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# Mesh Size Measurement Revisited

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# Contents

# 1 Introduction

In 1291 Philip IV the Fair, King of France, forbade *"de pescher avec engins de file de quoy la maille (n ait) la moule d'un gros tournois d'argent"* or, to fish with nets with meshes smaller than the size of a silver coin of that time (Hovart, 1985). This silver coin can be seen as a predecessor of the present-day wedge gauge used to check whether the meshes of fishing nets comply with modern technical regulations.

A mesh gauge developed by C. J. W. Westhoff under the auspices of the ICES Comparative Fishing Committee became the standard gauge for research activities in ICES countries in 1962 (ICES, 1962a) and became known as the ICES gauge (Figure 1). To make a measurement the ICES gauge exerts a fixed longitudinal measuring force on the mesh. The recommended measuring force is 4 kilogramforce (kgf). When the ICES gauge is correctly used, the measurements are free of human influence. Since its introduction the ICES gauge has been generally used in selectivity experiments, to provide scientific advice on minimum regulated mesh sizes. However, since 1962 a wide range of new twines and netting types have been adopted in the fishing industry. These modern twines vary significantly in thickness and stiffness, characteristics which affect both mesh size and selectivity.

For fisheries inspection the legal mesh gauge is the much simpler wedge gauge (Figure 2). The wedge gauge is normally operated by hand force and this makes the measurements liable to human influences. Therefore, a weight or dynamometer is used to control the measuring force in case the measurements are contested. Because this procedure generally yields lower mesh openings than the hand force, it is hardly ever requested by the fishermen.

It is generally acknowledged that the measurements made with the ICES gauge yield lower mesh openings than the wedge gauge used by fisheries inspectors (Ferro and Xu, 1996; Fonteyne *et al.,* 1998). This difference implies that a codend with the legal minimum mesh size, measured with the wedge gauge, will have a lower selectivity than anticipated, since the proposed minimum mesh size was based on experiments carried out with the ICES gauge.

The question as to whether a 4 kgf load is still appropriate to exert sufficient force to stretch the mesh fully lengthwise in modern netting types was first raised during an EU-sponsored Concerted Action Project to evaluate mesh measurement methodologies (Fonteyne *et al.,* 1998). The participants in this project (scientists, fisheries inspectors, fishermen representatives, netting manufacturers) recognized the need to consider the adoption of a standard mesh measurement method for use by enforcement agencies, scientists and the fishing industry. In 1998/1999 the ICES Working Group on Fishing Technology and Fish Behaviour (WGFTFB) established the need to refine mesh measurement methodologies to take account of the wider range of

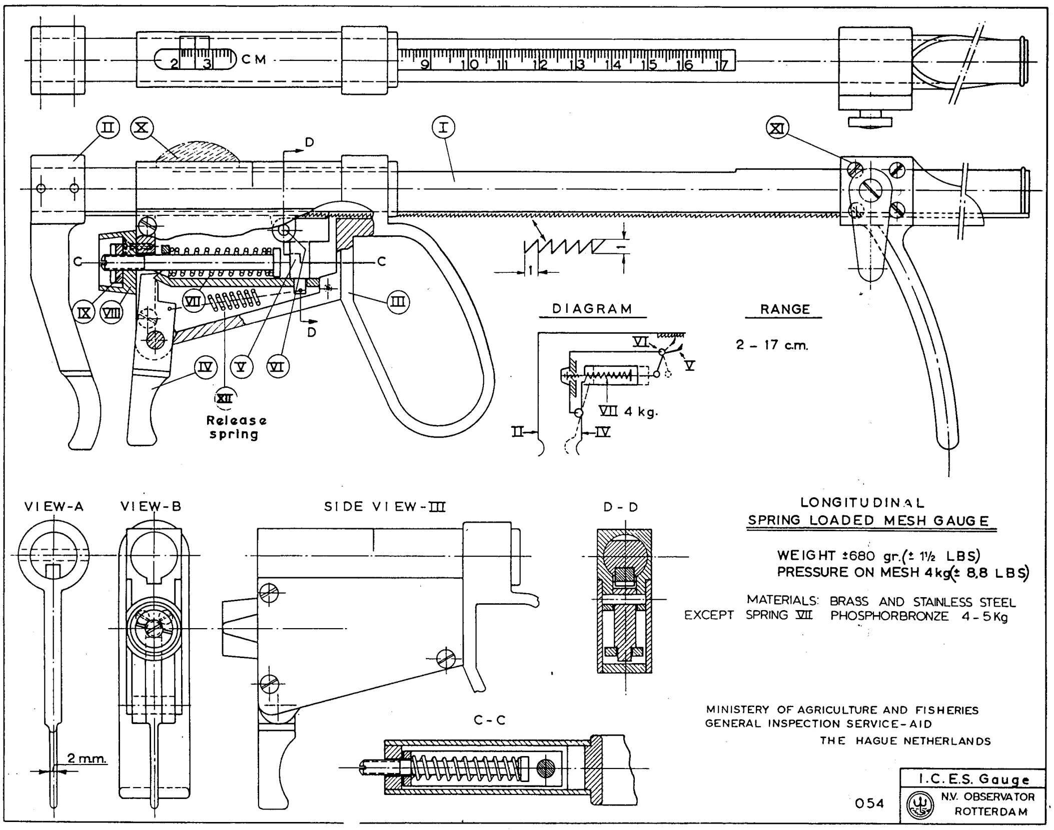

Figure 1. ICES Mesh Gauge.

twines and netting types used in the fishing industry since 1962. To deal with this request, ICES adopted Council Resolution 1999/2B02 and established a Study Group on Mesh Measurement Methodology (SGMESH) under the Fisheries Technology Committee with the following Terms of Reference:

a) advise on improvements and further standardization of current mesh measurement practices in view of the netting types now in use in ICES Member Countries;

b) consider whether the current definition of mesh size is still appropriate for scientific and industrial purposes;

c) compile an inventory of commercially available netting associated with the selectivity process, identifying the fisheries in which they are used;

d) consider the need to define groups of netting types for which the same measurement conditions (e.g., tension) can be applied; and

e) propose the specification of a suitable mesh measurement methodology and the conditions under which mesh measurements for all fishing gears in ICES areas are made.

The Study Group was active from 2000 till 2003 and had four meetings:

IJmuiden, The Netherlands, 8–9 April 2000;
Seattle, USA, 21–22 April 2001;
Sète, France, 3–5 June 2002; and
Oostende, Belgium, 19–21 March 2003.

A list of all participants in these four meetings is included at the end of the report.

The 2003 meeting concentrated on the analysis and discussion of the inter-laboratory tests made to determine the most appropriate measuring force, the proposal for a new mesh measurement methodology and the need for further standardization. The ultimate aim of the SGMESH was that the new methodology will be used by all: scientists, fisheries inspectors and the industry. With the general acceptance of the proposed methodology in mind, the Study Group was of the opinion that advice from inspection services and netting manufacturers should be sought in this matter and invited representatives of these services to its final meeting.

This *ICES Cooperative Research Report* reviews relevant definitions and current mesh measurement practices and reviews the activities of SGMESH that ultimately led to the proposals for a new mesh measurement methodology.

The work in preparing this report was carried out by a core group responsible for the numerous measurements and for analysing the data. The following persons have contributed to the core group's activities:

| | |
|---|---|
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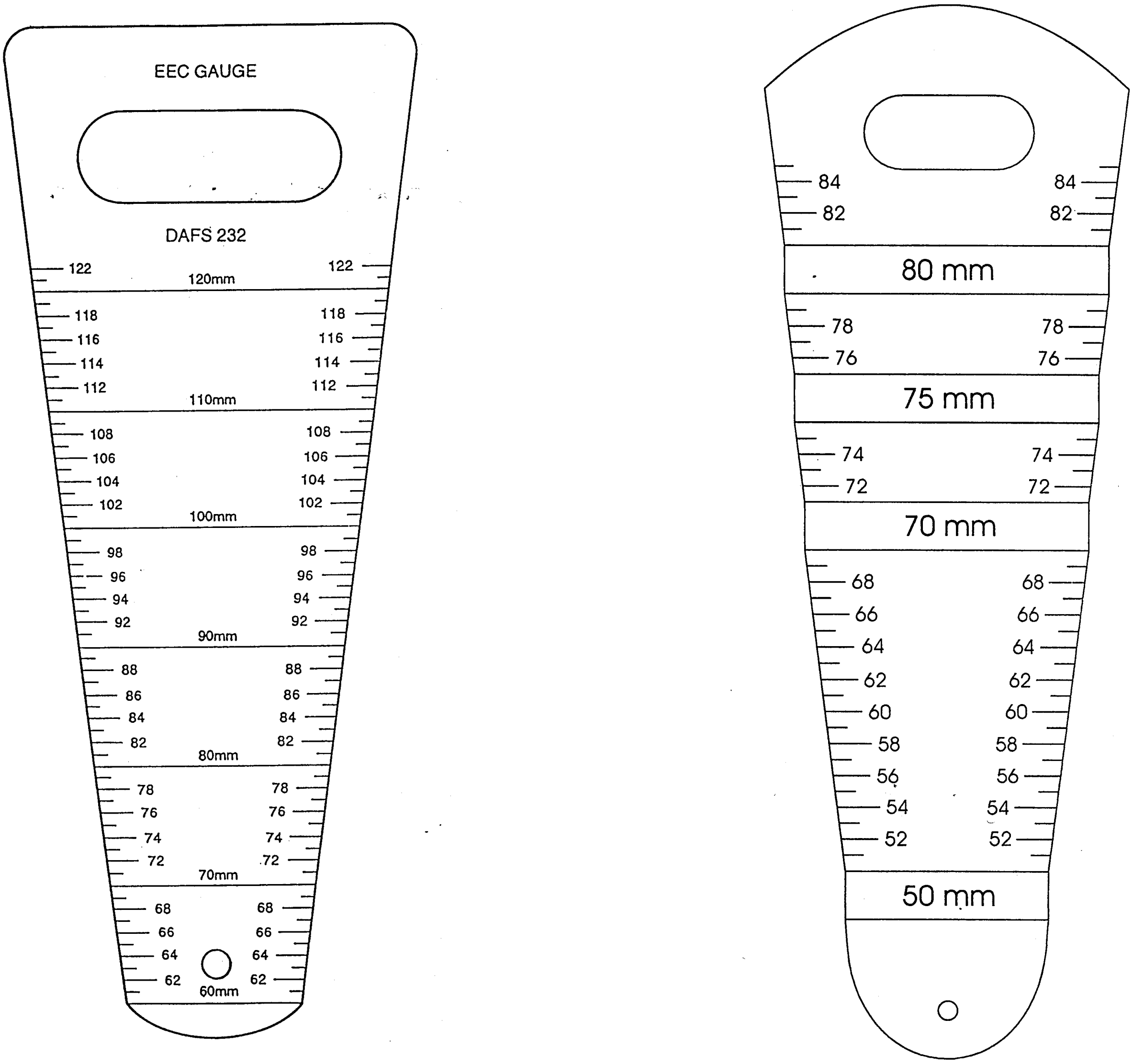


a

b

Figure 2. Wedge gauges.

# 2 Definitions and units

## 2.1 Definitions

The principal terms relating to netting for fishing nets are given in the International Standard EN ISO 1107- Fishing nets – Netting – Basic terms and definitions (Anon., 2003a). The terms of interest for the present publication are listed below:

***netting:*** a meshed structure of indefinite shape and size composed of one yarn or of one or more systems of yarns interlaced or joined, or obtained by any other means, for example by stamping or cutting from sheet material or by extrusion;

***netting yarn***: all type of yarns suitable for the manufacturing of netting;

the principal types of netting yarns are twines;

***netting twine:*** the product of one twisting operation embracing two or more single yarns or monofilaments;

***cabled netting twine:*** the product of further twisting operations embracing two or more netting twines;

***braided netting twine:*** the product of braiding or plaiting netting yarns and/or netting twines;

***linear density:*** designation of the fineness (or coarseness) of a yarn expressed as mass per unit length. According to the International Standard ISO 858 (Anon., 1973) netting yarns should be designated in the Tex System. The linear density in "tex" expresses the mass in grammes of 1000 m of yarn: 1 tex = 1 g / 1000 m. The complete designation of a netting yarn includes information on the linear density of the single yarn and on the number of single and folded yarns and twisting direction in each twisting operation. In practice, mostly only the linear density of the finished yarn is given, indicated as "resultant linear density" or Rtex;

***mesh:*** a design-formed opening, surrounded by netting material;

***diamond mesh:*** a mesh composed of four sides of the same length;

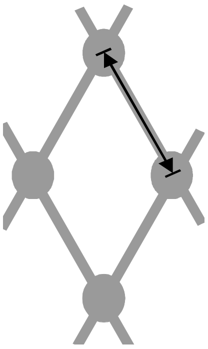
***square mesh:*** a diamond mesh in which adjacent sides are at right angles;

***N-direction:*** the direction at right angles to the general course of the netting yarn;

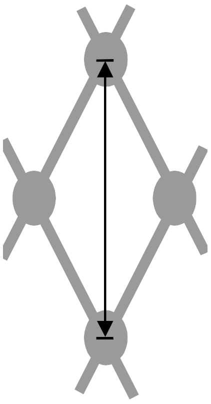
***T-direction:*** the direction parallel to the general course of the netting yarn;

Three different measures are used to indicate the mesh size:

- length of mesh side (bar length)
- length of mesh
- opening of mesh.

