.*, **4**, 191-211.

Pacific herring passing through 57 mm monofilament gillnets were collected by a fyke trap constructed in 10 mm knotless netting attached to the net. The fish in the cod-end of the fyke net were transported to a cage by a live barge. A 3.5% mortality occurred during transfer and transportation. The fish in the cage (952 individuals) was monitored weekly for nine months. The mortality was low with a 0.7% after five days and 1.9% after two weeks. However, mortality rose afterwards and almost all fish died in May probably due to warm temperature. Scale loss was estimated from the fish passing through the gillnet meshes. In a 1981 experiment, the degree of scale loss was found positively related to the size of fish. Large fish had severe scale loss, with a maximum scale loss of 40%. Laboratory experiments were conducted to determine the relation between scale loss and mortality by removing a portion of the scales from healthy fish. Even though a higher mortality was found in groups with severe scale loss, a wide spread disease in the tank prevented a conclusive comment on the subject.

Hill, B.J. and Wassenberg, T.J. (1992). The fate of discards from shrimp trawlers. In: *International Conference on Shrimp ByCatch*, pp115-123. 24-27 May 1992, Lake Buena Vista, Florida.

This conference presentation summarises two previous papers by the same authors (Hill and Wassenberg, 1990; Wassenberg and Hill, 1990). The major factors determining the fate of discards from Australian shrimp trawlers are whether or not the animals were alive when being discarded and whether they sank or floated. Cephalopods do not survive trawling while shelled mollusks and echinoderms appear to survive well. Survival of discards of major taxonomic groups are: fish 2%, crustaceans 51%, cephalopods 2%, total for all by-catches 11%.

Hislop, J.R.G. and Hemmings, C.C. (1971). Observations by divers on the survival of tagged and untagged haddock. *J. du Cons.*, **33**, 428-437.

Hopkins, T.E. and Cech, J.J., Jr. (1992). Physiological effects of capturing striped bass in gill nets and fyke traps. *Trans. Am. Fish. Soc.*, **121**, 819-822.

Blood samples were taken from striped bass (38-82 cm) caught by gillnets and by fyke traps and their blood biochemical properties were analysed. Gillnet caught fish were found more lethargic and acidotic, had higher Pco_2, hematocrit, plasma glucose and potassium concentration than fyke trap caught fish, indicating that the gillnet caught fish were physiologically more deleterious than the fyke trapped fish.

Hunsaker, D., II., Marnell, L.F. and Sharpe, F.P. (1970). Hooking mortality of Yellowstone cutthroat trout. *Prog. Fish-Culturist*, **32**, 231-235.

Trout (approximately 14" long) were caught by different hooks and baits. They were transferred to 26.3 cubic foot floating cages and observed for 10 days. Mortality was highest (73%) in fish which had swallowed the trolled single hook baited with worms. Other bait/fly combinations were trolled with single hooks but those fish that had not swallowed the hook, and the control, caught by electro-fishing, had considerably less mortality (<10%). Additionally, higher mortality was observed at higher water temperatures.

Jean, Y. (1963). Discards of fish at sea by northern New Brunswick draggers. *J. Fish. Res. Bd Can.*, **20**, 497-524.

This paper mainly deals with the level and types of discarding in the New Brunswick otter trawl fishery. The section related to the survival of discards are summarised below. Trawl captured cod and plaice were laid on the deck of the vessel for a period between 5 and 45 min before they were transferred into a tank filled with water (size of tank not mentioned). The number of survivors were determined after one hour. The survival rate was found inversely related to the time exposed on deck and air temperature in both cod and plaice. Larger fish had a higher survival rate in cod (size range 20 to 59 cm) and plaice (10 to 39 cm). Survival rate was 0% for 20-29 cm cod exposed for 45 min and 100% for 50-59 cm cod exposed for <5 min, while others sizes were in between these figures. Survival of plaice had similar values.

Lockwood, S.J., Pawson, M.G. and Eaton, D.R. (1983). The effect of crowding on mackerel (*Scomber scombrus* L.) - Physical condition and mortality. *Fish. Res.*, **2**, 129-147.

