MANUAL FOR GILLNET SELECTIVITY

by

René Holst
ConStat/DK

Niels Madsen &
Thomas Moth-Poulsen
Difta/DK

Paulo Fonseca &
Aidia Campos
IPIMAR/P

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1. INTRODUCTION

1.1 Background

The first manual of methods for measuring the selectivity of fishing gear was produced by Pope *et al* (1975); in the same year, an expanded review of gill net selectivity was published by Hamley (Hamley, 1975). In this review, the most important factors determining gill net selectivity are discussed, together with the methods used to date by different authors to estimate selectivity curves.

Important contributions arose in the last two decades which gave a better understanding of the principles of selection by the different types of fishing gears. At the same time, development of statistical models to data analysis, as a result of the increasing availability of computational means, has played a major role in the development of new methods and improvement of the existing ones.

In recent years, many efforts have been carried out with the aim of studying the selectivity of fishing gear used in the capture of commercial species, as well as developing new gear with improved selective properties. One of the gear types that has been heavily studied in what concerns selectivity is towed gear, and a manual of methods of measuring selectivity has been produced in 1995 for this type of gear by a subgroup of the ICES Working Group on Fishing Technology and Fish Behaviour.

With the present manual, it is intended to give a similar contribution in what concerns gill nets although it will be much smaller and simpler due to the time and number of persons allocated to the project. The main purposes of this work are to provide users with a tool for planning and performing selectivity tests, to present a standard method for data treatment and, finally, to update Hamley's review, providing a list of important contributions to these subjects.

This work has been produced at the scope of the EU project : "Methods and Standards for Gill Net Selectivity Research" (Proposal nº XIV/1810/C1/94). This is considered to be a first draft for a gill net selectivity manual, which will be revised at the end of this project.

1.2 Scope of the manual

1.2.1 Types of gears

The types of gears included in this manual are bottom set gill nets, trammels, tangle nets, semi-trammel nets, mixed (gill net and trammel) nets and driftnets. In practice, our discussion will be focused on the first three types, since they are the most commonly used in European waters, and those for which data are available at the scope of this project.

However, the methodology for data treatment and calculation of selectivity curves described here is extensive to the five types referred to, and so are the general considerations concerning planning and performance of sea trials.

1.2.2 Contents

The general structure for this manual includes four chapters, besides the introduction, as follows :

- Chapter 2 introduces the concepts of selection process and selectivity giving a brief overview of the basic problems related to the estimation of the selectivity of gillnets.

- Chapter 3 deals with designing and planning of the experiments. Section 2.1 provides a list of the factors which can affect selectivity, while in section 2.2 a discussion is presented concerning some of the parameters which are known to have an important effect in the selection process.

- Chapter 4 is dedicated to the conduction of the experiments at sea. Data to collect and measurement procedures are some of the points discussed, as well as decisions on the type of vessel to use and hire arrangements.

- Chapter 5 is dedicated to data analysis according to a statistical methodology developed within the scope of the present project.

1.2.3 Users

The manual is primarily aimed at fishery biologists or technologists involved in gear selectivity experiments. It is assumed that the users are familiar, to a certain extent, with the design and operation of gill nets *s.l.*, since the basic features on gear construction are not subject to a previous description. On the other hand, data analysis requires a basic knowledge on statistical procedures related to the methods used, and on advantages and constraints of the methods when applied to the existing data, subjects which cannot be fully covered in a manual of this type. In such experiments, it is recommended the existence of multidisciplinary teams including biologists, gear technologists and statisticians, since it is difficult that someone can deal simultaneously with all the aspects referred to above.

2. SELECTION PROCESS AND SELECTIVITY

According to Parrish (1963), selection in fishing can be defined as "any process that gives rise to differences in the probability of capture among the members of the exploitable body of fish". Such a general definition allows for the consideration of both between and within species selection during the different stages of the catch process.

In fact, the catch process (and hence selection) can be thought of as being divided in three distinct phases:

- probability that the occurrence of fish belonging to a single or different species coincides in time and space with the use of the fishing gear;
- probability that fish belonging to a single or different species encounters the fishing gear provided they are present when and where the gear is used (i.e., that fish are accessible to the gear);
- probability that fishing gear retains fish belonging to a single or different species, provided they have encountered it. (i.e., that fish are vulnerable to the gear).

The first two phases are essentially dependent on fish distribution and behavioural patterns, while in the latter the specific characteristics of the fishing gear play a fundamental role.

When between-species selection is considered capture will depend mainly on the behaviour displayed by each species towards the fishing gear, while in the case of within-species selection the retention of a fish will be driven by its specific characteristics (age, length or girth). In this case, selection is often taken as synonym of length selection, in spite the fact that where meshes are concerned selection is essentially a girth/mesh-opening related process. Selectivity is no more than the quantitative expression of selection.

Unlike what happens for trawl codend selection studies gill-net selection studies have the drawback of the lack of knowledge on the structure of the population encountering the gear (with the obvious exception of the direct estimation studies). As a consequence, selectivity estimates are based on the comparative fishing with gillnets of different mesh sizes (the so-called indirect technique), while keeping constant the other physical characteristics of the gear. Furthermore, some basic assumptions are usually taken into consideration, the most important of which is the Baranov's "Principle of Geometric Similarity", which states that if selection depends only on the relative geometry of the fish and meshes then all selection curves are similar. Therefor, the selectivity will be the same for any combination of fish length and mesh size for which their ratio is constant (Hamley, 1975), that is to say that all meshes are equally efficient for the length class they catch the best.

Notwithstanding, there are evidences that large meshsize nets have a greater efficiency for large fish (Ricker, 1949 *in* Hamley; Hamley and Regier, 1973). According to several authors this is related to the fact that larger fishes are more active than smaller ones, thus having a higher probability of encountering the nets (Rudstam *et al.*, 1984; Henderson and Wong, 1991). Therefore, catch should be thought as the product of encounter probability and retention probability. However, when indirect methods are used to estimate selectivity it is not possible to estimate the encounter probability. Some authors have tried to take it into account by considering the existence of a direct relation with the swimming speed (Rudstam *et. al.;* Densen, 1987; Hendersen and Wong).

By assuming an equal efficiency of the different nets (that is to say, all length classes have the same probability of encountering the nets) when this is not the case, one can be introduce a serious bias if selectivity is to be used for the correcting of catch size distribution. Nevertheless, it must be stressed that in either case the estimate of selectivity will be an unbiased one, since it is based on comparisons of catches within length groups (Hovgaard, not published).