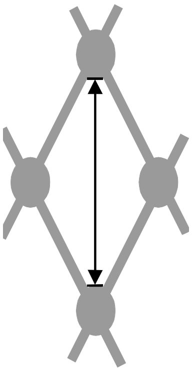


***length of mesh side:***
the distance between two sequential knots or joints, measured from centre to centre when the yarn between those points is fully extended.



***length of mesh:***
*for* knotted netting, the distance between the centres of two opposite knots in the same mesh when fully extended in the N-direction,

*for* knotless netting, the distance between the centres of two opposite joints in the same mesh when fully extended along its longest possible axis.



***opening of mesh:***
*for* knotted netting, the longest distance between two opposite knots in the same mesh when fully extended in the N-direction,

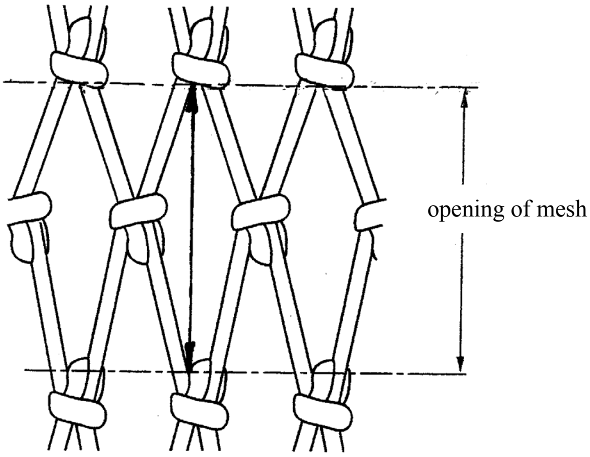
*for* knotless netting, the inside distance between two opposite joints in the same mesh when fully extended along its longest possible axis.

*Comments*

1) Since the mesh selection of fishing nets is directly related to the opening of mesh (Reeves *et al.,* 1992; Wileman *et al*., 1996), it is the opening of mesh that is measured for all scientific and control purposes. The netting industry, manufacturers and suppliers, often use the length of mesh (or the numbers of rows per metre) which is more appropriate from an engi-

neering point of view. There is frequently confusion over the netting industry measuring the length of mesh and the regulatory bodies measuring the opening of mesh. The length of mesh side is often an alternative to the length of mesh for fishermen and net makers when ordering netting. The term mesh size is often used to denote opening of mesh, e.g., as stated in Commission Regulation (EC) No 129/2003 (Anon., 2003b).

2) In knotted netting any mesh gauge can be positioned in two different ways relative to the knot, viz. on the knot or next to the knot. Especially in heavy netting these two possibilities may lead to a significant difference in measured mesh opening. Neither the measurement procedure recommended by ICES (ICES, 1962b) nor the different regulations give a decisive solution to this problem. The new standard EN ISO 1107 (Anon., 2003a) defines "opening of mesh" as "the longest distance between two opposite knots" and from this definition it follows that the mesh gauge should be inserted next to the knot as illustrated below.



3) In knotless netting, the netting yarns and the joints in the mesh are manufactured by the same machine in only one manufacturing process. Examples are Raschel netting, generally with small mesh sizes, and braided knotless netting. Direction in knotless netting can usually be related to the general course of the netting yarn, but not always because the general course of the netting yarn cannot in every case be determined. Usually, the direction of the longest possible axis of the mesh is parallel to the general course of the netting yarn. If the two axes are equal, the direction of the netting cannot be determined and the mesh size may be determined in either direction.

### 2.2 Units

Linear measurements are given in mm, unless otherwise stated.

Both kilogramforce (kgf) and Newton (N) are used as units of force in the national and European legislation. The relation between these units is: 1 kgf = 9.80665 N.

# 3 Review of current mesh measurement practices

Mesh measurements are performed by fisheries inspectors, fisheries scientists, netting manufacturers and fishermen. Unfortunately, these groups often use different gauges and measure different dimensions. For example, fisheries inspectors employ the flat wedge gauge (Figure 2) to control the mesh opening, whereas scientists make use of the ICES mesh gauge (Figure 1). The measure used for indicating the mesh size during the manufacturing process is the length of mesh. To check the opening of mesh a wedge gauge is used. Fishermen also use wedge gauges to control the mesh opening of their nets. This diversity creates a problem because the wedge gauge and the ICES gauge use a different measurement principle generally leading to a different outcome. A comprehensive evaluation of both instruments was made in the EU Concerted Action Project MESH (Fonteyne *et al.*, 1998), which forms the basis for the following review.

## 3.1 The wedge gauge

### 3.1.1 Description and measurement procedure

Wedge gauges used for enforcement practices are described in the relevant fisheries regulations, e.g., Commission Regulation (EC) No 129/2003 of the European Communities (Anon., 2003b). The gauges are usually made of 2 mm thick plates of durable material capable of retaining its shape. They have either tapering edges only (Figure 2a), or a series of parallel edged sides connected by intermediate tapering edges (Figure 2b). The taper is 1:8 on each side. The width in mm is inscribed on the gauge at 1 mm intervals. In the USA, wedge gauges are marked in 2.5 mm intervals on one edge, and in 1/8$^{th}$ inch intervals on the other.

To measure the opening of a mesh, the net is stretched in the N-direction of the meshes. The gauge is inserted into the mesh opening in a direction perpendicular to the plane of the net. The gauge is inserted either by manual force or by using a weight or dynamometer, until the resistance of the mesh stops further insertion. In the USA, only a 5 kg weight is used. The opening of each mesh corresponds to the width of the gauge at the point where further insertion of the gauge is prevented. The mesh size is expressed in mm and is the arithmetic mean of the total number of meshes measured, rounded up to the nearest mm. In the USA, the mesh size is expressed in eighths of inches, and the arithmetic mean of the total number of meshes is rounded to the nearest eighth.

According to the European regulation (Anon., 2003b) a series of 20 meshes is measured manually, without using a weight or dynamometer. If the mean mesh opening does not appear to comply with the rules in force, then two additional rows of 20 meshes each are measured. The mesh size is subsequently recalculated by taking into account all 60 meshes already measured. The result is considered the mesh opening of the net. If the captain of the vessel contests the mesh size thus determined, this measurement is ignored and the net is subjected to a new series of measurements. For this purpose the net is remeasured with a weight or dynamometer attached to the gauge. The choice of weight or dynamometer is at the discretion of the inspector. The mesh opening is determined by measuring only one series of 20 meshes. The weight is fixed by a hook to the hole at the narrow end of the gauge. The dynamometer can either be fixed to the hole at the narrow end of the gauge or to the handle.

For nets with a mesh size of 35 mm or less a force of 19.61 Newton (equivalent to a force of 2 kgf) is applied; for other nets the force is 49.03 Newton (equivalent to a force of 5 kgf). The accuracy of the weight or the dynamometer is certified by the competent national authority.

Wedge gauges are also used to check the opening of mesh during the netting manufacturing process. An international standard specifying a method for the determination of the mesh opening of fishing nets using a flat wedge gauge with measuring weights has recently been published (see Section 3.4 for details).

Fishermen use diverse wedge gauges to control the mesh opening of their nets. Fishermen are unlikely to use weights, only hand force.

### 3.1.2 Problems encountered with the wedge gauge

The description of the mesh gauges as given in the relevant regulations allows for differences in the final form of the gauge. The most striking possible differences are:

1) Different materials can be used as long as they are durable and capable of retaining the shape of the gauge.
2) There is not a unique plan shape: a choice can be made between a wedge gauge with tapered sides only and a gauge with alternating tapered and parallel sections.
3) The range of the mesh gauges to suit different ranges of mesh sizes is not standardized.
4) The weight of the gauges is not specified. The MESH project indicated a ratio of 1:5 between the lightest and the heaviest gauge for a given range.
5) The finishing of the edges is not specified.
6) Scale markings may extend to the edge of the gauge thus making these edges notched and likely to snag in the twine.

Post (1987) showed that different measurements are obtained with mesh gauges used by different fisheries inspection services, because they used different versions of the EU gauge. The measurement procedure given in the regulation gives less room for variation. In Europe little use is made of the 2 or 5 kg weight or a dynamometer. On the other hand, the standard measurement procedure of the US Coast Guard requires the insertion of the wedge gauge with a 5 kg weight (D. Gibson, Chief, Northeast Fisheries Training Center, USCG, personal communication).

Different reasons for not using the weight or dynamometer are given by EU inspectors:

- fishermen rarely contest the outcome of the measurements made by hand as they fear that the average mesh size derived from measurements with the use of a weight will be lower
- some inspectors consider that the weights are impractical and unsafe to use on board fishing vessels
- in most countries dynamometers are not type approved and the use of a spring to exert the force may not be accepted by the Courts.

The EU Regulation specifies that the accuracy of the weight or dynamometer shall be certified by the appropriate national authority but does not give directions for regular calibration of weights and dynamometers. In most countries re-calibration does not take place. If it is carried out, then the frequency differs between countries.

## 3.2 The ICES mesh gauge

### 3.2.1 Description and measurement procedure

The ICES gauge is the standard gauge for research activities, recommended by the International Council for the Exploration of the Sea (ICES, 1962a, b). The gauge is used with a pretension of 4 kgf. A similar instrument, the MARFISH Net Gauge, has been developed in the USA (Caruso and Carr, 1991).

The ICES mesh gauge was developed by C. J. W. Westhoff under the auspices of the Comparative Fishing Committee of the International Council for the Exploration of the Sea. The construction of the ICES gauge (ICES, 1962b; Anon., 1966) is given in Figure 1. The two jaws (components II and IV of Figure 1) which have a thickness of 2 mm are inserted into the diagonal of the mesh to be measured. The sliding hinged jaw IV is then pulled steadily away from the fixed jaw II by the handle III, thus stretching the mesh. The handle III is pulled further until the resistance of the stretched mesh against the sliding jaw IV is sufficient to cause the latter to pivot and compress the spring VII. The moment this happens the pawl V is actuated and engages in the rack on the underside of bar I thus locking the gauge and preventing any further movement of the jaw IV. Force on the handle is maintained to keep the gauge in the locked position while the mesh size is read from the position of jaw IV on the scale on the upper side of bar I. The precision is 1 mm. More consistent measurements are obtained if the gauge is operated twice in succession without removing the jaws from the mesh and the second reading taken as the mesh size. As soon as the force on the handles is released, the spring XII begins to return the sliding jaw IV to its closed position, the pawl disengages from the rack, and the gauge is ready for the next measurement.

It will be seen that the tension at which the gauge operates, i.e. the stretching force on the mesh when its size is measured, is determined automatically by the degree of compression of spring VII, which can be adjusted by screw VIII. The recommended tension is 4 kgf.

To test the gauge, a short, rigid test spring is used. It is provided with an eye at each end of sufficient size to allow it to fit easily over jaws II and IV. This spring is of a known length when under a tensile load of 4 kgf. The eyes of the test spring are fitted on jaws II and IV and the gauge is operated in the normal way. When the pawl engages in the rack and locks the gauge, the length is read off the scale. This length should correspond with the predetermined length of the spring under a load of 4 kgf. If the length from the scale is less then the gauge is not applying sufficient force; similarly, if the length is greater, the gauge is applying too much force. The force applied by the gauge can be corrected by removing the securing device at IX and adjusting the setscrew at IX until the gauge locks at the predetermined 4 kgf length of the test spring. Finally the setscrew must be secured. The scale reading can be checked by a simple standard measure to be sure that the jaws are not deformed, e.g., by a heavy knock. The test spring itself can be checked by measuring its length under the required load.

One noticeable outcome of the MESH project was that the procedure for selecting the meshes to be measured differs from one country to another. In general the meshes are selected in the wet codend, mostly in the upper panel, and measured in the N-direction. The number of meshes measured often depends on the time available. In general more meshes are measured on board research vessels than on board chartered commercial ships.

The ICES gauge is usually operated as described in the manual. The parallel jaws are inserted in the mesh and the mesh is then stretched diagonally under constant force until the pretension, usually 4 kgf, is exerted. Some users do not operate the gauge twice in succession as recommended (ICES, 1962b). As a rule the average mesh opening and the standard deviation are calculated.