Mackerel 24 to 41 cm TL (mean 30 cm) were handlined with barbless hooks and those in the best physical condition were released into a 0.75 m deep, 2 m diameter on-board tank. They were then transferred to experimental cages of 1 m cubed, 3 m cubed or hexagon shape of 3 m sides and 3 m deep for mortality tests associated with crowding, "slipping" and tagging. In the crowding tests, a known number of fish were put into a cage at a rate of 50 fish/min. Dead fish were counted and removed daily. Mortality was observed for up to 354 hours. For stocking densities between 5 and 100 fish/m^3, onset of mortality did not occur until the fish were held for six hours. For the 1 m cubed net after 48 hours, 50% mortality occurred with a stocking mortality of 30 fish/m^3, or 6.5 kg/m^3. Mortality for 3 fish/m^3 held in the hexagonal net had the lowest mortality, 4.3% after 354 hours. This mortality may be due to capture and transportation stress, and not due to holding stress associated with crowding. In simulated purse seine "slipping" tests, a large number of fish were held in a small cage (high stocking density) for a period of up to 45 min, then released into a large cage with a low stocking density. Mortality was found to be related to density and duration before "slipping" (stress time). The product of stress time (hour) and density (fish/m^3) was defined as the stress index. Mortality increased with the stress index. Tagged fish had a higher mortality (18.3%) compared with untagged fish (4.3%).

McLoughlin, R.J., Young, P.C., Martin, R.B. and Parslow, J. (1991). The Australian scallop dredge: estimates of catching efficiency and associated indirect fishing mortality. *Fish. Res.*, **11**, 1-24.

Average fishing efficiency was 11.6%, with 1% efficiency for scallops of 57 mm shell height and 28% for those of 86 mm shell height. The efficiency was not affected by dredge mesh size and tow direction. The mortality of scallop due to dredging was estimated to be 78-88% with only 12-22% of the initial stock landed as catch.

Messieh, S.N., Rowell, T.W., Peer, D.L. and Cranford, P.J. (1991). The effect of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. *Continental Shelf Research*, **11**, 1237-1263.

This is a good comprehensive review with many references on the subjected matter. A total of 4,260 licenses was issued in Atlantic Canada for mobile gear in 1988. A total of 785,512 hours were spent in trawling in NAFO areas in 1985. Inshore scallop dredges destroyed about the same amount of scallops as they caught. Fish and crabs were attracted to the dredge tracks within one hour of fishing in densities 3 to 30 times greater than that observed outside the tracks. Mortality of uncaught clams ranged from 30 to 92%. Numbers of animals were reduced by roughly 40% after dredging, but returned to the original levels in 10 months.

Pankhurst, N.W. and Sharples, D.F. (1992). The effects of capture and confinement on Plasma cortisol concentration in the snapper, *Pagrus auratus*. *Aust. J. Mar. Freshwater Res.*, **43**, 345-356.

Confinement in a net or capture by both longlines or trawls elevate snapper blood cortisol level to >2.8 times over that sampled underwater by divers or in fish 48 hours after capture. Higher cortisol levels were measured in fish caught by longlines with longer set durations. Fish captured by longlines set for 12 hours remained high, indicating recovery from stress did not occur in fish left on the longline. Cortisol levels returned to lower levels 48 hours after capture.

Parker, R.R., Black, E.C. and Larkin, P.A. (1959). Fatigue and mortality in troll-caught Pacific salmon (*Oncorhynchus*). *J. Fish. Res. Bd Can.*, **16**, 429-448.

Coho salmon caught by trolls were examined for their blood biochemistry at capture and thereafter. Mortality of troll-caught coho salmon in sea water ranged from 34% to 52% (0.95 confidence interval). Highest mortality occurred in the second hour. Time of maximum mortality rate coincides with the period of maximum blood lactate response. Survival occurred either when blood lactate did not reach the critical value of 125 mg/100 g blood or reached that level but subsequently subsided.