3. PLANNING AND DESIGNING EXPERIMENTS

3.1 Factors affecting selectivity

3.1.1 General considerations

Planning an experiment involves prior knowledge of the factors that can affect gear selectivity. A list including the main factors is presented below. Some of them, as those related to the gear, are easy to control, in opposition to those related to the fish or to environmental conditions. However, the importance of these last factors in affecting the results should be taken into account.

Gear parameters

- Gang and net dimensions
- Mesh size
- Hanging ratio
- Vertical slack
- Twine characteristics (material, construction, thickness, colour, flexibility...)
- Floatation and weight
- Soaking time
- Arrangement of nets in the fleet - sequence and joining between nets; interaction between nets

Parameters related to the fish

- Fish abundance
- Fish availability to the net
- Fish behaviour towards the net
- Fish size
- Fish shape (girth at different body points)
- Presence of by-catch
- Presence of predators (can reduce the soaking time)
- Net saturation
- Patchy distribution in the net (includes attracting effects by individuals caught)

Parameters related to the fishing operations

- Dimension of boats (low-lying vs. high-lying boats)
- Net handling techniques
- Environmental parameters
- Light level
- Sea state and currents
- Seabed type
- Depth
- Occurrence of water/bottom debris

Before starting the work at sea, preliminary information must be collected regarding the fishery. Information on the following points should be collected:

- Fish populations (species composition, distribution and abundance, seasonal variations, by-catch)
- Fishing grounds (location, fishing yields, type of bottom, presence of other static gear in the area)
- Types of vessels used (main characteristics, bridge and deck equipment)
- Net handling techniques
- Duration of fishing trips

The main sources for this type of information are the fishermen themselves, the fish landings at local ports, or historic information from national databases. Scientific information, if available, must also be collected regarding these parameters and others, such as:

- Fish growth for the main species
- Fish behaviour towards the gear
- Characterisation of the area in terms of environmental conditions

3.2 Net characteristics.

3.2.1 The nets

Before starting any selectivity experiment, one must be aware of the characteristics of nets used in commercial fishing and try to keep constant and similar to the commercial nets all the parameters except those in study.

In literature, there is a general lack of information concerning the technical characteristics, other than mesh size, of the gear used in selectivity experiments. This information should be given, since it is of primary importance for the comparison of results obtained.

3.2.1.1 Gang and net dimensions

Gang dimensions can be the commercial dimensions, depending on the type of experiment and vessel used. However, gang structure will often be different since in the same gang there may be different mesh sizes fishing together. This will lead to the choice of the net dimensions for each mesh size used.
Most authors use the same net dimensions for all mesh sizes. However, in other cases, the net length is not the same for all mesh sizes, in order to obtain a better sampling of a given length class interval. For the same reasons, the number of nets of each mesh size can be different. Whenever this happens, the fishing effort has to be corrected through the use of a converting factor or even better - incorporated in the selectivity model.

3.2.1.2 Mesh size

Mesh size is one of the most important parameters affecting selectivity in this type of nets, and therefore the most studied. Most of the works account for variations in mesh size while keeping constant the other factors that are known to affect selectivity.

The number of mesh sizes tested can vary, with at least one of them in commercial size. For the species in European waters for which selective studies have been conducted, the majority of the authors have used mesh intervals between 5 and 15mm, according to the species and the number of mesh sizes tested.

The different mesh sizes must be carefully checked out during net construction, as the actual mesh often differs from nominal values given by the netmaker. This is particularly important whenever the mesh interval chosen is low (10mm or less), in order to avoid that errors due to differences between actual and nominal mesh size can approximate the chosen interval.

What is important is that there is a good degree of overlap between the size distribution of the fish caught by the different mesh sizes. Therefore, one can start with a considerable number of mesh sizes (say 6 or 7), and eliminate some of them after a previous analysis of these curves or, inversely, start with few mesh sizes and incorporate intermediate ones, if needed.

For some authors, mesh size must increase following to a geometric series (Regier and Robson, 1966; Takagi, 1975; Jensen, 1986). This accounts for an increasing variance in selectivity curves with mesh size. However, in practice, the commercial availability of the different mesh sizes leads to the use of arithmetic series.

For all types of nets, fish modal lengths increase with an increase in mesh sizes used. The shape of the selection curves, particularly in what refers to the right arm, can also be affected by an increase in mesh size, since the use of higher mesh sizes can lead to a higher capture of entangled fish belonging to the higher length classes. This can be observed in gill nets, but is more frequent in entangling nets (Koike and Takeuchi, 1985; Koike and Matuda, 1988; Fujimori *et. al.*, 1992).

3.2.1.3 Hanging ratio

This is another of the gear parameters which can strongly affect selectivity as, for the same mesh size, the mesh opening varies with the hanging ratio. However, the effects in selectivity of changing the hanging ratio are less studied than those of mesh size.

As it was discussed before, in a gill net, it is not infrequent that fish, besides gilling or wedging, are also caught by entanglement, especially in what concerns the biggest length classes. Small variations in the hanging ratio do not significantly affect the percentage of individuals being caught in the two first ways, but they have more important effects in entangling, with the number of entangled fish increasing when values for this parameter decrease.

This means that the modal lengths in a gill net do not seem to be significantly affected by a small variation in the hanging ratio, but the selection range usually is, due to a variation in shape of the right arm of the selection curve, corresponding to the higher length classes caught mainly by entangling. This is valid for gill nets, but can be far more important for trammels (Acosta and Appeldoorn, 1995), since these are nets aiming at the capture of fish that are usually caught entangled.

3.2.1.4 Vertical slack

The vertical slack (defined as the ratio between the stretched length of the inner and the outer netting, in trammels and semi-trammel nets) is known to affect selectivity of these types of gears. Existing works (Koike and Matuda, 1988) point out that the selection curves obtained for trammels with vertical slack of 1:1 have the same shape as those for gill nets with the same mesh size. An increase in the vertical slack will mainly contribute to modify the shape of the right arm of the curve, due to an increased percentage of larger individuals that become entangled, with a lower influence in the selection of smaller individuals.

It seems that increasing the vertical slack leads to an increase in net efficiency, but this is valid only within a certain range of values for this parameter. Losanes *et al.* (1992a) state that the excess netting gathering at the lower part of the nets due to high values in slackness can increase visibility, lowering net efficiency.

Vertical slack can be controlled by the height of the walls in a trammel net.

There are some points in making the slack of the inner sheet larger with increasing mesh size in the experimental gang; larger fish need larger sacks to be entangled in. Often commercial sheets have the same walls (outer sheets) with increasing mesh size but the inner sheet also keeps the same number of meshes in height which means that the sheet will have more slack because it increases the stretched height of the inner sheet.