### 3.2.2 Problems encountered with the ICES gauge

The MESH project came to the conclusion that mesh measurements for scientific purposes are characterized by a lack of uniformity. This is true for both the measuring instruments and the measurement procedures. This lack of uniformity occurs because no clear directives exist. The only existing written recommendations for measuring the mesh opening of codend meshes can be read in the report of the ICES Mesh Selection Working Group 1959–1960, published in 1964 (ICES, 1964). These recommendations leave room for interpretation and are only rarely applied nowadays.

The ICES mesh gauge can be considered as the standard mesh gauge in fisheries research. Due to the set force applied to the mesh, the measurements are close to being free of human bias. Also the ICES gauge can be calibrated easily. The wedge gauge is often used for comparison. The wedge gauges are the same as those used for inspection. Hence the comments made in Section 3.1.2 also apply.

The selection of the meshes to be measured is based on the selective performance of the gear. Hence the meshes are mostly chosen in the upper panel of the codend since this is the part of the gear where most mesh selection takes place (Wileman *et al.*, 1996). The number of meshes measured is usually much larger than for inspection but the reason for choosing a certain number is not always clear.

### 3.3 Comparison of the wedge and ICES mesh gauges

The MESH project identified the advantages and disadvantages of the wedge and ICES gauge as follows:

*Wedge gauge*

| Pro | Contra |
|---|---|
| • simple<br>• cheap<br>• internationally accepted<br>• generally accepted in legislation<br>• durable<br>• easy to maintain<br>• portable<br>• well tested | • human influence<br>• instrument not well defined, i.e.:<br>1. material<br>2. finish<br>3. weight<br>4. ranges<br>• not suitable for fine and heavy twines<br>• attachments needed for reproducible measurement<br>• several instruments needed for a range of measurements<br>• results biased by friction between gauge and netting<br>• results biased by angle of insertion<br>• poor ergonomics |

*ICES gauge*

| Pro | Contra |
|---|---|
| • consistent<br>• simple to operate<br>• minor human influence<br>• portable<br>• well tested<br>• direct reading | • calibration frequently needed<br>• acceptance by court questionable<br>• constant need for maintenance<br>• danger of wear<br>• poor ergonomics<br>• rather expensive |

After reviewing the positive and negative features of these gauges a list of requirements for an “ideal” mesh gauge was drawn up. The requirements can be grouped in three categories:

1) Measuring principle and objective;
2) Design; and
3) Legal aspects.

*1) Measuring principle and objective*

- mesh opening when fully extended by a controlled force
- all types of netting
- range 10–300 mm
- precision: 1 mm
- calibration of measuring force and distance measured
- direct reading of measuring force applied

- direct reading of mesh opening

*2) Design*

- minimal human influence
- no bias from material characteristics
- simple to operate
- portable, especially for safe boarding of fishing vessels
- easy maintenance
- automatic recording/logging of measurement data possible
- good ergonomics
- easy to calibrate

*3) Legal aspects*

- acceptability throughout the EU
- type approved
- unambiguous measurement procedure

Whether these requirements are met by the EU wedge gauge or the ICES gauge is indicated in the table below.

| Requirement | Wedge gauge | ICES gauge |
|---|---|---|
| **Measuring principle and objective** | | |
| • mesh opening | ✓ | ✓ |
| • all types of netting | no | no |
| • range 10–300 mm | ✓ | no |
| • precision: 1 mm | ✓ | ✓ |
| • calibration of measuring force and distance measured | (1) | ✓ |
| • direct reading of measuring force applied | (2) | no |
| **DIRECT READING OF MESH OPENING** | no | ✓ |
| **Design** | | |
| • minimal human influence | no | (3) |
| • no bias from material characteristics | no | ✓ |
| • simple to operate | ✓ | ✓ |
| • robust and durable | ✓ | (✓) |
| • portable | ✓ | ✓ |
| • easy maintenance | ✓ | no |
| • automatic recording/logging possible | no | no |
| • good ergonomics | no | no |
| • easy to calibrate | (1) | ✓ |
| **Legal aspects** | | |
| • acceptability all over the EU | ✓ | no |
| • type approved | ✓ | no |
| • unambiguous measurement procedure | no | no |

(1) If the wedge gauge is used with hand force calibration of the force is impossible. It is, however, possible to calibrate a dynamometer.
(2) When using a dynamometer the force perpendicular to the netting is measured, not the force in the plane of the netting.
(3) The human influence is minimal if used in the correct way (see Section 3.2.1).

The MESH project report concluded: “It is clear that neither gauge is wholly satisfactory. Both gauges meet the requirements of simplicity and robustness. Only the wedge gauge is specified in the EU regulations for enforcement. Its major drawback is that the measurement is not free of human influence and consequently is not objective.” and “The ICES mesh gauge meets the requirement of minimal human influence since it operates with a pre-defined force which can easily be calibrated, though again a spring is used for this calibration. The disadvantage of gauges with springs (ICES and dynamometer types) is that the Courts question the accuracy of springs and are not readily convinced of the reliability of calibration procedures.”

Since none of the existing mesh gauges fulfils all the essential requirements listed above, it was recommended that a new, advanced instrument be developed. An EU project with the cooperation of professional instrument builders was thought to be the best approach to achieve this aim. This recommendation finally resulted in the EU Combined R&D and Demonstration Project “Development and testing of an objective mesh gauge” (OMEGA) (www.dvz.be/omega). This project started in October 2002 and will be finalized in February 2005, after which the OMEGA mesh gauge will become commercially available.

## 3.4 Standardization

Attempts have been made by the International Organization for Standardization (ISO) to adopt the ICES gauge as the standard gauge for mesh measurements on fishing nets. These attempts failed, mainly because the measuring force is controlled by a spring whose characteristics may change over time. Moreover, a test spring is used to calibrate the gauge.

Recently the Working Group CEN/TC 248/WG 3 Fishing Nets of the European Committee for Standardization (CEN), in collaboration with Technical Committee ISO/TC 38 “Textiles”, edited an international standard for a method of test for the determination of mesh size (Anon., 2003c,d). The standard has two parts:

Part 1 – Mesh opening (Anon., 2003c); and
Part 2 – Length of mesh (Anon., 2003d).

Part 1 specifies a method for the determination of the mesh opening using a flat wedge gauge. It is applicable to active fishing gears. The draft standard is based upon international legislation for fisheries inspection. However, both the wedge gauge and the measuring procedure are more precisely described. The most important differences are:

- the gauge shall be made of an aluminium alloy;
- tapering sides only;
- edges must be rounded;
- printed or engraved markings shall end 2 mm from the edges;
- 4 size ranges are defined;
- no measurement by hand force;
- the measuring forces are:
    - 2 kgf for mesh sizes of 50 mm or less;
    - 5 kgf for mesh sizes above 50 mm up to 120 mm;
    - 8 kgf for mesh sizes above 120 mm;
- a minimum of 20 consecutive meshes (in the N-direction) shall be measured.

The draft standard has an important Informative Annex which recognises the limitations of the use of the wedge gauge as follows:

*“The method of test for the determination of the mesh opening is basically drawn upon international legislation for the purpose of fisheries inspection (e.g., Commission Regulation (EEC) No 2108/84 of 23 July 1984 laying down detailed rules for determining the mesh size of fishing nets). Recently the methodology using the flat wedge mesh gauge has been questioned. The method is considered as not sufficiently precise and objective, especially when using hand force to operate the mesh gauge.*

*The present European Standard has taken account of the criticism towards the wedge gauge by giving a more precise description of the mesh gauges and by using a weight only to exert the measuring force. The method described in the standard is appropriate for the determination of the mesh opening under controlled laboratory conditions but is considered as being less suitable for use at sea.*

*It is the intention to modify the present European standard as soon as a method suitable for all environmental conditions becomes available.”*

Part 2 of the draft standard deals with the determination of the length of mesh using a ruler. It is applicable to passive fishing gears. Since the present document focuses on the measurement of the mesh opening, this part of the standard is not further discussed here.

## 3.5 Related regulations

To improve the selectivity of towed gears the EU has recently legislated maximum permitted twine thicknesses for several fishing gears (Anon., 2000a; 2001a; 2001b; 2001c). To control the twine thickness a pair of pliers (Figure 3) is used with semi-circular holes milled towards the front end of each jaw such that, when the gauge is fully closed, circular holes are formed having diameters equal to the relevant maxima set out in the rules in force (Anon., 2003b). When the thickness of the twine prevents the closure of the jaws or the twine does not pass easily through the whole when the jaws are closed, the twine thickness is considered to be too large.

# 4 Inventory of towed gear codend materials

At present most problems in measuring the opening of mesh are related to codend meshes of towed gears. Static gears are generally made of finer twines and require a modified measuring technique. Mesh selection in purse seines is of minor importance and hence mesh measurements are seldom carried out. As a consequence SGMESH decided to concentrate only on the codends of towed gears. The Study Group began by collecting an inventory of materials used in codends by different ICES countries.

A codend material inventory format with the following parameters was discussed and agreed upon by the Study Group:

- country
- gear type
- netting material
- netting construction
- number of twines (single/double/triple)
- length of mesh
- opening of mesh
- yarn type (e.g., monofilament, multifilament; the diameter of monofilament yarns is between 0.1 mm and 1.0 mm, the diameter of multifilament yarns is < 0.05 mm (Klust, 1982)).
- twine construction (twisted/braided)
- runnage (m/kg)/Rtex (g/1000 m)
- twine thickness (mm)
- frequency of use.

An overview of typical codend materials used in the following countries was obtained: Belgium, Canada, Germany, Italy, the Netherlands, Norway, Spain, Sweden, the USA and the UK. The European Association of Netting Manufacturers also supplied information on the netting materials manufactured for codend construction.

The characteristics of the 128 codends in the inventory (Table 1) can be summarized as follows:

**Material**: 78% of the netting types are made of polyethylene (PE) yarns, 19% is of polyamide (PA) and only 3% of polyester (PES).

**Mesh openings and gears**: most entries (81%) in the list are codends for demersal fish or *Nephrops* trawls or seines. The mesh opening ranges from 70 to 165 mm, but one otter board trawl for skate has a mesh size of 300 mm. The remaining 19% codends are used in a variety of trawls for shrimp, pelagic fish, Mediterranean demersal fish, squid and molluscs. The mesh opening varies from 15 to 60 mm.

**Netting construction**: 92% of the codends are made of knotted netting, only 8% are knotless. The netting types are made of single (34%), double (65%) or triple twine (1%).

**Twine construction**: the netting twines are mostly braided (85%), 10% are twisted and 5% codends are made of Raschel knotless netting. The twisted twines and Raschel netting are generally made of polyamide fibres. Incomplete information was given on the fibre types, but it can be assumed that most PE twines are made of monofilaments (two were reported as split fibre). PA twines in netting for trawls are generally made of multifilaments.

**Twine thickness and runnage / linear density**: the nominal twine thickness varied from 1.8 to 9.4 mm. Data on the runnage and/or linear density was only available for a limited number of entries.

The Study Group noted the existence of specific netting materials for which the current mesh measurement techniques, i.e. wedge or ICES gauges, may not be appropriate. Examples of such materials include:

- stiff netting used in the Baltic cod trawl exit windows;
- some knotless netting constructions; and
- netting constructions to reduce the effective mesh opening such as K-meshes (meshes with unequal bar lengths), netting with inverted (twisted) knots and hexagonal meshes.

Due to new legislation aiming at the improvement of species and length selectivity of towed gears, the use of square mesh netting has increased recently. The other netting constructions listed above, however, are not thought to be widely used.

# 5 Experimental work

## 5.1 Introduction

The main twine characteristics which may effect mesh opening and hence selectivity are elongation and flexural rigidity (Ferro and O'Neill, 1994). These two characteristics also affect longitudinal mesh opening.

It is generally assumed that up to a certain load, Hooke's law holds for netting yarns. The slope of the stress-strain curve usually remains constant over the initial part of the curve. Effects in this region are normally described as elastic, in that stress is proportional to strain, and if the fibre is only deformed by a small extension, or load, it should recover to the original dimension. This linear relationship is true as long as the deformations are not too large. For higher loads the deformation becomes plastic.