Pawson, M.G. and Lockwood, S.J. (1980). Mortality of mackerel following physical stress and its probable cause. *ICES Rap. Pro.-ver. Reun.*, **177**, 439-443.

Mackerel were caught with barbless hooks. Good live specimens were held at a density of less than 20 fish/m^3 in 2 x 2 x 0.6 m deck tanks. Fish were then taken to floating net pens where crowding and "slipping" tests were carried out. A density of 5.5 fish/m^3 in 3 m cubed was used as control. Live mackerel were also taken from a mid-water trawl towed for 15 min, and the effect of being "dried up" was investigated. Mackerel at a density of <50 fish/m^3 suffered less than 25% mortality within seven days held in the 2 m cubed nets. At a higher density of 500 fish/m^3 and less freedom (1 m cubed pen), 100% mortality occurred within 24 hours. When mackerel were held at 1,500 fish/m^3 for 30 min and then "slipped" into a lower density (1.25 fish/m^3) in the large pens (4.5 m cubed pens), 100% mortality occurred within 50 hours. However, very few fish died within five hours even at the highest density. Mortality of 100% occurred for mackerel taken from a mid-water trawl within 22 hours in deck tanks. Lactic acid built up 4-5 hours after capture by feather hooks, mid-water trawl or held at high densities, returned to near-normal levels after 8-12 hours in large pens where the fish were allowed to swim quietly.

Pelzman, R.J. (1978). Hooking mortality of juvenile largemouth bass, *Micropterus salmoides*. *Calif. Fish and Game*, **64**, 185-188.

Hatchery reared sub-yearling largemouth bass 139.8 to 264.3 mm in total length were hand-line hooked in different areas of the mouth where force was applied from the line simulating the angling process. Hooked fish were then de-hooked after 30 sec of the "line-playing" process and returned to the tank (6,800 litres). They were observed for 60 days for mortality. The results showed that esophageally-hooked fish had a much higher mortality (mean 56%) than those hooked in other areas. The controls (not subjected to hooking process) had a mortality mean of 2%.

Pierce, R.B. and Tomcko, C.M. (1993). Tag loss and handling mortality of northern pike marked with plastic anchor tags. *N. Am. J. Fish. Manag.*, **13**, 613-615.

Pike used for handling and tagging mortality studies were caught with traps. After tagging they were released into a net pen 2.4 x 2.4 x 1.2 m deep and observed for five days for mortality. Mortality was 2.4% for both trapped and tagged fish.

Pikitch, E.K. and Erickson, D.L. (1993). Development and evaluation of a methodological approach for estimating the post-capture survival of trawl-caught Pacific halibut (*Hippoglossus stenolepis*). *University of Washington Report*, **FRI-UW-9304**, 21pp.

Pacific halibut (40-80 cm long) captured by an otter trawl towed for 1.17 to 1.25 hours at 2.5 to 3.0 knots at depth of 55 to 93 m were put into cages (1.52 x 1.83 m bottom, 1.07 x 1.37 m top, 1.52 m high) after being hauled onboard. Two or six fish were kept in each cage for one or five days. Mortality was determined at the termination of each observation. Five-day survival (22% to 32%, mean for each holding density) was lower than one-day survival (57% to 63%). Longer deck exposure time reduces survival significantly. Nearly all fish died after 20 min exposure to air.

Robertson, L., Thomas, P. and Arnold, C.R. (1988). Plasma cortisol and secondary stress response of cultured red drum (*Scianops ocellatus*) to several transportation procedures. *Aquaculture*, **68**, 115-130.

Rutecki, T.L. and Meyers, T.R. (1992). Mortality of juvenile sablefish captured by hand-jigging and traps. *N. Am. J. Fish. Manag.*, **12**, 836-837.

Mortality of hand-jigged and pot caught sablefish was investigated to determine the tagging mortality of different capture methods. Size 4 long shanked J-hooks were used for hand-jigging, while 151 cm diameter, 29 cm high pots with 25.4 cm wide tunnel entrance were used for trapping. The captured fish (total 150 juveniles from each capture

method, 22-30 cm fork length) were tagged with Floy tags and introduced to onboard live tanks (size not mentioned) for transportation to 3,800 litre laboratory tanks. Hand-jigged sablefish had less mortality than pot-caught fish, and mortality in summer was less than in the winter. After one week, mortality of hand-jigged fish was 19% compared with 75% for pot-caught fish. After 35 days, pot-caught fish suffered 96% mortality, while the hand-jigged fish had a mortality of 35%.