3.2.1.5 Twine characteristics

Small diameter twine normally has a better catching power than larger diameter but when the diameter decreases, the mechanical breaking point decreases as well, and at some level the net is torn too easily. The diameter of the twine should therefore increase with mesh size having a constant (mesh size)/twine diameter-ratio. However, it is very difficult to keep this ratio constant from commercial netting. Commercial netting tends to increase the twine diameter in steps, or keep the diameter constant.

Elasticity changes with twine type, and it might be that some of the differences in catching power between different twine types could be directly related to the elasticity. However, the visibility of the twine and the capacity to pick up dirt also alter with twine type.

Many scientific - and not scientific (fishermen´s) theories deal with colours related to fishing power and depth. Therefore always use the same colour throughout the gang.

3.2.1.6 Floatation and weight

Floatation and weight affect the vertical slack and the drift of bottom nets over the ground with the tide. The slackness will often result in more fish entangled (mostly large fish). Drift over the ground can increase the catch (especially with flatfish) but can also cause a lot of trouble on hard bottom. Always choose exactly the same type and amount of floatation and weight as the commercial metier to study but be aware that sheets of smaller mesh sizes are heavier and hence need more floatation (and sometimes more weight).

3.2.1.7 Soaking time

Soaking time effects on catch efficiency proved to be significant, but no general trend has been defined relating to these parameters. Koike and Takeuchi (1982) in gill net experiments refer that the catch efficiency increases with an increase in soaking time, while Minns and Hurley (1988) came to opposite conclusions. Results obtained seem to be dependent on specific differences in the activity patterns and net-saturation effects. In tank experiments, Losanes *et al.* (1992b), using gill nets and entangling nets (trammel and semi-trammel nets) found a more complex relationship between soaking time and catch efficiency, with increasing efficiency within a short soaking time, after which a tendency to decrease was observed and a new increase for longer soaking times. The rate of fish escapement from the net after capture can partially explain these results. In this case, it was observed that escapement was usually successful within 40 min. to 1.5h after capture, after which the captured fish seem to either weaken or stop struggling.

Space limitation in gill nets can account for the effects of saturation, since once a fish has been captured in a mesh, the surrounding ones are not capable of catching other fish. Saturation effects in gill nets were reported by Meth (1970) in Hamley (1975) and Koike and Takeuchi (1982); the presence of struggling fish, which makes the nets more obvious, and of dead fish, may cause fish available to the nets to avoid the area, through some type of alarm reaction.

If it is not under testing, soaking time must remain constant for all the mesh sizes fished in order to minimize bias and, moreover, if saturation effects are known for some species, the nets must not stay too long in the water.

3.2.1.8 Arrangement of nets in a gang - sequence and joining between nets.

In most experiments, the gang consists of one net from each mesh size joined together. Interaction between nets can occur in the same gang since the efficiency of one meshsize may be affected by adjacent meshsizes. For instance, leading effects can occur for larger fish which can be guided along small mesh sizes until they are captured by a larger one.
These problems can be minimied by disposing the different meshsizes at random within each gang, and leaving gaps between them instead of tying them end-to-end.
On patchy fishing grounds, the use of nets of commercial lengths will sometimes result in gangs that extend the patches, the outermost nets being, under these conditions, exposed to a different amount of fish. In such situations, it is advisable to have nets below commercial length.
It is well known that end effects and changes in geometry at the ends affects selectivity. Non commercial length of the nets might also affect the overall geometry of the gang Therefore, the different meshsizes should be represented evenly at the end positions of the gangs as nets close to anchors and buoy lines fish differently. For the rest of the nets in the gang a random distribution will be appropriate.

3.2.2 Other parameters affecting fishing efficiency and selectivity

(the fish, the fishing operations and environmental parameters)

For those fish which are caught gilled or wedged, the catching process depends on the relative geometry of the mesh and the fish. Therefore, it is often stated that fish measurements should include girth perimeter, which is in principle more related to mesh size than length values. Consequently, some authors have used fish girths in evaluating the selectivity. However, fish length is easier to measure and, according to Reis and Pawson (1993), the variance of girth measurements for a given length is normally higher than that of length for the same girth. Differences in the degree of maturity or in stomach content of fish caught can account for these effects, as well as differences in body compressibility.

The cross-sectional shape of the fish is also a parameter that affects selectivity, since species of the same girth can have completely different cross-sectional shapes and, therefore, their retention for the same net mesh size will be completely different. Data available relating to length, girth, body depth and body width is an important source of information when estimating selectivity.

Besides fish size and shape, the catching efficiency can be affected by net saturation, which is highly dependent on fish abundance and fish behaviour towards the net, as discussed. On the other hand, contagious distributions have been reported (Berst and McCombie, 1963) in nets, which can probably be related to schooling behaviour.

Selectivity can be affected by several parameters related to the fishing operations. Net handling techniques can influence the number of fish caught in the case where fish are loosely enmeshed, as it is the case for large herring. Farran (1936) *in* Hamley (1975) refers that a significant proportion of the herring caught in gill nets can be lost while hauling up the nets. The use of low-lying boats in gill net fisheries allows both for a compensation of these effects and preservation in fish condition. For these boats, a shorter lift is required to haul up and, therefore, a lower proportion of fish is likely to be lost or damaged.

Environmental parameters can also affect gill net selectivity. Since most fish reactions to the nets are visual reactions, the light level is of primary importance, influencing the behaviour of fish towards the nets to a large extent. Seabed type can also have an effect on water turbidity and hence visibility, affecting fish behaviour.

4. CONDUCTING THE EXPERIMENTS AT SEA

4.1 Data to be collected

The work at sea depends to a great extent on the data being collected, which in turn are closely related to the type of experiment and objectives to be achieved. If the main purpose of the experiment is to study the selectivity of commercial gear for one or more species in a given area, the work on board commercial vessels is a guarantee that fishing conditions are the same as those in commercial fishing. At the same time it is often a guarantee of a larger catch which is absolutely critical in selectivity experiments.

If the experiment is aimed at a more specific purpose, such as to evaluate the way of fish retention in the meshes or to study net saturation effects, research vessels can be used. Research vessels are recommended whenever the use of commercial boats cannot guarantee a good control over the experiment, or if there is a need for special facilities that cannot be found in the last ones.

Distinction is made between data that must be recorded, because either they are necessary to carry out the analysis or are known to play a relevant role in the selection process (1), and optional data, which can influence the selection process to a lower extent (2).