Table 1. Inventory of codend materials in use in the ICES area.

| Country | Gear | Netting | | | | | Yarn | | | | Origin/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Material | Construc-tion | No of Yarns | Length of Mesh | Opening of Mesh | Twine Type | Construction | Runnage | Thickness (mm) | Application |
| B | TBB-Crangon | PA | Knotted | Single | 22 | | multi | Twisted | | | 100% |
| B | TBB-flatfish | PE | Knotted | Double | | 80 | mono | Braided | | 4.0 | Van Belen |
| B | TBB-flatfish | PE | Knotted | Double | | 80 | mono | Braided | | 4.0 | Senaflex |
| B | TBB-flatfish | PES | Knotted | Double | | 80 | multi | Braided | | 3.0 | Bay of Biscay only |
| B | TBB-flatfish | PES | Knotted | Double | | 80 | multi | Braided | | 4.0 | Bay of Biscay only |
| B | TBB-flatfish | PE | Knotted | Double | | 80 | mono | Braided | | 4.0 | EUROLINE 5–10% |
| B | TBB-flatfish | PES | Knotted | Single | | 82 | multi | Braided | | 4.5 | 5–10% |
| B | TBB-flatfish | PE | Knotted | Double | | 82 | mono | Braided | | 3.5 | EUROLINE |
| B | TBB-flatfish | PE | Knotted | Double | | 82 | mono | Braided | | 3.5 | PREMIUM |
| B | TBB-flatfish | PE | Knotted | Single | | 82 | mono | Braided | | 6.0 | Type 2001 |
| B | TBB-flatfish | PE | Knotted | Double | | 82 | mono | Braided | | 4.0 | Type 2002 |
| B | TBB-flatfish | PE | Knotted | Double | | 82 | mono | Braided | | 4.0 | BREZLINE |
| B | TBB-flatfish | PE | Knotted | Double | | 84 | mono | Braided | | 4.0 | BREZLINE 90% |
| B | OTB-*Nephrops* | PE | Knotted | Double | | 82 | mono | Braided | | 4.0 | BREZLINE 90% |
| B | OTB | PE | Knotted | Single | | 105 | mono | Braided | | 4.0 | roundfish |
| B | OTB | PE | Knotted | Double | | 110 | mono | Braided | | 5.0 | roundfish, BREZLINE 90% |
| | | | | | | | | | | | |
| CA | OTB-Cod | PE | Knotted | Double | | 155 | | Braided | | 5.5 | cod, haddock, saithe |
| CA | OTB-Cod | PE | Knotted | Double | | 155 | | Braided | | 6.0 | cod, haddock, saithe |
| CA | OTB-shrimp | PE | Knotted | Double | 50 | 45 | | Braided | | 1.8 | shrimp |
| CA | OTB-shrimp | PE | Knotted | Double | 50 | 43 | | Twisted | 210/72 | 2.5 | shrimp |
| CA | OTB-redfish | PE | Knotted | Double | | 105 | | Braided | | 4.0 | redfish |
| CA | OTB-redfish | PE | Knotted | Double | | 105 | | Braided | | 5.5 | redfish |
| CA | OTB-redfish | PE | Knotted | Double | | 105 | | Braided | | 6.0 | redfish |
| CA | OTB-skate | PE | Knotted | Double | | 300 | | Braided | | 6.0 | skate |
| CA | OTB-Cod | PE | Knotted | Double | 92 | 76 | | Braided | | 5.0 | cod, sole, rockfish |
| CA | TBB | PE | Knotted | Single | 38 | 30 | | Twisted | 380/48 | No.30 | |
| | | | | | | | | | | | |
| D | OTM | PE | Knotted | Double | | 100 | mono | Braided | 86 | 6.0 | Reykjanes |
| D | OTB | PE | Knotted | Double | | 105 | mono | Braided | 185 | 4.0 | Baltic Sea |
| D | OTB | PE | Knotted | Single | | 105 | mono | Braided | 185 | 4.0 | Baltic Sea |
| D | OTB | PE | Knotted | Double | | 117 | mono | Braided | 86 | 6.0 | NW Atlantic |
| D | OTB | PE | Knotted | Single | | 110 | mono | Braided | 36 | 8.0 | N Pacific, EUROLINE Premium |
| D | OTB | PE | Knotted | Double | | 120 | | Braided | 60 | 6.0 | EUROLINE, Baltic Sea |
| D | OTB | PE | Knotted | Double | | 142 | splitfibre | Braided | 75 | 6.0 | Cotesi |
| D | OTB | PE | Knotted | Single | | 35 | splitfibre | Braided | | 2.0 | Cotesi |
| D | OTB | PE | Knotted | Double | | | mono | Braided | 165 | 4.0 | |
| | | | | | | | | | | | |
| E | OTB | PA | Knotted | Double | 100 | 80 | multi | Braided | R5555tex | 4.0 | monkfish, megrim and demersal spp. |
| E | OTB | PA | Knotted | Double | 120 | 100 | multi | Braided | R5555tex | 4.0 | hake fishery |
| E | PTM | PE | Knotted | Double | 120 | 100 | multi | Braided | | 4.0 | hake fishery |
| E | PTM | PE | Knotted | Single | 120 | 100 | multi | Braided | | 6.0 | hake fishery |

Table 1. Continued. Inventory of codend materials in use in the ICES area.

| Country | Gear | Netting | | | | | Yarn | | | | Origin/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Material | Construc-tion | No of Yarns | Length of Mesh | Opening of Mesh | Twine Type | Construc-tion | Runnage | Thickness (mm) | Application |
| E | OTB | PE | Knotted | Single | | 90 | multi | Braided | 125 m/kg | 5.0 | Grand Sole fisheries |
| UK | PTB | PE | Knotted | Double | 120 | 102 | | Braided | | 5.0 | haddock, cod, whiting, flatfish |
| UK | MTB | PE | Knotted | Double | 120 | 103 | | Braided | | 6.0 | haddock, cod, whiting, flatfish |
| UK | MTB | PE | Knotted | Single | 80 | 72 | | Braided | | 4.0 | *Nephrops* |
| UK | MTB | PE | Knotted | Single | 80 | 74 | | Braided | | 3.0 | *Nephrops* |
| UK | OTB | PE | Knotted | Single | 80 | 72 | | Braided | | 4.0 | *Nephrops* |
| UK | STM | PES | Knotless | Single | 50 | 40 | | Braided | | 3.0 | herring |
| UK | OTB | PA | Knotted | Single | 40 | 36 | | Twisted | 210/15 | | shrimps |
| UK | OTB | PA | Knotted | Single | 40 | 36 | | Twisted | 210/20 | | shrimps |
| UK | OTB | PE | Knotted | Double | 120 | 100 | | Braided | | 6.0 | haddock, cod, whiting, flatfish |
| UK | OTB | PE | Knotted | Double | 130 | 110 | | Braided | | 6.0 | haddock, cod, whiting, flatfish |
| UK | OTB | PE | Knotted | Double | 120 | 100 | | Braided | | 5.0 | haddock, cod, whiting, flatfish |
| UK | SSC | PE | Knotted | Double | 120 | 100 | | Braided | | 5.0 | haddock, cod, whiting, flatfish |
| UK | SSC | PE | Knotted | Double | 120 | 100 | | Braided | | 4.0 | haddock, cod, whiting, flatfish |
| UK | Pair gears | PE | Knotted | Double | 120 | 100 | | Braided | | 6.0 | haddock, cod, whiting, flatfish |
| UK | Pair gears | PE | Knotted | Double | 120 | 100 | | Braided | | 5.0 | haddock, cod, whiting, flatfish |
| UK | MTB | PE | Knotted | Double | 120 | 100 | | Braided | | 6.0 | haddock, cod, whiting, flatfish |
| UK | MTB | PE | Knotted | Double | 120 | 100 | | Braided | | 5.0 | haddock, cod, whiting, flatfish |
| UK | MTB | PE | Knotted | Double | 120 | 100 | | Braided | | 5.0 | haddock, cod, whiting, flatfish |
| UK | MTB | PE | Knotted | Single | | 70 | | Braided | | 6.0 | *Nephrops* |
| UK | MTB | PE | Knotted | Single | | 70 | | Braided | | 5.0 | *Nephrops* |
| UK | OTB/twinOTB | PE | Knotted | Single | | 70 | | Braided | | 5.0 | *Nephrops* |
| UK | OTB/twinOTB | PE | Knotted | Single | | 70 | | Braided | | 4.0 | *Nephrops* |
| UK | OTB/twinOTB | PE | Knotted | Single | 77 | 70 | | Braided | | 3.0 | *Nephrops* |
| UK | STM/PTM | PA | Knotted | Double | 50 | 40 | | Twisted | 210/96 | | mackerel, herring |
| UK | STM/PTM | PA | Knotted | Treble | 40 | 30 | | Twisted | 210/72 | | blue whiting |
| UK | STM/PTM | PA | Knotted | Single | 22 | 15 | | Twisted | 210/72 | | sprat |
| UK | TBB | PE | Knotted | Double | 130 | 115 | | Braided | | 6.0 | haddock, cod, whiting, flatfish |
| UK | SSC | PE | Knotted | Double | 125 | 100 | | Braided | | 6.0 | haddock, cod, whiting, flatfish |
| UK | OTB | PE | Knotted | Double | | 105 | | Braided | 80.66 | 5.0 | haddock, cod, whiting, flatfish COMPACT twine |
| UK | OTB | PE | Knotted | Double | | 105 | | Braided | 54.49 | 6.0 | haddock, cod, whiting, flatfish COMPACT twine |
| UK | OTB | PE | Knotted | Double | | 105 | | Braided | 122.00 | 5.0 | haddock, cod, whiting, flatfish |
| UK | SSC | PE | Knotted | Double | | 105 | | Braided | 183.45 | 4.0 | haddock, cod, whiting, flatfish |
| UK | Pair gears | PE | Knotted | Double | | 105 | | Braided | 59.49 | 6.0 | haddock, cod, whiting, flatfish COMPACT twine |
| UK | Twin OTB | PE | Knotted | Double | | 105 | | Braided | 80.66 | 5.0 | haddock, cod, whiting, flatfish COMPACT twine |
| UK | Twin OTB | PE | Knotted | Single | | 73 | | Braided | 183.45 | 4.0 | *Nephrops* |
| UK | Twin OTB | PE | Knotted | Single | | 73 | | Braided | 132.55 | 4.0 | COMPACT twine, *Nephrops* |
| UK | OTB | PE | Knotted | Single | | 73 | | Braided | 183.45 | 4.0 | *Nephrops* |
| USA | trawl | Euroline | Knotted | Double | 7.25" | 6.5" | Mono | Braided | | 5.0 | cod |
| USA | trawl | Euroline | Knotted | Single | 60 | 1 7/8" | Mono | Braided | | 3.0 | squid |
| USA | trawl | poly? | Knotted | Single | 2.25" | 1 7/8" | Mono | Twisted | | 2.0 | squid |

Table 1. Continued. Inventory of codend materials in use in the ICES area.

| Country | Gear | Netting | | | | | Yarn | | | | Origin/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Material | Construc-tion | No of Yarns | Length of Mesh | Opening of Mesh | Twine Type | Construc-tion | Runnage | Thickness (mm) | Application |
| **EUROCORD** | | | | | | | | | | | |
| NO | OTB | HDPE | Knotted | Double | 169 | 140 | Mono | Braided | 75 | 6.0 | |
| NO | OTB | PA | Knotted | Double | 169 | 140 | Multi | Braided | 75(65**) | 6.0 | |
| IS | OTB | HDPE | Knotted | Single | 165 | 135 | Mono | Braided | 40 | 8.0 | redfish |
| UK | OTB | HDPE | Knotted | Double | 125 | 100 | Mono | Braided | 75 | 6.0 | haddock, cod, whiting, flatfish |
| CA | trawls | euroline | Knotted | Double | x | x | Mono | Braided | x | x | |
| CA | trawls | premium | Knotted | Double | x | x | Mono | Braided | x | x | |
| USA | trawls | premium | Knotted | Double | x | x | Mono | Braided | x | x | |
| USA | trawls | euroline | Knotted | Double | x | x | Mono | Braided | x | x | |
| RU | trawls | premium | Knotted | Double | X | x | Mono | Braided | x | x | |
| PT | trawls | euroline | Knotted | Double | X | x | Mono | Braided | x | x | |
| IS | trawls | PE | Knotted | Double | X | x | Mono | Braided | x | x | |
| ES | trawls | euroline | Knotted | Double | X | x | Mono | Braided | x | x | |
| UK | trawls | PE | Knotted | Double | X | x | Mono | Braided | x | x | |
| ES | trawls | euroline | Knotted | Double | X | x | Mono | Braided | x | x | |

x: differs from area to area
** after treatment

TBB: beam trawl
OTB: bottom otter trawl
OTM: midwater otter trawl
PTM: midwater pair trawl
SDB: Danish seine
MTB: multiple bottom trawl
STM: single midwater trawl (= OTM)
SSC: Scottish seine

PA: polyamide
PE: polyethylene
PES: polyester
HDPE: high density polyethylene

multi: multifilament
Mono: Monofilament

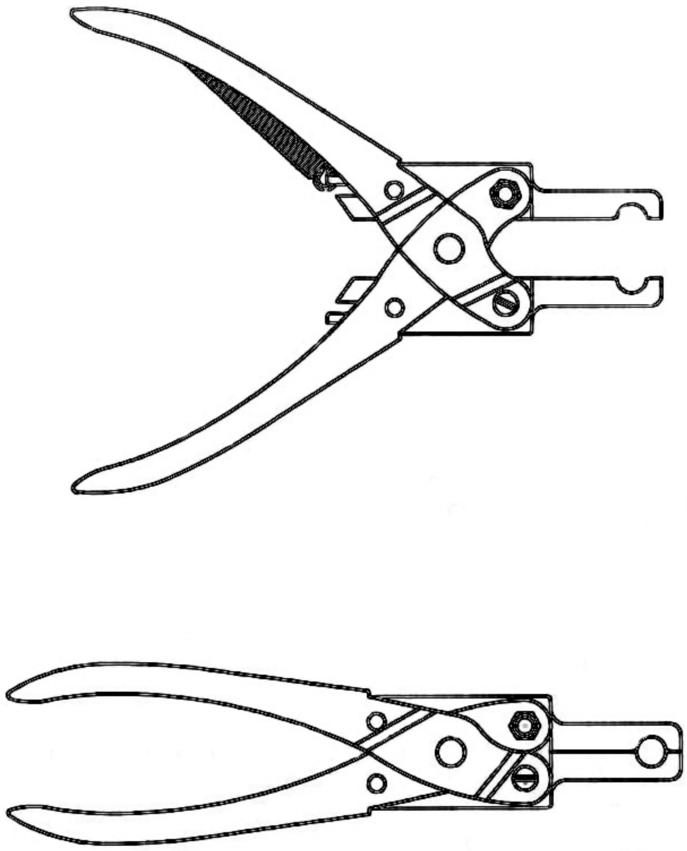


Figure 3. Pliers gauge for twine thicknss measurement.