Rutledge, W.P. and Pritchard, D.L. (1977). Hooking mortality of largemouth bass captured by artificial lures and natural bait. In: *Catch-and-release Fishing as a Management Tool*, Barhart, R.A. and Roelofs, T.D. (eds), pp109-118. Arcata, California: California Cooperative Fishery Research Unit.

Schill, D.J., Griffith, J.S. and Gresswell, R.E. (1986). Hooking mortality of cutthroat trout in a catch and release segment of the Yellowstone River, Yellowstone National Park. *N. Am. J. Fish. Manag.*, **6**, 226-232.

Soldal, A.V., Engas, A. and Isaksen, B. (1989). Simulated net injuries on saithe. *ICES Fish Capt. Comm. FTFB WG Meeting*, Dublin 1989, 8pp.

Blood biochemistry and mortality were measured in saithe (30-60 cm) with simulated net injuries (forced passing through 110 mm mesh), anaesthetised, and anaesthetised and with scale and mucus removed (<5% scale removal). Observation and blood samples were made over a period of 14 days. The scale-removed group had the highest mortality during the second half of the observation period (6-14 days).

Soldal, A.V., Engas, A. and Isaksen, B. (1993). Survival of gadoids that escape from a demersal trawl. *ICES Mar. Sci. Symp.*, **196**, 122-127.

This paper describes three seperate experiments: a) survival of net-penned saithe as discussed in Soldal *et al.* (1989); b) tank experiments on the effect of net injuries and exhaustion on survival of cod and haddock; and c) a field experiment on the survival of trawl escapees (cod and haddock). In the tank experiment, fish were treated for muscular exhaustion (forced to swim at 1.35 m/s increasing to 2 m/s); a combination of net injury and exhaustion; and lastly, a combination of skin damage and exhaustion. Net injuries were simulated by forcing fish to pass through 100 and 110 mm mesh, while skin damage was simulated by removing scales and mucus at the area of maximum cross-section or at the tail. Haddock had 10-20% mortality in the combination treatments. Both haddock and cod survived muscular fatigue. During the field experiment, cod and haddock escapees were collected in a net cage (2 x 2 x 5 m long), attached to a hooped cod-end cover. The trawl was fitted with either a 135 mm diamond mesh cod-end, or a grid sorting device and towed at 3.6 to 3.8 knots at depths between 30 to 60 m. The control groups were from the same collection device but without a cod-end (open trawl). The collection cage was released from the cod-end cover using a remote acoustic release before the trawl was hauled. Each cage was then towed at one knot to a sheltered area of 20 m depth and anchored as a survival observation cage. A total of nine cages were observed using ROV equipped with a U/W video camera for a duration of 12 to 16 days. No mortality was recorded for cod, with 0 to 6.5% for mesh escaped haddock and 5.4 to 10.5%

for grid escaped haddock. Control groups had higher mortality than treated fish and was considered invalid.

Steven, B.G. (1990). Survival of king and Tanner crabs capture by commercial sole trawls. *Fish. Bull.*, **88**, 731-744.

King and tanner crabs were the by-catches from trawlers operating in the Eastern Bering Sea for yellowfin sole, rock sole and Pacific cod. Trawl tows ranged from 1 to 6.4 hours with catches averaging 20 tons. Crabs were examined for vitality, injuries and immediate mortality. They were then placed in tanks 1.0 x 1.0 x 0.7 m for 48 hours for monitoring of delayed mortality. The combined immediate and delayed mortality for both crab species was 78-79% (survival rate 21-22%) after two days observation. Crabs classified as alive and active at capture time had a very high survival rate of more than 92%. Survival increased with shell age (molting shell, hard shell or old shell), short time onboard exposure and exposure to air. Vitality, which is an index of activity, was considered to be a better indicator of mortality than injury.