4.1.1 Gear data

Together with the gear specification, a technical drawing should be presented containing its relevant characteristics.

a) Net type (1)

Bottom set gill nets
Tangle nets
Trammels
Semi-trammel nets
Mixed nets (gill nets/trammels)
Driftnets

b) Mesh sizes

Nominal mesh size (1)
Actual mesh size (1)

c) Net dimensions - number of meshes in height and width, by mesh size (1)

d) Twine characteristics

Netting material (PA,PET) (1)
Yarn type (monofilament, multifilament, multimonofilament, super-multimonofilament, multimonofilament-twine, mono-ace) (1)
Knotted/knotless (1)
Twine colour (1)
Twine number and diameter, by mesh size (1)
Linear density (2)
Flexibility (2)
Breaking strength (2)

NOTE : In the case of trammels, semi-trammel nets and mixed nets (gill nets/trammels), data on c) and d) must be discriminated for inner and outer walls of netting.

e) Floatline

Length (metres) (1)
Material (PA,PE,PP) (1)
Diameter (1)
Construction (twisted, braided, floats incorporated) (2)
Linear density (2)
Breaking strength (2)
Number of floats (2)
Dimensions of floats (2)
Floats material (Plastic, Rubber, other...) (2)
Floats buoyancy (2)
Total buoyancy (1)

f) Leadline

Length (metres) (1)
Material (PA,PE,PP) (1)
Diameter (1)
Construction (twisted, braided, leaded rope with weights incorporated) (2)
Linear density (2)
Breaking strength (2)
Number of weights (2)
Material (Fe, Pb,...) (2)
Weight (2)
Total weight (1)

g) Hanging line

Cable material (cotton, PA,PE,PP) (1)
Cable diameter (1)
Construction (twisted, braided) (1)
Number of meshes in the joining (1)
Hanging ratio in the floatline and the leadline (in the case of trammels or semi-trammel nets, hanging ratio must be specified for the inner and outer netting) (1)

h) Side ropes

Length (1)
Material (PA,PE,PP) (1)
Construction (1)
Diameter (1)
Linear density (2)
Breaking strength (2)

i) Hauling ropes (2)

Material (PA,PE,PP)
Construction (twisted, braided)
Diameter
Linear density
Breaking strength

j) Buoys

Number (1)
Diameter (1)
Material (Rubber, other) (2)
Buoyancy (2)

k) Anchors

Number (1)
Material (Fe, other) (2)
Weight (2)

4.1.2 Vessel data

a) Vessel name/registration (1)
b) Vessel type (gill netter or other types) (1)
c) Research vessel/commercial vessel (1)
d) Length overall (2)
d) GRT (2)
e) Engine power (2)
f) Hauling equipments (1)
    Power
    Hauling speed

4.1.3 Haul data

a) Haul number (1)
b) Date (1)
c) Shooting time for each gang (1)
d) Hauling time for each gang (1)
e) Coordinates for each gang (1)
    Start shooting (1)
    End shooting (1)
f) Depth (1)
g) Sea state (1)
h) Current speed and direction (2)
i) Wind speed and direction (2)

4.1.4 Catch data

For each mesh size:

a) Weight
    Total weight (1)
    Weight by species (1)

b) Target species
    Scientific name (1)
    Common name (1)

c) By-catch species
    Scientific name (1)
    Common name (1)

For each target species :

a) Sample size measured (1)
b) Length of individuals within the sample (Total length, fork length, carapace length) (1)
c) Girth perimeter (1)
d) Weight of individuals (2)
e) Sex (2)
f) Maturation state (2)

NOTE : For by-catch species, the same parameters can be recorded, though optional.

4.2 Measurement procedures

4.2.1 Mesh measurements

It is strongly advised to take the inside measure (without knots) of the mesh as different knots are used and because it is easier to relate to girth measurements and the catch process.

Commercial sheets from a large production are often very uniform in the mesh sizes of sheets coming from the same batch production and very few measurements (10-20) are needed to establish the correct mesh size. These meshes from modern commercial production also seem to have a rather constant size during and after use, probably because most tension is applied to the float- and leadline.

Manufacturers of sheets can sometimes be persuaded to produce a smaller batch of sheets in different mesh sizes for scientific use. However, it is not uncommon in such a production that the mesh sizes within the sheets vary more than acceptable because it often takes many sheets to find the correct adjustment of the net machine.

There are no authorised way to conduct mesh measurements. The ICES gauge normally used for towed gears applies a force far too large for the twine used in gill nets. A wedge gauge is not convenient either. It is common to use a simple measuring board and apply the force of a finger touch. This force is, however, rather subjective and can be substituted by a fixed load between 30-50 grammes from a sprig balance.

4.2.2 Girth measurements

Girth measurements can have several purposes. Often a girth/mesh perimeter ratio is calculated and related to fish shape. These ratios can be compared and are pretty constant for the modal girths of species with the same shape. The ratios, or just the maximum girth, are important in the preliminary design of an experiment to establish the correct mesh sizes to be used in the gang in order to target the most abundant fish sizes.

It is obvious that it is more relevant to measure girth than length in relation to gill net selectivity, and some research projects only measure girth of the fish caught. However, these measurements are very time consuming and length (either fork- or total length) is measured instead. Whatever is chosen it is appropriate to calculate the length/girth relations. These are often, but not always, linear regressions.

When a selectivity curve has more than one mode, it is likely that the fish are caught in different ways. If this is the case, it is relevant to record the way of enmeshment and proportion of the catch enmeshed in the different ways. It is common to measure girth at two or three positions where the species is frequently enmeshed. Upon that the girth at a position where the marks from the mesh are seen is often recorded.

In trammel nets and nets with low hanging ratio it is often very difficult to judge the position of the first enmeshment because the fish are heavily entangled.

Positions on a roundfish where girth is measured could for example be: Aft end of maxillar, aft end of gill cover and maximum girth.

On flatfish it could be: Position where gill cover meets the side (bottom) of the fish, aft end of gill cover, the anal spine or aft of the pectoral fin.

There is no standardised way to conduct girth measurements. The largest problem is girth round soft parts of the fish. These parts change texture according to time after capture, fish condition or if the fish is drowned (dead in the net).

A procedure used with some success is to measure firm parts (i.e. maxillar and head) with a wire and soft parts with a tape. Both should form a loop around the fish and should be tensioned by a (say) 50 g spring balance. The reduction of the wire from stretched (the girth) is measured on a measuring board.

Because the maximum girth is not the same place on every fish within a species, a fixed point has to be chosen.