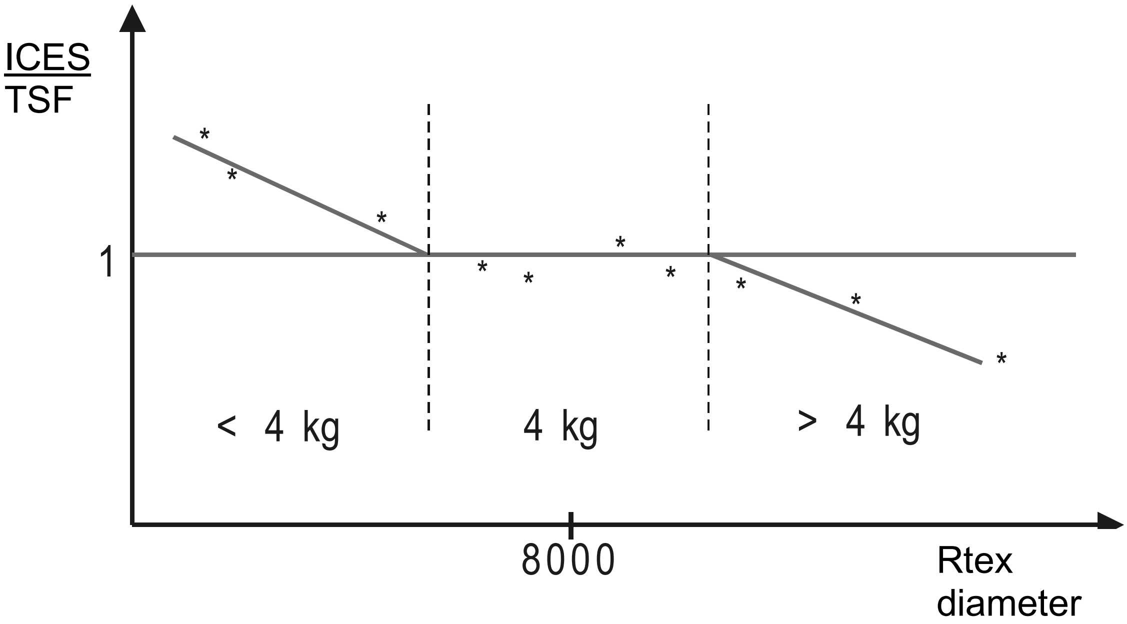


Figure 4. Ratio between the mesh size obtained with a 4 kgf measuring force (ICES) and with the Textile Standard Force (TSF) in relation to the twine thickness for all mesh constructions.

The point at which this occurs is the *yield point*. Klust (1982) states that for netting yarns made of polyethylene (PE), polyester (PES) and polypropylene (PP) the load-elongation curves are almost linear. For netting yarns made of polyamide (PA) the load elongation curves are more parabolic. A more recent study (Anon., 2000b) demonstrated that knotted netting had greater elongation than the original twine, and only at high load values did the differences become significant. It may be assumed that the netting materials are elastic within the range of loads applied to the meshes in the present study.

Several publications report on the effect of twine thickness on selectivity (Anon., 2000b; Lowry and Robertson, 1996) but studies on the effect of stiffness on mesh size measurement are rare. O'Neill (2003) made a theoretical investigation of mesh size measurement. The effect of twine bending stiffness, frictional resistance, boundary slope and gauge force were examined. The measurement method which the analysis most approximates was that of the ICES gauge. It was found that in relation to twine bending stiffness the magnitude of the measuring force is critical. At low measuring forces, changes in these forces will yield relatively large variations in the measured mesh opening. With increasing twine stiffness, higher measuring forces will also be subject to this higher variation. The influence of mesh gauge force was presented for a number of specific examples representative of mesh types used by the industry. Most variation of mesh size occurs in the range 0 to 50 N. The ICES gauge exerts 20 N on each mesh bar and so any variation in the parameters studied is likely to lead to appreciable variation in measured mesh size.

For a specific measuring force the elongation of netting yarns naturally increases with decreasing twine thickness. The ICES gauge is calibrated to deliver a constant measuring force of 4 kgf. This means a varying stress (force per unit area) on the twine for different twine thicknesses. This variation is in conflict with common practice for length measurement of textile yarns, which is performed under constant stress. The International Organisation for Standardization establishes a pre-tension corresponding to the weight of 250±25 m of the netting yarn to be measured (Anon., 1974; Anon., 1976; Klust, 1982). This measuring force is referred to as the Textile Standard Force (TSF).

The TSF is equal to the 4 kgf force used with the ICES gauge for single twine meshes of R8000tex. For meshes with twines of around R8000tex the ratio between the mesh openings measured with a 4 kgf measuring force and a force based on the TSF will be around 1. For lower Rtex values the ICES gauge overestimates the mesh size while underestimation occurs for values over 8000. This relationship is graphically represented in Figure 4.

In order to address the Study Group's Term of Reference d)

> *"consider the need to define groups of netting types for which the same measurement conditions (e.g., tension) can be applied;"*

the group decided to investigate the difference between measurements with constant force and with constant stress (ICES, 2000). It was recommended to perform opening of mesh measurements on representative codend netting materials used today in ICES countries. The opening of mesh should be measured with the ICES gauge with a constant force of 4 kgf and a stretching force corresponding to the TSF.

To deal with the Study Group's Term of Reference e)

> "*propose the specification of a suitable mesh measurement methodology and the conditions under which mesh measurements for all fishing gears in ICES areas are made*;"

the group carried out a comparison of the ICES 4 kgf gauge with the wedge gauge used for fisheries inspection and new measuring forces were tested in order to establish the most suitable value for currently used nettings.

This leads to the following set of mesh size measurements:

a) with the ICES mesh gauge with a load of 4 kgf;

b) with a load corresponding to the Textile Standard Force;

c) with a flat wedge gauge and hand force;

d) with a flat wedge gauge with a weight of 2 kgf (meshes <= 35 mm) or 5 kgf (meshes > 35 mm) or a dynamometer;

e) with a 10 kgf load (meshes <55 mm); and

f) with a 13 kgf load.(meshes <55 mm).

## 5.2 Selection of new measuring forces to be tested

Ideally the measuring force for a specific netting twine should be related to the linear density. Alternatively the twine thickness could be used if a significant correlation exists between twine thickness and linear density. This relationship was studied for the netting materials involved in the mesh measurements.

The option of a measuring force depending on the linear density of the netting twine was discussed in length by the Study Group. It was realised that both twine thickness and linear density can only be measured accurately under laboratory conditions. Since mesh measurements are generally carried out at sea, values of the linear density or the twine thickness are not easily obtainable. Therefore the Study Group decided to test measuring forces based on single values (ICES, 2002). The rationale for defining these measuring forces is set out hereafter.

The most frequently used twine thicknesses in the ICES area, as derived from the netting materials inventory (Table 1), are given in Table 2. PE is preferred for the larger twine thicknesses (and meshes), whereas PA is more commonly used for smaller twine thicknesses (and smaller meshes). Since larger mesh codend netting is generally constructed from PE twines, a measuring force should be selected appropriate to the range of twine thicknesses for that material. Smaller meshes are mostly constructed from PA twines and consequently the appropriate measuring force should be applicable to that material. Table 3 gives the Textile Standard Forces required for these twines.

To improve the selectivity of towed fishing gears the EU has legislated maximum permitted twines for several fishing areas:

1) Irish Sea (ICES area VIIa): 6 mm for single twine; multiple-twine netting is prohibited (Anon., 2000a);
2) ICES areas VIIb, c, f, g, h, j, k and VIIIa, b, d, e: for mesh sizes > 55 mm: 6 mm single twine and 4 mm double twine (Anon., 2001a);
3) North Sea (ICES area IV and IIa, b) and West of Scotland (ICES area VI): for mesh sizes > 55 mm: 8 mm single twine and 5 mm double twine (Anon., 2001b); and
4) Baltic Sea: for 130 mm mesh: 6 mm single twine and 4 mm double twine (proposal for an amendment to Council Regulation (EC) No 2555/2001 (Anon., 2001c).

The Study Group anticipated that for the North Sea and West of Scotland fisheries areas this restriction would lead to replacement of the heavier twines by 5 mm double twine and possibly 8 mm single twine (ICES, 2002).

A recent proposal for a Council Resolution (Anon., 2002) incorporates former Council and Commission Resolutions regarding technical measures for the protection of juvenile marine organisms. The area covered is the Community waters outside the Baltic and the Mediterranean. The document stipulates for the codend and extension piece with a mesh size > 55 mm, a maximum twine thickness of 6 mm for single-twine netting and of 4 mm for double-twine netting.

In selecting new measuring forces, it is important that the transition should not be detrimental to codend selectivity and therefore deliver results similar to the present procedures set down in technical measures legislation. Current enforcement legislation is based on the use of the wedge gauge operated by hand or with a 5 kg weight to be used when measurements are contested (2 kg for meshes < 35 mm). According to Schwalbe and Werner (1977) a weight of 5 kgf would theoretically impose a longitudinal force of 20 kgf on the mesh being measured. Friction between gauge and netting, however, may considerably reduce the resulting measuring force. Ferro and Xu (1996) demonstrated that for four PE netting samples with a twine thickness between 2.7 mm and 4.5 mm, readings equivalent to the 5 kgf wedge gauge can only be obtained with an ICES gauge having more than 8 kgf spring force.

The data in Table 3 indicate that a measuring force of 10 kgf would be appropriate for PE nettings of double 5 mm twines or single 7 mm twines. At its 2002 meeting, (ICES, 2002) the Study Group considered that mesh opening measurements made with a longitudinal measuring force of around 100 N (10 kgf) would also approximate those obtained with a wedge gauge used with a 5 kgf weight. A measuring force of 100 N would probably underestimate the mesh opening of single 8 mm PE twines, which at that moment (2002) was thought to become more widely used. In this case a measuring force of 130 N would be more appropriate (Table 3). The Study Group therefore decided to conduct mesh opening measurements using 100 N and 130 N longitudinal forces.

Proportionally, the present 2 kg weight used with the wedge gauge for the measurement of smaller meshes corresponds to the 4 kgf longitudinal force provided by the ICES gauge. The Study Group therefore decided to test the smaller mesh materials (< 55 mm) with a 40 N measuring force.

## 5.3 Material and methods

*Netting materials*

Thirty-four samples of netting used for the construction of codends were measured. These samples are representative of the most important towed fishing gears employed in the ICES areas. The main characteristics are summarized in Table 4. The selected netting materials are used in Belgium (3), Canada (5), Denmark (3), Germany (5), Iceland (1), the Netherlands (4), Norway (5), Sweden (3), the United Kingdom (3) and the United States (2). Eleven netting samples were made of twisted or braided multifilament polyamide twines, 21 of braided polyethylene, and 2 samples consisted of knotless, twisted polyethylene. The nominal twine thickness ranged from 1.2 to 10.8 mm, the nominal linear density from R780tex to R53500tex. The nominal mesh size varied from 18 mm to 190 mm.