Stringer, G.E. (1967). Comparative hooking mortality using three types of terminal gear on rainbow trout from Pennask Lake, BC. *Can. Fish. Cult.*, **39**, 17-21.

Thorson, K.N. (1972). Subcutaneous hemorrhage in captive sablefish (*Anoplopoma fimbria*): a possible link to mortality. *J. Fish. Res. Bd Can.*, **29**, 1089-1090.

Sablefish captured by pot traps at depths between 150 and 310 fathoms and subsequently transported in towing barges to pens developed subcutaneous hemorrhage in the body and fins. The author suggested that hemorrhaging was caused by fish impacts against the pot wall and embolisms arising from rapid decompression. Fish with extensive hemorrhaging survived for a shorter period in captivity compared to those with less extensive hemorrhaging. Therefore, development of hemorrhaging in fish can contribute to mortality in captivity. This type of mortality might also contribute to the low tag return rate for this species.

Toivonen, A. and Hudd, R. (1993). Survival of undersized salmon after release from the trap net. ICES CM B:10, 6pp.

Undersized salmon (<60 cm) taken from traps fished at depths of between 8 and 17 m, which would otherwise be released back to the sea, were caged (cage size not mentioned) for up to 10 days. Thirty-five out of 54 (65%) undersized salmon died in the cages. Fish that died spent an average of 4.4 days in the cages.

Veen, J.F.de, Huwae, P.H.M. and Lavaleye, M.S.S. (1975). On discarding in the sole fishery and preliminary observations on survival rates of discarded plaice and sole in 1975. ICES CM/F:28, 9pp.

Discards of sole and plaice from beamtrawls were graded into six categories according to their physical condition. They were kept in basins hung in tanks for four days and

survival rates were determined. The six categories and percentage occurrence for plaice (P) and sole (S) were: A - fish lively, slime layer intact, no visible damage to skin (P 13.6%, S 6.5%); B - fish lively, slime layer not intact, slight scratches on skin (P 26.5%, S 24.9%). C - fish not so lively, slime layer partly removed, loss of scales near tail (P 25.9%, S 24.7%). D - fish sluggish, slime layer mostly removed, many scales missing (P 6.1%, S 17.1%). E - fish sluggish, slime layer lost, most scales missing (P 15.9%, S 22.0%). F - fish dead (P 7.0%, S 6.5%). There was a slight decrease in damage with an increasing length in plaice. There was also a tendency of more damage from more powerful vessels due to the heavier gears they were towing. Survival of both species decreased as the degree of damage was increased from A to F. The survival was also decreased with an increase in tow duration, from 50% for 20 min tow to 25% for 120 min tow, and with an increasing length of exposure time on deck.

Vincent-Lang, D., Alexandersdottir, M. and McBride, D. (1993). Mortality of coho salmon caught and released using sport tackle in little Susitna River, Alaska. *Fish. Res.*, **15**, 339-356.

Wardle, C.S. (1972). The changes in blood glucose in *Pleuronectes platessa* following capture from the wild: a stress reaction. *J. Mar. Biol.*, **52**, 635-651.

Wardle, C.S. (1981). Physiological stress in captive fish. In: *Aquarium Systems* Hawkins, A.D. (ed.), pp403-414. London: Academic Press.

Muscle glycogen is converted to lactic acid during vigorous swimming or escape action. A large part of this lactic acid can be used to reform glycogen in the fit fish, but any weakening of this active metabolism, such as stress reaction during capture, can cause the lactate to pass into the bloodstream and hasten death. Loss of scales and damage to the epidermis can lead to osmotic dehydration, loss of equilibrium and death. Herring were found to survive better in a mixture of sea water and fresh water.

Warner, K. (1978). Hooking mortality of lake-dwelling landlocked Atlantic salmon, *Salmo salar*. *Trans. Am. Fish. Soc.*, **107**, 518-522.

Warner, K. (1979). Mortality of landlocked Atlantic salmon hooked on four types of fishing gear at the hatchery. *Prog. Fish-Culturist*, **41**, 99-102.