On flatfish it is convenient simply to measure width instead of girth and converting to girth afterwards by multiplying by two and a converting factor.

4.2.3 Net measurements

To make the nets as close to commercial as possible it is advisable (and cheaper) to let a good netmaker do the job. If a commercial ship is used it is convenient to use the netmaker who normally services the ship as this ensures a situation as close to commercial as possible. It is, however, a common experience that even if every parameter is specified, and it is emphasised the nets to be accurate, the nets come out in slightly different (and variable) lengths than specified. All parameters therefore have to be checked before use, and all nets must be measured by floating line length at least before and after the experiment.

4.3 Choice of the vessel and hire arrangements

4.3.1 Commercial boats - Research ships

As gill nets are passive gears, selectivity would perhaps not be as different for the two types as it is for towed gears.

Commercial boats can handle many more nets, make less damage to the nets and know better fishing grounds than research ships.

4.3.2 Hire arrangements

Gill netters are often small ships which are more sensitive to weather conditions than other fishing ships. If possible make a "stand by" arrangement under which the research crew can join the fishery when it is possible and go home when it is not.

If the fishery is with day trips and the fishing ground is not far from the harbour, the commercial ship can eventually shoot your fleets itself when the weather has become good after a period without suitable weather conditions. The skipper will then phone you as he steams out to shoot the nets and you can gather your team and travel to the harbour in time for the nets to be hauled.

The aim of the cruise is that the research leader gets as many of the target species in the right size range as possible, provided he can handle the catch.

If the skipper is paid a fixed amount of money for his inconvenience, it is often difficult to agree upon how big this inconvenience must be - put in other words: as a cruise leader you can not be sure your demands to the catch will be fulfilled.
If a guaranteed hire is paid to the ship, the skipper will not necessarily fish optimally because more catch means more work, reduced quotas and money for ice and boxes. It is a good idea to pay the skipper these expenses upon the guaranteed hire.

Combinations of guaranteed hire plus a percentage of the catch can also be arranged.

An arrangement which can be very successful is a guaranteed hire plus a bonus to the skipper and each of the crew (outside of the ships account) for each successful fleet hauled (from a scientific point of view) i.e. concerning damage and number of fish.

5. Statistical analysis.

5.1 Introduction

The analysis of data sampled from gillnet experiments has been conducted by a rich variety of methods. One of the most popular is due to Holt (1963) and is still frequently used in literature. This method, along with most of its successors, is characterised by an being algebraic recipe rather than a statistical model. The major drawback of these methods, is the lack of assumptions on the underlying distributions, thereby disabling any statistical inference on the data. Regier and Robson (1966) and Hamley (1975) reviewed some of the most common methods. Besides descriptions of individual models, these papers also contain discussion on central selectivity concepts. Holst et al. (1995) made comparative studies of the behaviour of 7 different methods across six different data sets, with the overall conclusion that the derived population structures proved to be invariant regardless of the method, they were calculated under.

A first attempt to model gillnet data within the framework of a proper statistical model was done by Kirkwood and Walker (1986) and given a general formulation by Millar and Holst (1996) in terms of log-linear models. This method is given the appropriate acronym GILL*N*ET: Generalised Including Log-Linear *N* Estimation Technique. This approach is a generalised extension to the SELECT model Millar (1992), as it, estimates the selection curves and an optional intensity parameter, and also allows for estimation of an assumed population distribution.

Across all methods, there has been a large support of and belief in the principle of geometrical similarity, stated by Baranov (1948). This principle claims that selectivity only depends on the relationship between circumference of the fish and the mesh size in use. It is however clear that the morphology of certain species can violate the principle, and likewise there are different ways of capturing the fish. For a more detailed discussion of the validity of the principle see Hamley (1975).

Important exceptions, methods which neglect the principle of geometrical similarity, are the methods by Holt (1963) and the one by Kirkwood and Walker (1986), both assuming a fixed spread for all selection curves.

Another commonly agreed assumption is that all nets have the same efficiency for their modal length class, and hence that the selectivity curves are all of the same height.

The statistical method for analysing gillnet data, described in this chapter, is the GILL*N*ET method, which is unconstrained as regards the above mentioned assumptions.

5.2. The basic model

Data collected using gillnets, trammel nets and hooks are count data which traditionally are handled within the framework of contingency tables by imposing a multiplicative structure on data.

The number y_{lj} of fish of length *l* that encounter the *j*'th gillnet are suitably described as observations from independent Poisson distributions Y_{lj}, with a rate that is the product of parameters reflecting the abundance of the length class and fishing intensity of the net λ_l and p_j respectively.

$$Y_{lj} \sim Po(p_j \cdot \lambda_l)$$

Let $r_j(l)$ denote the retention probability of length *l* fish in the *j*'th gear. It then easily follows that n_{lj}, the observed number of length *l* fish caught in the *j*'th net, are observations from independent Poisson distributions

$$N_{lj} \sim Po(p_j \cdot \lambda_l \cdot r_l(j))$$

Literature shows many suggestions on the functional form of $r_j(l)$, some of which relate to fish behaviour and morphology, (e.g. Hamley, 1975). That discussion is also briefly touched in Millar and Holst (1996), but is beyond the scope of the present model presentation. As it will be seen below, the general approach in the GILL*N*ET method is very flexible and the limited collection of selectivity functions given here can be extended in natural ways, such as including bimodal curves.

Likewise it is natural to model the abundance over length classes as a continuos function rather than discrete parameters for individual length classes. For a valid and useful application of the extended model, that includes fitting of a continuos population, it is however necessary to have information on the structure of the abundance, to enable a reasonable choice of the functional form. This is often not the case, and hence the simple analysis, aimed only at fitting the selection curves, will probably be the most common . No precise guidelines can be given on this topic, but if reliable information exists, either from direct experiments, previous studies, biological knowledge or in other ways, a (pre-) analysis should include an estimation of the abundance.