*Twine thickness measurement*

The accuracy of the nominal twine thickness was verified by measuring the thickness of twine samples using an optical instrument recently developed through collaboration between Fisheries Research Services – Marine Laboratory Aberdeen, Yarn Engineering Services UK and Lawson-Hemphill USA. The optical method was originally developed in the 1980s (Ferro, 1989) and adopted by the ICES Study Group on Twine Thickness Measurement (Ferro, 1983). The instrument developed in 2001 uses a 1mm wide laser beam to illuminate the twine. The instrument detects the position of the twine edges and the thickness is taken as the difference between these two readings. Cylindrical steel rods are used for calibration.

All twine samples were sent to Fisheries Research Services – Marine Laboratory in Aberdeen where twine measurements were performed. The measurements were made on 2 m lengths of spooled twine. Each twine was stretched across the measurement area, one end secured with a V-notch to grip the twine and the other end placed around a pulley and tensioned by suspending a weight.

Table 2. Most frequently used twine thicknesses.

| | | Frequency in the inventory | |
|---|---|---|---|
| Material | Twine thickness (mm) | Single twine | Double twine |
| PA (14 samples) | <= 2 | 7 | |
| | 2 – 6 | | 7 |
| PE (74 samples) | <4 | 3 | 5 |
| | 4 | 7 | 14 |
| | 5 | 2 | 16 |
| | 5.5 | | 2 |
| | 6 | 4 | 18 |
| | >6 | 3 | |

PA: polyamide; PE: polyethylene.

Table 3. Textile Standard Force (TSF) for most commonly used PE and PA netting twines.

| PE | | TSF (gr) | |
|---|---|---|---|
| Twine thickness | Rtex | Single twine | Double twine |
| 4 | 6 824 | 3 412 | 6 824 |
| 5 | 10 659 | 5 329 | 10 659 |
| 6 | 15 345 | 7 673 | 15 345 |
| 7 | 20 883 | 10 441 | 20 883 |
| 8 | 27 271 | 13 636 | 27 271 |

| PA | | TSF (gr) | |
|---|---|---|---|
| Twine thickness | Rtex | Single twine | Double twine |
| 2 | 2 580 | 1 290 | 2 580 |
| 3 | 5 721 | 2 861 | 5 721 |
| 4 | 10 067 | 5 034 | 10 067 |
| 5 | 15 605 | 7 802 | 15 605 |
| 6 | 22 325 | 11 162 | 22 325 |

PA: polyamide; PE: polyethylene.

Table 4. Characteristics of measured netting samples.

| Country | Sample designation | Material | Nominal twine thickness (mm) | Nominal linear density (Rtex) | Braided/ twisted / knotless netting | Single/ double/ triple twine | Nominal mesh opening (mm) |
|---|---|---|---|---|---|---|---|
| BE | DVZ 1.2 SIN | PA | 1.2 | 780 | Twisted | Single | 18 |
| BE | DVZ 4 DBL | PE | 4.0 | 6 250 | Braided | Double | 82 |
| BE | DVZ 5 SIN | PE | 5.0 | 8 000[1] | Braided | Single | 82 |
| CA | DFO 1.8 SIN | PE | 1.8 | 1 700 | Braided | Single | 50 |
| CA | DFO 4 DBL | PE | 4.0 | 5 600 | Braided | Double | 150 |
| CA | DFO 5 DBL | PE | 5.0 | 8 100 | Braided | Double | 80 |
| CA | DFO 5.5 DBL | PE | 5.5 | 10 940 | Braided | Double | 105 |
| CA | DFO 6 DBL | PE | 6.0 | 11 140 | Braided | Double | 140 |
| D | BFAFi 2.2 DBL | PA | 2.2 | 3 400 | Braided | Double | 40 |
| D | BFAFi 2.6 SIN | PA | 2.6 | 4 800 | Braided | Single | 40 |
| D | BFAFi 4 DBL | PA | 4.0 | 12 000 | Braided | Double | 110 |
| D | BFAFi 6 DBL | PA | 6.0 | 20 000 | Braided | Double | 130 |
| D | BFAFi 8 SIN | PA | 8.0 | 35 800 | Braided | Single | 120 |
| DK | DIFRES 1.5 SIN | PA | 1.5 | 1 211[1] | Twisted | Single | 35 |
| DK | DIFRES 4 SIN 75 | PE | 4.0 | 5 263[1] | Braided | Single | 75 |
| DK | DIFRES 4 SIN 105 | PE | 4.0 | 5 263[1] | Braided | Single | 105 |
| IS | IMR-IS 6 DBL | PE | 6.0 | 10 800 | Braided | Double | 135 |
| N | IMR-N 5 DBL PA | PA | 5.0 | 15 400 | Braided | Double | 138 |
| N | IMR-N 3.2 TRI | PE | 3.2 | 5 300 | Braided | Triple | 137 |
| N | IMR-N 5 DBL PE | PE | 5.0 | 13 900 | Braided | Double | 138 |
| N | IMR-N 7.1 UC | PE | 7.1 | 21 170 | Knotless | Single | 133 |
| N | IMR-N 10.8 UC | PE | 10.8 | 53 500 | Knotless | Single | 139 |
| NL | RIVO 2 SIN | PA | 2.0 | 2 450 | Twisted | Single | 40 |
| NL | RIVO 2 DBL | PA | 2.0 | 2 450 | Twisted | Double | 40 |
| NL | RIVO 4 DBL | PE | 4.0 | 5 208[1] | Braided | Double | 80 |
| NL | RIVO 6 DBL | PE | 6.0 | 12 500 | Braided | Double | 80 |
| S | IMR-S 1.5 SIN | PA | 1.5 | 1 632[1] | Twisted | Single | 36 |
| S | IMR-S 3.5 SIN | PE | 3.5 | 3 915 | Braided | Single | 70 |
| S | IMR-S 4 SIN | PE | 4.0 | 5 400 | Braided | Single | 107 |
| UK | MARLAB 3 SIN | PE | 3.0 | 4 060 | Braided | Single | 74 |
| UK | MARLAB 5 SIN | PE | 5.0 | 13 632 | Braided | Single | 70 |
| UK | MARLAB 6 DBL | PE | 6.0 | 14 225 | Braided | Double | 100 |
| US | MDMF 6 DBL | PE | 6.0 | 13 333[1] | Braided | Double | 152 |
| US | MDMF 8 SIN | PE | 8.0 | 27 027[1] | Braided | Single | 190 |

[1] Runnage: linear density derived from runnage.

A load of 25% of the nominal Rtex was applied during the measurement. The twine was then allowed to settle for a period of time dependent on the material and construction type. Two measurements were then taken at 10 mm intervals along the twine length, the second reading being at ninety degrees to the first to provide an average thickness (this dual measurement is especially useful in twines where the cross-section may not be circular). Approximately forty measurements were taken for each sample.

Since no spooled twine samples could be obtained for the German PA and the Icelandic PE nettings, the twine thickness was measured directly on the netting using a calliper.

*Linear density measurement*

The linear density of the twines used for the thickness measurements was derived by weighing a known length of the twine. The length of the twine to be weighed was marked under a load equal to 25% of the nominal Rtex value. An apparatus as described in Klust (1982) and recommended by the International Organisation for Standardization (Anon., 1974) was used for measuring the length.

*Mesh opening measurement*

The mesh opening was measured with either the ICES or the flat wedge gauge. An alternative method was developed for mesh measurements with the TSF and the newly proposed measuring forces. A list of experiments made is given in Section 5.1.

*ICES mesh gauge*

The ICES gauge is described in Section 3.1. Measurements on netting with large knots may cause problems since the jaws of the ICES gauge can be placed under or at the side of the knot. In the present measurements the jaw was positioned to the side of the knot. This gives the largest mesh opening, corresponding to the definition given in Section 2.1.

*Flat wedge gauge*

The measurements were made with the flat wedge gauges used by fisheries inspectors for minimum mesh size control. Where possible, fisheries inspectors were recruited to make the measurements. See Section 3.2 for a description of the gauges. The wedge gauge was either pushed into the mesh to be measured by hand force or a weight of 5 or 2 kgf was used. Some samples were measured using a dynamometer instead of a weight.

*Measurements with a load corresponding to the Textile Standard Force (TSF) or the 10/13 kgf measuring force*

The TSF was calculated from the nominal Rtex value. Since the load that can be applied with the ICES gauge is limited to about 6 kgf, a modified method had to be used for measurements with the TSF and the 10 and 13 kgf measurement forces. The method is based on the use of an ICES mesh gauge for which the blocking mechanism has been disabled so that the movable jaw can move freely along the bar with the length scale (Figure 5). With the instrument held in a vertical position, the mesh to be measured is mounted over the jaws and a weight corresponding to the measuring force (TSF) minus the weight of the movable jaw is attached to the handle of the movable jaw. The mesh opening is read on the scale of the ICES gauge.

*State of the netting*
All measurements were made on dry netting under normal laboratory conditions with no extremes of temperature and humidity. The rationale for measuring on dry netting was:

- the effect of the measuring force is investigated, not the changes in mesh size due to the state of the netting (dry or wet)
- to avoid bias due to samples being more or less wet, it is easier to maintain the same measuring conditions in the dry state.

*Number of measurements*
Sixty meshes were measured in each series of measurements. Preliminary tests on a number of netting samples showed that measuring 60 meshes will yield a mean mesh size with a precision of 1 mm at the 95% level and mostly at the 99% level. For legislative purposes 60 meshes are also used (if the average of the first 20 meshes is below the minimum mesh size, see Section 3.1.1). It is logical to select, as for inspection, 3 rows of 20 meshes.

*Statistical analysis*
To establish the relationship between twine thickness and linear density several trend line types were calculated, using the statistical tools provided with the Microsoft ® Excel 2002 software. Based on the $r^2$ value, the best model was chosen.

Scatter plots comparing individual mesh measurements obtained by different methods (ICES 4kgf, wedge hand, wedge 5 kg weight) were obtained using STATISTICA data analysis software system version 6 (StatSoft, Inc, 2003). An in depth analysis of these data was the subject of a separate study. The details of this study are given in Annex 1.

To detect groups of netting types for which the same measurement conditions can be applied, similarities among the sample twine thicknesses were evaluated by means of the Hierarchical Cluster Analysis (Anderberg, 1973). Starting with the total Rtex (Rtex of a single twine multiplied by the number of twines) and the variation between the ICES and TSF method (%) (calculated by dividing the difference between the ICES and the TSF value by the TSF value), clustering was performed using the squared Euclidean distance and single linkage. All the statistical procedures were performed using the *SPSS Rel. 10.0* software package (Anon., 1999). For multiple twine nettings the equivalent single twine thickness was calculated from the calculated twine thickness/Rtex relationships. For single twine netting the measured twine thickness was used.

## 5.4 Results and analysis

### 5.4.1 Twine thickness and linear density

*Twine thickness*
The results of the twine thickness measurements are given in Table 5. For the PA samples of 2 mm or less, measured by the optical method, the difference between the measured and the nominal values can be ignored. The measured value of the 5 mm PA twine, however, was 0.5 mm larger than the nominal value.

The PE twines, ranging from 1.8 to 10.8 mm, showed greater differences, varying between 0.02 mm and 0.85 mm. The measured twine thickness was smaller than the nominal value in 15 out of 20 samples.

*Linear density*
Of the 23 samples for which comparisons could be made, 15 had a measured value that was larger than the nominal value (Table 5).

*Comparison between twine thickness and linear density*
A power trend line gave the best fit between the linear density and the twine thickness for both PA (Figure 6) and PE twines (Figure 7). Nominal values were used where measured values were not available.
The nearly quadratic relations are:

$$\text{for PA twines: Rtex} = 672.32 \text{ thickness}^{1.9297} \quad (r^2 = 0.9918) \tag{1}$$

$$\text{for PE twines: Rtex} = 438.71 \text{ thickness}^{1.9748} \quad (r^2 = 0.9521). \tag{2}$$

The different coefficients are explained by the difference in density of PA and PE.

### 5.4.2 Mesh opening

A summary of the average mesh openings obtained by the different methods and measuring forces is given in Table 6.

Figure 5. Experimental setup for TSF measurements.