Mortality of hatchery reared landlocked Atlantic salmon (age II) hooked on four different types of hooks and released was low (5%) after 3-5 days. Those fish that were purposely allowed to swallow worms had a much higher mortality (73%). Fish with deep hooking and with the hook left in the mouth and the leader cut had a mortality of 57% after 14 days. But mortality was significant higher for deeply hooked fish with the hook subsequently removed (90%).

Wassenberg, T.J. and Hill, B.J. (1989). The effect of trawling and subsequent handling on the survival rates of the by-catch of prawn trawlers in Moreton Bay, Australia. *Fish. Res.*, **7**, 99-110.

Trawl hauls lasted 60 min and the catch was sorted in 20 min 85% of by-catch crustacea and 20% of bony fish by-catch were still alive eight hours after sorting. The survival tank was 50 x 35 x 25 cm deep while cages for crab measured 15 x 15 x 30 cm. Water temperature was 22-26°C, with a salinity of 34-37‰.

Wassenberg, T.J. and Hill, B.J. (1993). Selection of the appropriate duration of experiments to measure the survival of animals discarded from trawlers. *Fish. Res.*, **17**, 343-352.

Fish and invertebrates were by-catches of shrimp trawls. The by-catches were separated and exposed to air for 12-15 min before being introduced to transport tanks and transferred to laboratory tanks (80 x 60 x 25 cm, or 1.8 dia 75 cm high) within three hours of capture. They were observed for seven days in the laboratory. Most invertebrate species had a survival rate of 70% in seven days, while only one species of fish had a survival rate of more than 30%. Most deaths occurred within three days after capture. It was therefore suggested that four days is an adequate duration for discard survival experiments of this nature.

Wells, R.M., Tetens, V. and Devries, A.L. (1984). Recovery from stress following capture and anaesthesia of antarctic fish: haematology and blood chemistry. *J. Fish. Biol.*, **25**, 567-576.

A rise in haematocrit and haemoglobin and a fall in blood pH were observed in anaesthetised Antarctic cod however, blood values stabilised after 8 to 24 hours. Stress resulting from 12 hours on a set line showed a more pronounced change in blood characteristics but returned to resting level after 24 to 70 hours. A change in blood ATP was noticed in severely stressed fish.

Wertheimer, A. (1988). Hooking mortality of chinook salmon released by commercial trollers. *N. Am. J. Fish. Manag.*, **8**, 346-355.

An experiment was conducted to evaluate the mortality of chinook salmon caught by trolls with lures (6/0 barbed hook) and released back to the sea due to the closure of the fishing season. Troll-caught chinook salmon were electrically stunned and then released into a 175-litre live tank after the hook was removed from the mouth. The fish were then transported in similar sized tanks to net pens of 1,700 m^3 (12 m deep, 142 m^2 surface area) in 7 to 60 min. Survival was monitored by divers in the following five days. Mortality was found to be related to the types and severity of the wounds, hooking position and fish size. Mortality was highest if fish were hooked on gills. Mortality was also higher in sub-legal size (<66 cm fork length) fish than legal size fish. The overall mortality was 24.5% for sub-legal chinook and 20.5% for legal chinook.

Wood, C.M., Turner, J.D. and Graham, M.S. (1983). Why do fish die after severe exercise? *J. Fish. Biol.*, **22**, 189-201.

Farmed trout were aortically cannulated for serial blood sampling and then after a full recovery were subjected to a 6 min vigorous chase in a circular tank of 91 cm diameter. After 6 min, the fish were returned to a 4 x 7 x 30 cm chamber where they were observed and their blood sampled for 12 hours. Delayed mortality of trout following intensive exercise was ~40%. Post-exercise mortality may not be due to excessive "lactic acid", but due to intracellular acidosis.

Xu, G., Arimoto, T, and Inoue, Y. (1993). The measurement of muscle fatigue in walleye pollack (*Theragra chalcogramma*) captured by trawl. *ICES Mar. Sci. Symp.*, **196**, 117-121.