The same concerns also apply for modelling the intensity parameter. An example of a useful application of this, is in the case where not all nets are of the same length. In that situation the efficiency of the *j*'th net is suitably modelled as being proportional to the length of that net

$$p_j = c \cdot \ell_j$$

where ℓ_j is the length of the *j*'th net. The log likelihood function becomes

$$L = \sum_{l,j} n_{lj} \cdot \log(\nu_{lj}) - \nu_{lj} = \sum n_{lj} \cdot \left[\log(p_j) + \log(\lambda_l) + \log(r_j(l))\right] - p_j \cdot \lambda_l \cdot r_j(l)$$

where terms $-\log(n_{lj}!)$ have been omitted. Maximisation of L is in general a non-trivial task to pursue and will in many cases require custom software. However, for a large range of choice of the components p_j, λ_l and $r_j(l)$ the logarithm of $\nu_{lj} = p_j \cdot \lambda_l \cdot r_j(l)$, can be given a linear expression

$$\log(\nu_{lj}) = \log(p_j) + \log(\lambda_l) + \log(r_j(l)) = \sum_i a_i \cdot f_i(l, j)$$

where $f_i(l, j)$ are functions depending only mesh-size and/or length-classes.
The advantage of using this transcription is that it greatly facilitates the estimation. Most standard statistical software packages include tools for fitting log-linear models. In section 4.5. code is given for S-Plus, SAS and Genstat. In case no assumptions are made on the distribution of the abundance, the length acts as a classification variable and is regarded nuisance; This situation conforms with the SELECT model.

Example 1

Assume that $r_j(\cdot)$ has the form of a unit height gamma distribution

$$r_j(l; \alpha, \beta) = \left(\frac{l}{(\alpha - 1) \cdot \beta}\right)^{\alpha - 1} \exp\left[\alpha - 1 - \tfrac{l}{\beta}\right]$$

In accordance with Baranovs principle of geometrical similarity, assume that modal length and spread are proportional to the mesh-size m_j:

$$\mu_j = \alpha_j \cdot \beta_j = k_1 \cdot m_j \text{ and } \sigma_j = \alpha_j \cdot \beta_j^2 = k_2 \cdot m_j$$

this is equivalent to

$$\alpha_j = \alpha \text{ and } \beta_j = k \cdot m_j$$

It now follows that

$$\log(r_j(l)) = (\alpha-1)\cdot\log\left(\frac{l}{(\alpha-1)\cdot k\cdot m_j}\right) + (\alpha-1) - \frac{l}{k\cdot m_j} = a_0 + a_1\cdot\log\left(\frac{l}{m_j}\right) + a_2\cdot\frac{l}{m_j}$$

Which is seen to have a linear form. Here $a_1 = \alpha - 1$, $a_2 = -\frac{1}{k}$ and a_3 is redundant.
After the model has been estimated values of k and α can be extracted by backwards calculations and finally values of modal length and spread can be assessed :

$$k = -\frac{1}{a_2} \quad \text{and} \quad \alpha = a_1 + 1$$

If the model should include estimation , for example, a gamma shaped population structure, the model would be

$$\log(\lambda_l) + \log(r_j(l)) = a_0 + a_1\cdot\log\left(\frac{l}{m_j}\right) + a_2\cdot\frac{l}{m_j} + a_3\cdot l + a_4\cdot\log(l)$$

5.3 Models

The general approach presented in 4.2 allows for a very large range of different selectivity- and population-curves. A collection of the most commonly used selection curves are given below.

Model	Selection Curve $r_j(l)$	$\sum_i [a_i]\cdot\{f_i(l,j)\}$
Normal location shift	$\exp\left(-\frac{(l-k\cdot m_j)^2}{2\sigma^2}\right)$	$\left[\frac{k}{\sigma^2}\right]\cdot\{l\cdot m_j\}+\left[-\frac{k^2}{2\sigma^2}\right]\cdot\{m_j^2\}$
Normal scale shift	$\exp\left(-\frac{(l-k_1\cdot m_j)^2}{2(k_2\cdot m_j)^2}\right)$	$\left[\frac{k_1}{k_2}\right]\cdot\left\{\frac{l}{m_j}\right\}+\left[-\frac{1}{2k_2}\right]\cdot\left\{\left(\frac{l}{m_j}\right)^2\right\}$
Lognormal	$\frac{1}{l}\exp\left(\mu_1+\log\left(\frac{m_j}{m_1}\right)-\frac{\sigma^2}{2}-\frac{\left(\log(l)-\mu_1-\log\left(\frac{m_j}{m_1}\right)\right)^2}{2\sigma^2}\right)$	$\left[\frac{1}{\sigma^2}\right]\cdot\left\{\log(l)\cdot\log\left(\frac{m_j}{m_1}\right)-\frac{1}{2}\log^2\left(\frac{m_j}{m_1}\right)\right\}+\left[1-\frac{\mu_1}{\sigma^2}\right]\cdot\left\{\log\left(\frac{m_j}{m_1}\right)\right\}$
Gamma	$\left(\frac{l}{(\alpha-1)\cdot\beta}\right)^{\alpha-1}\exp\left(\alpha-1-\frac{1}{\beta}\right)$	$[\alpha-1]\cdot\left\{\log\left(\frac{l}{m_j}\right)\right\}+\left[-\frac{1}{k}\right]\cdot\left\{\frac{l}{m_j}\right\}$

Table 1 :

A collection of important selection curves and their specification as log linear models. All curves model modal length and spread proportional to m_j, except "Normal location shift", which assumes a fixed spread.

5.4 Analysis

A brief discussion on the successive steps in an analysis session, followed by a practical example, demonstrates how the practical analysis is conducted.

An anlalysis of a gillnet dataset should follow along the traditional path of a statistical analysis :

1. Data Collection
2. Data Inspection
3. Fitting a model
4. Assessing the fit
5. Refitting
6. Presentation of the final model

This schedule is of course only a rough guideline, and does not intend to foresee all the exceptions that comprise real life analyses.

5.4.1. Data Collection

Collection of data is associated with the planning and design of the experiment. Important practical matters related to this topic are treated in other chapters of this manual.

Data sampled from single sets in gillnet experiments are generally too scarce to allow for analysis. Consequently it is common practice to pool data from an experiment over all sets. An unfortunate consequence of this is that variation between sets is neglected.

The question of design and power analysis (how many sets are needed to detect a pre-specified difference between nets with a given probability) is outside the scope of this manual. It is however an extremely important part of the experiments, in order to obtain data valid for inference.

5.4.2. Data Inspection

Before proceeding into fitting an appropriate model, raw data should be inspected for any defects or anomalies in case the data indicates unusual behaviour. If this can be related to serious deviations from the experimental design data can optionally be trimmed, for instance by omitting the affected settings.

Trimming of data should only be done as an exception and only on well reasoned grounds. If the anomalies are inexplicable, data should remain unchanged; That is to say that *data should speak for itself, rather than being deferred to say what we expect them to say*.
A thorough inspection requires access to the raw data, set by set.

If the experimental conditions over different sets have varied, for example different logistic characteristic, data can be separated into two or more different sub-sets. Subsequently these sub-sets can be pooled, if tests have detected no significant difference in the statistics of interest.