Table 5. Comparison of measured and nominal twine thicknesses and linear densities.

| Sample Designation | Material | Braided /twisted / knotless netting | Nominal twine thickness (mm) | Measured twine thickness (mm) | Difference measured -nominal thickness | Nominal linear density (Rtex) | Measured linear density (Rtex) | Difference measured-nominal linear density |
|---|---|---|---|---|---|---|---|---|
| DVZ 1.2 SIN | PA | Twisted | 1.2 | 1.23 | 0.03 | 780 | 812 | 32 |
| IMR-S 1.5 SIN | PA | Twisted | 1.5 | 1.53 | 0.03 | 1 632[1] | 1 450 | -182 |
| DIFRES 1.5 SIN | PA | Twisted | 1.5 | 1.49 | -0.01 | 1 211[1] | 1 414 | 203 |
| RIVO 2 SIN/DBL | PA | Twisted | 2.0 | 2.01 | 0.01 | | 2 450 | |
| IMR-N 5 DBL PA | PA | Braided | 5.0 | 5.52 | 0.52 | 15 385 | 15 520 | 135 |
| DFO 1.8 SIN | PE | Braided | 1.8 | 2.01 | 0.21 | 1 700 | 1 800 | 100 |
| MARLAB 3 SIN | PE | Braided | 3.0 | 3.19 | 0.19 | 4 060 | 4 077 | 17 |
| IMR-N 3.2 TRI | PE | Braided | 3.2 | 3.07 | -0.13 | 5 300 | 4 733 | -567 |
| IMR-S 3.5 SIN | PE | Braided | 3.5 | 2.92 | -0.58 | 3 915 | 3 883 | -32 |
| DFO 4 DBL | PE | Braided | 4.0 | 3.75 | -0.25 | 5 600 | 5 687 | 87 |
| DIFRES 4 SIN 75/105 | PE | Braided | 4.0 | 3.65 | -0.35 | 5 263[1] | 5 578 | 315 |
| DVZ 4 DBL | PE | Braided | 4.0 | 3.98 | -0.02 | 6 250[1] | 6 953 | 703 |
| RIVO 4 DBL | PE | Braided | 4.0 | 3.94 | -0.06 | 5 208[1] | 5 998 | 790 |
| DFO 5 DBL | PE | Braided | 5.0 | 4.77 | -0.23 | 8 100 | 8 197 | 97 |
| IMR-N 5 DBL PE | PE | Braided | 5.0 | 5.66 | 0.66 | 13 900 | 14 463 | 563 |
| MARLAB 5 SIN | PE | Braided | 5.0 | 5.68 | 0.68 | 13 632 | 13 830 | 298 |
| DVZ 5 SIN | PE | Braided | 5.0 | 4.43 | -0.57 | 8 000 | 7 918 | -82 |
| DFO 5.5 DBL | PE | Braided | 5.5 | 5.15 | -0.35 | 10 940 | 11 170 | 230 |
| RIVO 6 DBL | PE | Braided | 6.0 | 5.70 | -0.30 | 12 500 | 11 068 | -1 432 |
| DFO 6 DBL | PE | Braided | 6.0 | 5.15 | -0.85 | 11 140 | 11 175 | 35 |
| MDMF 6 DBL | PE | Braided | 6.0 | 6.08 | 0.08 | 13 333[1] | 12 813 | -520 |
| MARLAB 6 DBL | PE | Braided | 6.0 | 5.62 | -0.38 | 14 225 | 14 467 | 242 |
| IMR-N 7.1 UC | PE | Braided | 7.1 | 6.26 | -0.84 | 21 170 | 21 020 | -150 |
| MDMF 8 SIN | PE | Braided | 8.0 | 7.66 | -0.34 | 27 027[1] | 24 510 | -2 517 |
| IMR-N 10.8 UC | PE | Braided | 10.8 | 9.98 | -0.82 | 53 500 | 59 545 | 6 045 |

[1] Runnage: linear density derived from runnage.

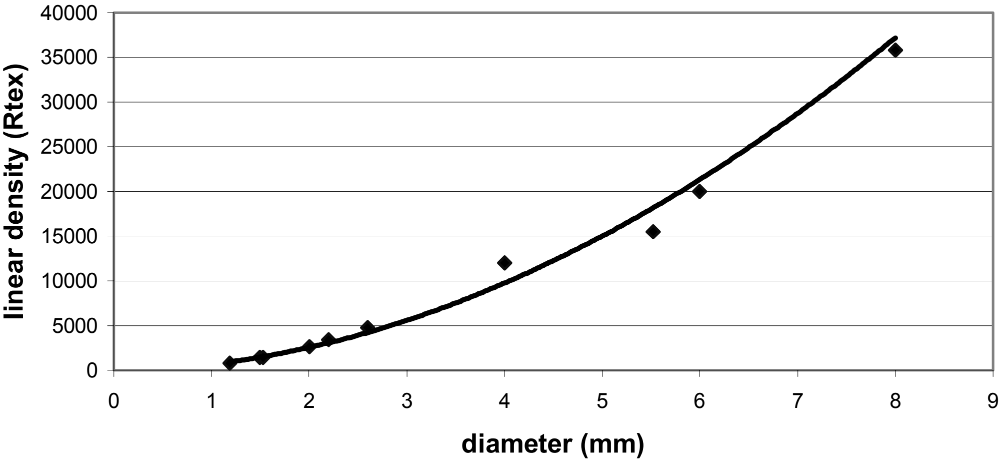


Figure 6. Linear density in relation to the twine thickness for PA twines.

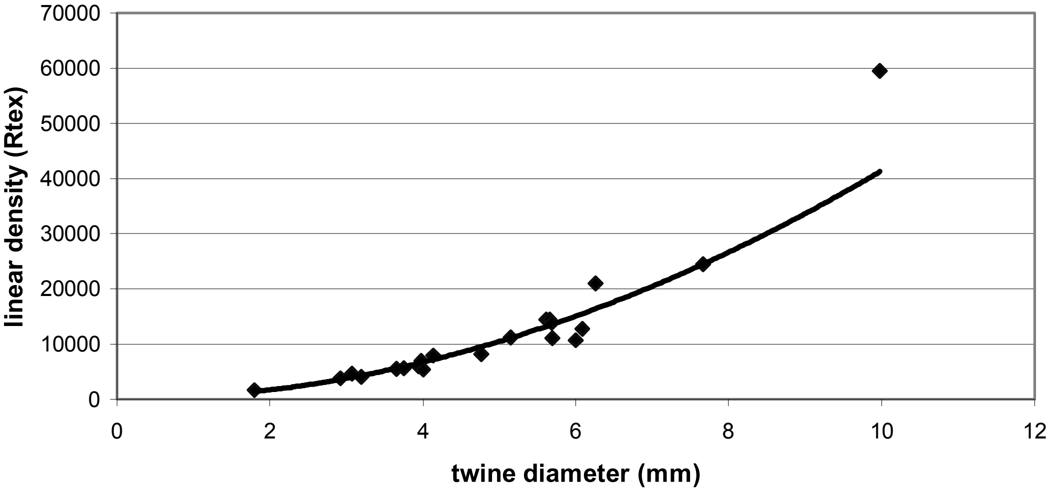


Figure 7. Linear density in relation to the twine thickness for PE twines.

Table 6. Results of mesh opening measurements[1].

| | | | | | Average Mesh Opening (mm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample designation | Material | Twine thickness (mm) | Single Double Triple | Rtex | ICES gauge 4 kgf | TSF x no of yarns | Wedge gauge hand force | Wedge gauge 5 or 2 kgf | 10 kgf | 13 kgf |
| BFAFi 2,2 DBL | PA | *2.2* | DBL | *3 400* | 41.9 | 42.8 | 39.2 | 40.8 | | |
| BFAFi 2,6 SIN | PA | 2.6 | SIN | *4 800* | 47.1 | 45.7 | 42 | 45.3 | | |
| BFAFi 4 DBL | PA | *4.0* | DBL | *12 000* | 113.0 | 118.8 | 109.5 | 112.1 | 113.4 | 114.7 |
| BFAFi 6 DBL | PA | *6.0* | DBL | *20 000* | 132.1 | 143.1 | 134.5 | 134.6 | 140.1 | 139.5 |
| BFAFi 8 SIN | PA | *8.0* | SIN | *35 800* | 119.9 | 127.0 | 119.8 | 120.1 | 124.2 | 125.2 |
| DFO 1,8 SIN | PE | 2.0 | SIN | *1 700* | 50.9 | 47.2 | 49.2 | 54.7 | | |
| DFO 4 DBL | PE | 3.746 | DBL | 5 687 | 146.5 | 147.1 | 148.9 | 148.4 | 148.3 | 149.6 |
| DFO 5 DBL | PE | 4.765 | DBL | 8 197 | 82.3 | 83.7 | 87.7 | 86.8 | 84.1 | 85.2 |
| DFO 5,5 DBL | PE | 5.149 | DBL | 11 170 | 105.3 | 108.3 | 110.6 | 111.2 | 108.2 | 109.1 |
| DFO 6 DBL | PE | 5.146 | DBL | 11 175 | 131.6 | 134.3 | 134.6 | 136.3 | 133.9 | 134.7 |
| DIFRES 4 SIN 75 | PE | 3.653 | SIN | 5 578 | 106.5 | 104.4 | 109.7 | 108.4 | 108.7 | 109.9 |
| DIFRES 4 SIN 105 | PE | 3.653 | SIN | 5 578 | 70.5 | 68.8 | 75 | 72.6 | 73.0 | 74.0 |
| DIFRES1,5 SIN | PA | 1.493 | SIN | 1 414 | 34.1 | 30.5 | 34.9 | 32.7 | | |
| DVZ 4 DBL | PE | 3.976 | DBL | 6 953 | 81.0 | 81.7 | 84.0 | 83.1 | 83.4 | 84.2 |
| DVZ 5 SIN | PE | 4.132 | SIN | 7 918 | 86.9 | 86.9 | 90.9 | 89.6 | 90.9 | 91.7 |
| DVZ 1,2 SIN | PA | 1.19 | SIN | 812 | 21.5 | 18.7 | 18.3 | 20.3 | | |
| IMR-N 3,2 TRI | PE | 3.066 | TRI | 4 733 | 135.2 | 142.2 | 141.8 | 137.7 | 142.8 | 143.6 |
| IMR-N 5 DBL | PE | 5.661 | DBL | 14 463 | 137.7 | 147.1 | 141.4 | 140.0 | | |
| IMR-IS 6 DBL | PE | *6.0* | DBL | *10 800* | 134.1 | 140.8 | 137.2 | 136.3 | 141.0 | 143.5 |
| IMR-N 7,1 UC | PE | 6.26 | SIN | 21 020 | 133.2 | 138.7 | 137.2 | 135.2 | 138.7 | 140.5 |
| IMR-N 10,8 UC | PE | 9.981 | SIN | 59 545 | 133.7 | 143.1 | 137.6 | 137.0 | 140.8 | 142.5 |
| IMR-N 8 DBL | PA | 5.517 | DBL | 15 520 | 136.8 | 146.6 | 137.5 | 137.5 | 143.5 | 146.0 |
| IMR-S 3,5 SIN | PE | 2.924 | SIN | 3 883 | 71.6 | 71.0 | 74.8 | 76.2 | 75.6 | 77.8 |
| IMR-S 4 SIN | PE | *4.0* | SIN | *5 400* | 107.1 | 106.1 | 107.3 | 111.7 | | |
| IMR-S 1,5 SIN | PA | 1.528 | SIN | 1 450 | 37.0 | 35.6 | 38 | 36.4 | | |
| MARLAB 3 SIN | PE | 3.191 | SIN | 4 077 | 68.6 | 68.0 | 76.1 | 75.0 | 76.3 | 78.4 |
| MARLAB 5 SIN | PE | 5.682 | SIN | 13 830 | 74.7 | 78.8 | 81.2 | 79.4 | 81.0 | 82.6 |
| MARLAB 6 DBL | PE | 5.615 | DBL | 14 467 | 99.5 | 104.3 | 104.6 | 101.9 | 101.4 | 103.0 |
| MDMF 6 DBL | PE | 6.083 | DBL | 13 333 | 149.8 | 158.3 | | 165.9 | 156.3 | 158.3 |
| MDMF 8 SIN | PE | 7.662 | SIN | 27 028 | 184.6 | 191.2 | | 189.3 | 190.0 | 191.2 |
| RIVO 4 DBL | PE | 3.944 | DBL | 5 998 | 75.2 | 77.0 | 82.6 | 80.9 | 80.4 | 81.0 |
| RIVO 6 DBL | PE | 5.695 | DBL | 11 068 | 76.6 | 83.5 | 89.4 | 84.2 | 84.1 | 84.8 |
| RIVO 2 SIN | PA | 2.005 | SIN | 2 650 | 37.8 | 36.6 | 37.7 | 42.5 | | |
| RIVO 2 DBL | PA | 2.005 | DBL | 2 650 | 35.2 | 34.7 | 35.4 | 39.9 | | |

[1] Twine thickness and linear densities printed in *italics* are nominal values.

*Comparison of existing methodologies*

Figure 8 compares the mesh openings as measured with respectively the ICES 4 kgf gauge, the hand operated wedge gauge and the wedge gauge loaded with a weight. Differences in terms of percentages are given in Table 7. Throughout the following comparisons two groups of netting samples can be distinguished:

- small mesh netting (<55 mm mesh opening) made of thin twines (< 3 mm twine thickness)
- large mesh netting of larger meshes (=> 55 mm mesh opening) and heavier twines (=>3 mm twine thickness).