Walleye pollack were taken from commercial trawls towed at 3.8-4.6 knots for 50-180 min at depths ranging from 154 to 235 m. Muscle samples were taken either 2 min after the trawl was hauled on board or, from the captured fish were put into a 500 litre tank and sampled between 0.3 and 24 hours during recovery. ATP and ATP-related compounds and lactic acid were measured from muscle samples. Lactic acid levels of fish muscle after 18 min (0.3 hour) recovery were higher than that immediately after capture. But the level of lactic acid decreased as recovery time increased.

TABLE 1

Potential unallocated mortality in different stages in the catching process

Gear: **Bottom trawl** Species: **Cod**

Stages of capture process	Reaction/ stress	Injury	Prim mort	Sec mort	Potential recovery	Relative magnitude	RIUM
Herding/concentrating -Response to ground gear - Swim in the net mouth	2	1	0	1	3	1	?
Filtration - Escapement in net body - Selection in the cod-end	3	2-1	1	?	?	4	?
Fisherman's selection	4	4	3	?	1		

TABLE 2

Potential unallocated mortality in different stages in the catching process

Gear: **Seine net** Species: **Plaice**

Stages of capture process	Reaction/ stress	Injury	Prim mort	Sec mort	Potential recovery	Relative magnitude	RIUM
Herding	2	0-1	0	0	4	0	0
Filtration	3	1	1	0	4	1	1
Fisherman's selection	4	2	1	1	3	2-3	1

TABLE 3

Potential unallocated mortality in different stages in the catching process

Gear: **Dredge** Species: **Scallop**

Stages of capture process	Reaction/ stress	Injury	Prim mort	Sec mort	Potential recovery	Relative magnitude	RIUM
Raking	1-2	0-4	0-4	0-1 ?	?	2	2
Filtration	3	3	3	3	1	3	3
Fisherman's selection	3	2	1	?	?	2	1 ?

TABLE 4

Potential unallocated mortality in different stages in the catching process

Gear: **Purse-seine** Species: **Herring, Iceland**

Stages of capture process	Reaction/ stress	Injury	Prim mort	Sec mort	Potential recovery	Relative magnitude	RIUM
Surround/set	0-1	0	0	0	4	2	?
Pursing	2	1	0	0			
Hauling/drying up	3	1	1	1	3		
Net burst	4	3	1 ?	2 ?	2	1	1
Fisherman's selection	4	3	2	2	1	1	1 ?

TABLE 5

Potential unallocated mortality in different stages in the catching process

Gear: **Gillnet** Species: **Cod**

Stages of capture process	Reaction/ stress	Injury	Prim mort	Sec mort	Potential recovery	Relative magnitude	RIUM
Tangling/gilling	3	2	2	?			
Escapement - live	3	2	1	1 ?	3	?	?
Drop out - dead			4		0	1 ?	
Fisherman's selection	4	3	3	?	?	2 ?	

TABLE 6

Potential unallocated mortality in different stages in the catching process

Gear: **Bottom longline** Species: **Alfonsin (*Sebastes*)**

Stages of capture process	Reaction/ stress	Injury	Prim mort	Sec mort	Potential recovery	Relative magnitude	RIUM
Attraction							
Hooking	2	1-2	1				
Escapement (*in situ*)	2	2	?	?	3 ?		
Escapement (retrieval)	2-3	3	3		0-1	0-1	
Fisherman's selection	4	3	3-4		0-1	3	3