5.4.3. Fitting the model

Analysis of gillnet experiment data is impeded by the lack of non-selective data. This means that the actual shape of the selection curve is unknown and no “true” selection curve can be claimed. The primary choice of a model must therefore be based on empirical and biological knowledge such as ways of capture, morphology of the fish, experiences from previous and comparable experiments etc. Also practical observations done during the fishing time can be useful in this step.

The actual fitting of a model is most easily accomplished by use of a standard statistical software package. Many of these include tools for maximum likelihood estimation of log linear models. Codes for implementation of a gamma selection model in three different packages, are given in section 4.5. Similar codes for other models are easily adapted.
A program customised for this use is presently under development by ConStat.

5.4.4. Assessing the fit

Once a model has been fitted, the standard maximum likelihood theory provides various tools for validation of the goodness of fit. The most important single statistic is the deviance *D*, (which is automatically computed by most statistical programs). This statistic measures the overall goodness of fit, provided the assumptions on the error structure hold. As a general rule of thumb the deviance and the degrees of freedom should be within the same order of magnitude. The degrees of freedom (*df*) is also computed automatically and equals the number of observation units (# length classes times # mesh sizes) minus the number of estimated parameters. The deviance can be evaluated by referring it to a chi-square distribution :

$$D \sim \chi^2(df)$$

Justification or rejection of a model should never based on the deviance alone. If $\frac{D}{df} > 1$ data are said to be over-dispersed. Over-dispersion can be interpreted either as lack of fit, that is to say a bad choice of model, or from violation of the assumption of an underlying Poisson distribution. In many disciplines that make use of the Poisson distribution, over-dispersion is more the rule than the exception, and this is particularly true for many biological phenomena, where individuals do not behave independently. An alternative error structure might be the negative binomial distribution, but this often involves more computational effort and customised software.

A more detailed source of information on *how* the fit is bad can be found by looking at residual plots. The (deviance-)residuals $res_{l,j}$ and the deviance (*D*) are related by :

$$D = \sum_{l,j} res_{l,j}^2$$

The precise definition of $res_{l,j}$ is of no interest here, but can be regarded similarly to the "standard" residual.

For data like gillnet data that relates to two variates (length and a mesh-size), a residual plot is most conveniently arranged as a projected 3D surface (see example below). A good fit is characterised by *"small"* and *"randomly"* distributed residuals. Under ideal conditions, when the Poisson distribution is met and a "true" model has been chosen, the residuals are distributed according to a standard normal distribution *N(0,1)*. Hence all residuals should be within the range 2. A thorough inspection of a residual plot can give valuable information on where and how the selected model fails to describe the data; This can in turn be used for an improved choice of model.

Processing of the selection curves may also provide information to the plausiblity of the fit.

5.4.5. Refitting

On basis of the first analysis and assessment of the fit the analyst might want to look for an improved model, i.e. a model that decreases the deviance and avoids systematic trends in the residual plots. If, for instance, the residual plot indicates that the selection curves could be bi-modal (and if this can be reasoned from a biological point of view as well) this could be tried out. As an example the uni-modal normal scale model can be extended to a bi-modal by

$$a_0 + a_1 \cdot \frac{l}{m} + a_2 \cdot \left(\frac{l}{m}\right)^2 + a_3 \cdot \left(\frac{l}{m}\right)^3 + a_4 \cdot \left(\frac{l}{m}\right)^4$$

The process of fitting, evaluation and refitting is iterated until a satisfactory result is obtained or the collection of applicable models is exhausted. It is however important to keep in mind that selection of a model is not an objective process, but involves a personal judgement between different topics, such as adequate degree of explainable variation and ease of interpretation.

5.4.6. Presentation of the final model

Presentation of a fitted (and acceptable) model often serves more purposes than simply concluding the analysis. A primary interest of the analysis is to obtain a model that can be used in building a basis for actions, such as legislation and imposing regulations concerning mesh sizes on the fishery. Other objectives of the presentation are documentation and evaluation of the results obtained.

Plots of the selection ogives are a convenient presentation of the overall fit. This gives a quick and qualitative impression of the fit, that is an intuitive assessment of its plausibility.
As mentioned above, no “true” selection curve can be claimed, hence plots of the curves are more of visual interest rather than an actual quantitative justification. The residual plot, on the other hand, contains much more precise information and can be used as a tool for inference and refinements. The overall fit is summarised in the deviance statistic and its degrees of freedom, but as lack of fit cannot be distinguished from violation of the assumed error structure (over-dispersion), the deviance should not be used in isolation as a measure of the goodness of fit.

The model itself is conveniently presented by plotting the selection curves and listing modal lengths (and spreads) in tabular form.

For validation of the selectivity of the nets, it is relevant to tabularise modal lengths and their standard deviations. These can be derived from the linear expression (cf. example 1). It is however good statistical practice also to give estimates of the parameters and their standard deviations.

Example 2

A short and in no way exhaustive analysis of the data presented in the paper by Kirkwood and Walker (1986) follows and gives only the core results.

Length class mm	Number in net of mesh size (cm)							
	5,08	*7,62*	*10,16*	*12,7*	*15,24*	*17,78*	*20,32*	*22,86*
450	1	10	0	0	0	0	0	0
550	3	17	12	0	0	0	0	0
650	2	6	37	0	0	0	0	0
750	0	3	56	25	0	0	0	0
850	1	2	49	76	22	0	0	0
950	1	4	24	50	37	3	0	0
1050	1	2	13	41	58	13	3	0
1150	0	3	5	36	30	28	5	0
1250	0	2	1	12	17	35	19	3
1350	0	0	0	2	4	13	10	5
1450	0	0	0	2	1	3	5	2
1550	0	0	0	0	0	2	3	7
1650	0	0	0	0	0	0	3	4

Tabel 2:

Observed numbers by length class of gummy sharks (Mustelus antarcticus) caught in nets of eight mesh size

Each of the four models listed in table 1 were fitted to the data. The results for the smallest mesh size is listed in table 3.

Model	Parameters	Deviance
Normal Location	(μ,σ) = (372.47,175.07)	231.90
Normal Scale	(μ,σ) = (410.98,85.03)	525.66
Gamma	(α,β) = (26.53,15.35)	342.18
Log Normal	(μ,σ) = (5.99,0.1917)	274.52

Table 3:

Fitted parameters for the smallest mesh-size and deviances for the fit. All have 89 degrees of freedom

It is seen that the normal location produces the smallest deviance, but not significantly smaller than the log normal model.

The residual plots for the four models show very similar patterns, and in particular the normal scale, the gamma and the log-normal are very alike. The improved fit of the normal location seems mainly to be located in the smallest and the largest mesh-size. For none of the four models the residuals appear to be randomly distributed. On the contrary, the plots seem to be divided into five diagonal regions with alternating signs. This indicates two interesting points :

1. The fits are varying between systematically overestimation and underestimating the catch in different intervals of length classes.
2. The signs of the residuals appear to be dependent on the ratio between mesh size and length.

The above suggest that an alternative model should be based on a bimodal selectivity curve. A bimodal extension of the normal location model was fitted and the deviance statistic was reduced to 174,77 on 86 degrees of freedom model.

Fig. 1 : Selectivity curves for the fit of the “Gummy Shark” data. The Normal Location assumes a fixed spread whereas the rest are consistent with the principle of geometrical similarity.

Fig 2 : Plots of the deviance residuals from the fits of the “Gummy Shark” data.. A • indicates a positive residual and a O a negative. The area of the circle is proportional to the absolute value of the residual

5.5 Software

Most standard statistical software package contain tools for fitting log-linear model, and below is given code for fitting the gamma selection curve in three major packages. Other models should be easily derivated from these examples.

5.5.1. S-Plus code

The basic units in Splus data are vectors. Gillnet data are appropriately represented in three vectors `lens, msizes` and `catch` all of the samme length. The k'th entry of contains the corresponding information for k´th combination of length and mesh-size.

The S-Plus code for fitting the scale gamma selection curves is

```
var1 <- lens/msizes
var2 <- log(lens/msize)
glm(catch~var1+var2+as.factor(lens),family=poisson)
```

5.5.2. Genstat code[1]

Like Splus Genstat operates on vectors and the vectors `catch, lens` and `msizes` are given the same format and values here. Furthermore a factor `lfac` is created, containing the length as a classification variable.

```
factor [levels = !( 5.08, 7.62 ... 22.86)] lfac ;
values = !(8(5.08, 7.62 \ ... 22.86))
```

The Genstat code for fitting the scale gamma selection curves is

```
calc var1 = lens/msizes
calc var2 = log(lens/msizes)

model [distribution = poisson ; dispersion = *] catch
fit var1, var2, lfac
```

5.5.3. SAS code

SAS is constructed from a different operational paradigm than Splus and Genstat. A unit in a SAS data set is an observational or calculated unit, containing fields `lens, msizes` and `catch` with obvious meanings.

---

[1] [1] The Genstat code is due to Robert Fryer SOAFD Marine laboratory, Aberdeen, Scotland.

The SAS code for fitting the gamma scale selection curve is

```
Data dat;
var1=lens/msizes;
var1=log(lens/msizes);
lfactor=lens;

Proc genmod;
   class lfactor;
   model catch=lfactor var1 var2/dist=P;
```

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APPENDIX 1

Attempt of a technical description of twine used in gill net netting

A description of the most common used nylon (polyamid, PA) twine (in Denmark).

Type:	name also called
Multifilament	Old type nylon twine
Monofilament	Mono
Multimonofilament	Multimono
Super-Multimonofilament	Super-Multi, Super soft
Multimonofilament-Twine	Mono-twine
Mono-Ace	

Twine Thickness:

Most common systems used:

Denier system:(Often used for Multifilament and mono-ace). Typical 210/3, where there are three strands each of the dimension 210 Denier. The "210" means, that 9000 meters of the filamentstogether weight 210 grammes before twisting. 210/9 has 3 strands with the filaments of each weighing 3 x 210 g for 9000 m before twisting.

Diameter: Diameter in mm (often with monofilament).

Japanese Nr.: (Often used with multimono, super-multi and mono-twine). Typical 1,5x4 (multi-mono) 0,5x12 (super-soft) or 5x3 (mono-twine), where the first number is the Japanese Nr. and the last the number of monofilament units the final twine has. One Japanese unit equalizes 220 Denier.

Japanese Nr.	Total Denier	Diameter in mm.
0.4	88	0.104
0.6	132	0.127
0.8	176	0.147
1.0	220	0.162
1.5	330	0.202
2	440	0.234
3	660	0.284
4	880	0.329
5	1100	0.368
6	1320	0.403

Other systems:Tex = g/1000 m
Nm = m/kg

The Physical composition of the twine

Multifilament: A nylon multifilament twine is composed of from two or more twisted strands each of which is composed of numerous small filaments of under 0.1 mm diameter twisted together.

The twine is non transparent, rather firm and unelastic. The strands are often twisted clockwise, S, whereas the next (higher) level (final twine) is twisted counter clockwise, Z.

Monofil: Consists of one solid nylon thread. For this type, and the following the double weaver's knot are often used and the netting is stretched mechanical in the depth direction or autoclaved in order to fix the knots.

Multimonofil: Consists of from 3 (1.5x3) to 10 (1.5x10) monofil threads, which are loosely twisted round each other, but not round their own axis. In the examples above, the monofil thread have the Japanese number 1.5 which is 0.2 mm in diameter.

Super Multimonofil: Is constructed in the same way as multimonofil, but the monofil threads used are thinner and more numerous; typically 0.5x8 or 0.5x12, The last mentioned has thus 12 monofil threads of Japanese Nr. 0.5 = 0.12 mm. in diameter. As indicated by the name "Supersoft", the twines are very soft.

Mono-Twine: Is usually twisted of 3 monofil treads, each twisted round their own axis clockwise S, and on each other counter clockwise Z. In this way a stiffer twine is produced than the multimonofil. Typical twines are 4x3 and 5x3, with 3 treads of Japanese numbers 4 or 5 respectively.

Mono-Ace: Is a very loosely twisted, silky twine, which taking the example of 225/6 would consist of 6 strands of Denier number 225, each consisting of numerous loosely twisted unbroken filaments (smaller than 0.1 mm in diam.). This twine is strong, but is more easily worn. Mono-Ace is often used for trammel nets or tangle nets for cod.

Dimensions of netting for gill nets:

The length of the netting is given in knots, which is number of knots in a row when the netting is stretched in lengthwise (number of half meshes). The meshsize is usually given in half mesh length in mm. The stretched length (hanging ratio = 1) in mm. of the net is thus = meshsize (halfmesh) x knots(numbers in length).

Unlike the length, the depth of the netting is given by the numbers of full meshes, and will normally end with ½.

Hanging ratio is actual length of gill net headline/floatline (excluding bare extensions) divided by full stretched length of netting mounted to it.