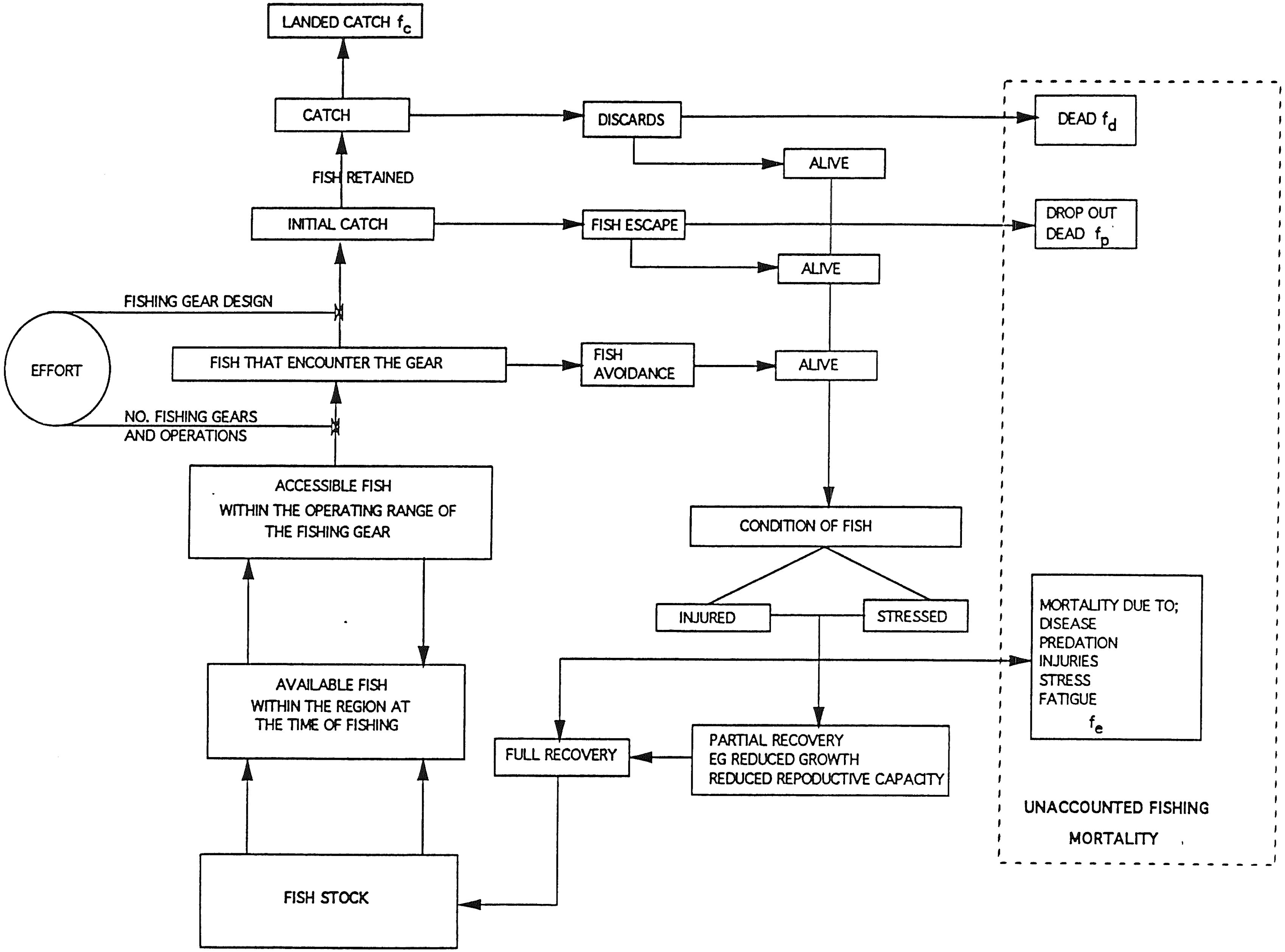

Figure 1. Fishing mortality model combining landed catch, discards, drop out, fish escape and avoidance mortality

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	Haddock	7 - 78	Fatigue mortality experiment. Fatigue mortality estimated at 0 - 27%	Beamish, 1966
Trawls	Gadoids		Otter trawl and Danishs 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 mins 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	Melanogrammus sp.		Otter trawl. Dead and injured fish found in the wake of the trawl. 163-169 dead fish/hr 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	Anon, 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	Nontarget catch. Mortality varied depending on moult condition	Smith and Howell, 1987
Trawls	Atlantic halibut	65	65% mortality after 48h compared to 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: 0-15:0	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, J.F. 1973
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, D.H. 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

Figure 2. Fish mortality after escape from fishing gears