Scatter plots for the methodologies compared are presented in Figure 9. The measuring methods are abbreviated as ICES: ICES 4 kgf gauge; WH: hand operated wedge gauge; WW: wedge gauge with a 2/5 kg weight or dynamometer.

*ICES 4 kgf – Wedge gauge hand force*

The results for the netting samples with large meshes are quite clear. In all cases but two, the ICES gauge yields smaller average mesh openings than the wedge gauge, operated by hand. The differences range from –14.3 to +3.2%.

The small mesh netting samples give a more variable picture. The ICES gauge gives lower average mesh openings for three samples (-2.3 to -0.6%), and higher values for the five others (0.3 to 17.5%).

*ICES 4 kgf – Wedge gauge 2/5 kg weight*

Again the ICES gauge gives lower average mesh openings for all but one sample of the large mesh netting samples, and differences ranging from –9.7 to 0.8%. For most samples the differences are smaller than with the hand operated wedge gauge.

The small mesh samples give again a mixed picture. The differences vary between –1.8 and +5.9%.

*Wedge gauge hand operated – wedge gauge 2/5 kg weight*

In general the wedge gauge used with a weight gives smaller average mesh openings than the hand operated wedge gauge for the large mesh netting samples. For seven samples the mesh openings were larger if measured with the weight. The differences range from –5.8 to 4.1%.

The tendency was again less clear for the small mesh samples, with differences between both methods varying between –6.3 and 12.7%.

A detailed statistical analysis of the data was made and is given in Annex 1. Due to the lack of data for all possible categories of netting samples, the group of small meshes had to be restricted to netting samples of single, twisted PA twines. The netting samples retained for the group of large meshes consisted of single and double braided PE twines. The modelling approach used is known as a "mixed effects model". An exploratory analysis suggests that for the small mesh netting samples the ICES gauge and the wedge-hand appear to be similar in variation, the wedge-hand yielding slightly higher values than the ICES gauge. The wedge-weight method seems to display a larger variation. However, the analysis of the three samples with a nominal mesh size of 35–36 mm, summarized in Table 8, revealed that there is a considerable overlap between the confidence intervals and it is not possible to detect any statistical difference between the three methods. The results for the large mesh data set are displayed in Table 9. They demonstrate that the ICES gauge gives significantly smaller mesh openings than both the wedge-hand and wedge-weight methods. The latter two methods do not appear to be significantly different. An analysis was also made of the main factors affecting the mesh measurements. For the small mesh group the effect of Rtex could be investigated (Rtex and twine thickness are strongly correlated and since Rtex provided the best fit, this parameter was retained in the model). Interaction effects Method:Sqrt-(Rtex) were significant for all three methods, meaning that Rtex has different impacts upon the three methods (Table 10). For the large mesh group twine thickness yielded a better fit than Rtex. Both Sqrt(thickness) and the "twine" factor (single/double) appeared to be significant, together with different interaction effects (Table 11).

*Comparison between the 4 kgf ICES gauge and the TSF measuring force*

Table 12 compares the average mesh sizes obtained with both measuring forces. A t-test for paired samples was performed for each data set. The difference between the two averages was statistically significant for all netting samples for which the TSF was different from 4 kgf.

Because of the different density of PA and PE, and hence the different relationship between linear density and twine thickness of PA and PE (see equations (1) and (2)), the analyses were made separately for the netting samples of both materials.

The ratio between the mean mesh opening obtained with the 4 kgf ICES gauge and the mean mesh opening obtained with the TSF measuring force for the PA nettings is graphically presented in Figure 10. The ICES gauge overestimates the mesh opening for practically all twine thicknesses under 3 mm. The largest difference was 15% for a 1.2 mm twine thickness. From a twine thickness of 4 mm the ICES gauge underestimated the mesh opening. The difference was 5–8%.

A similar situation occurs for PE netting (Figure 11). For twine thicknesses under 3 mm the mean mesh openings are overestimated by the 4 kgf ICES gauge (by 8% for a twine thickness of 1.8 mm). For twine thicknesses of 3–4 mm the difference is ± 2%. For larger twine thicknesses the mesh openings are underestimated by 4–8%.

The cluster analysis yielded the dendrograms shown in Figures 12 and 13. It appears that a two-cluster solution may be appropriate for both PA and PE nettings. For PA nettings the upper group in the plot includes the samples from 1.2 mm single twine to 2.2 mm double twine (equivalent of 3.3 mm single). The lower group includes meshes from 4.0 mm double (equivalent of 6.2 mm single) to 8.0 mm single).

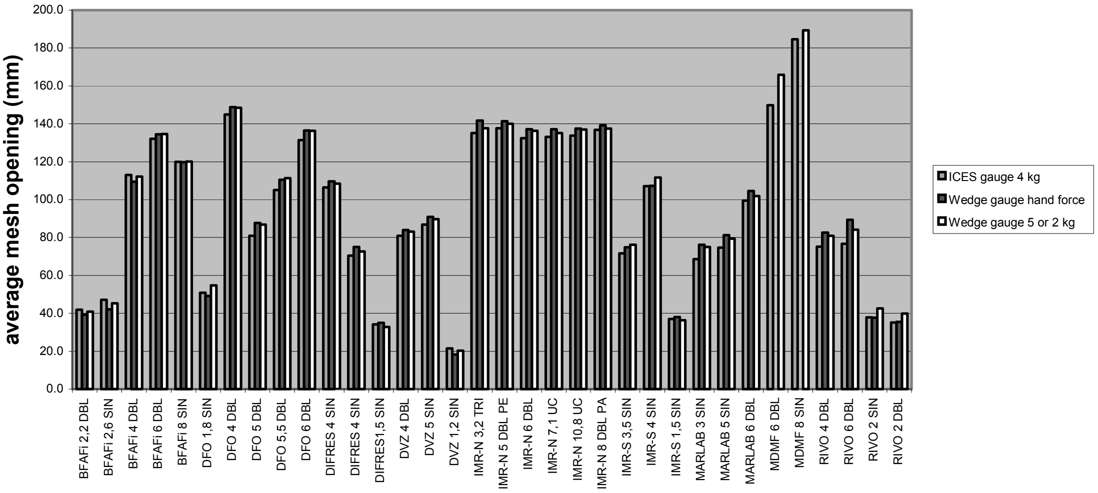
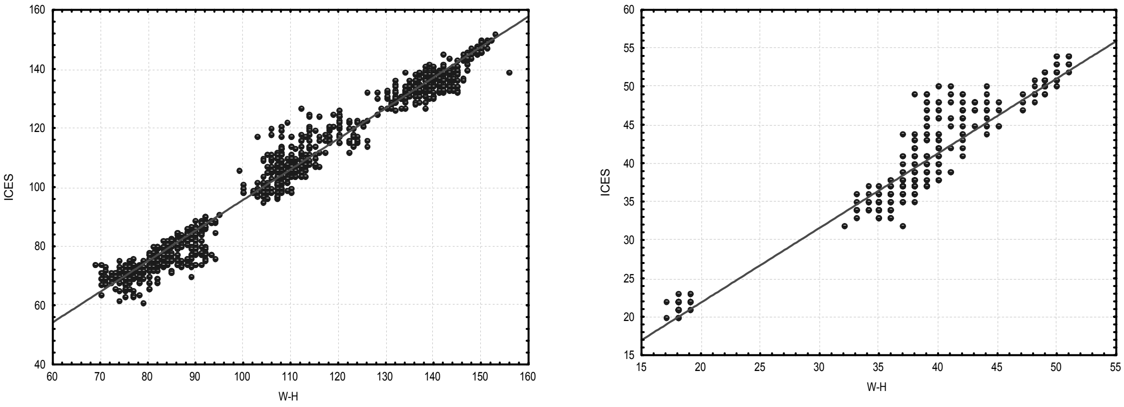


Figure 8. Comparison of existing methodologies.

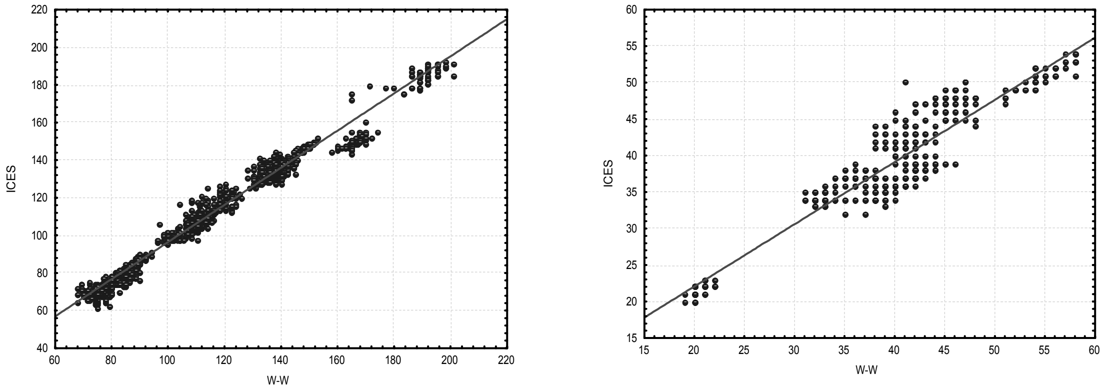
Table 7. Comparison between different gauges.

|  |  |  |  |  | Mean Mesh Opening (mm) – (standard deviation) |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample designation | Material | Twine thickness (mm) | Single Double Triple | Rtex | ICES gauge 4 kgf (ICES) | Wedge gauge hand force (WH) | Wedge gauge 5 or 2 kgf (WW) | (ICES-WH)/ WH | (ICES-WW) /WW | (WW-WH)/ WH |
| Smaller meshes, smaller twine thicknesses |  |  |  |  |  |  |  |  |  |  |
| BFAFi 2,2 DBL | PA | *2.2* | DBL | *3 400* | 41.9 (1.54) | 39.2 (1.20) | 40.8 (1.46) | 6.9% | 2.7% | 4.1% |
| BFAFi 2,6 SIN | PA | *2.6* | SIN | *4 800* | 47.1 (1.55) | 42 (1.80) | 45.3 (1.84) | 12.1% | 4.0% | 7.9% |
| DFO 1,8 SIN | PE | 2.0 | SIN | *1 700* | 50.9 (1.73) | 49.2 (1.11) | 54.7 (2.15) | 3.5% | -6.9% | 11.2% |
| DIFRES1,5 SIN | PA | 1.493 | SIN | 1 414 | 34.1 (0.67) | 34.9 (1.00) | 32.7 (0.85) | -2.3% | 4.3% | -6.3% |
| DVZ 1,2 SIN | PA | 1.19 | SIN | 812 | 21.5 (0.72) | 18.30.51) | 20.3 (0.65) | 17.5% | 5.9% | 10.9% |
| IMR-S 1,5 SIN | PA | 1.528 | SIN | 1 450 | 37.0 (0.57) | 38 (0.79) | 36.4 (1.12) | -2.6% | 1.6% | -4.2% |
| RIVO 2 DBL | PA | 2.005 | DBL | 2 650 | 35.2 (1.27) | 35.4 (1.25) | 38.9 (1.55) | -0.6% | -11.8% | 12.7% |
| RIVO 2 SIN | PA | 2.005 | SIN | 2 650 | 37.8 (0.98) | 37.7 (1.21) | 42.5 (1.16) | 0.3% | -11.1% | 12.7% |
| Larger meshes, larger twine thicknesses |  |  |  |  |  |  |  |  |  |  |
| BFAFi 4 DBL | PA | *4.0* | DBL | *12 000* | 113.0 (3.57) | 109.5 (3.24) | 112.1 (3.11) | 3.2% | 0.8% | 2.4% |
| BFAFi 6 DBL | PA | *6.0* | DBL | *20 000* | 132.1 (2.76) | 134.5 (3.23) | 134.6 (3.00) | -1.8% | -1.9% | 0.1% |
| BFAFi 8 SIN | PA | *8.0* | SIN | *35 800* | 119.9 (3.56) | 119.8 (3.56) | 120.1 (2.52) | 0.1% | -0.2% | 0.3% |
| DFO 4 DBL | PE | 3.746 | DBL | 5 687 | 146.5 (2.22) | 148.9 (1.83) | 148.4 (2.00) | -1.6% | -1.3% | -0.3% |
| DFO 5 DBL | PE | 4.765 | DBL | 8 197 | 82.3 (1.88) | 87.7 (1.70) | 86.8 (1.75) | -6.1% | -5.2% | -0.9% |
| DFO 5,5 DBL | PE | 5.149 | DBL | 11 170 | 105.3 (2.76) | 110.6 (2.73) | 111.2 (2.53) | -4.7% | -5.3 | 0.6% |
| DFO 6 DBL | PE | 5.146 | DBL | 11 175 | 131.6 (3.73) | 134.3 (3.71) | 136.3 (3.53) | -2.0% | -3.5 | 1.5% |
| DIFRES 4 SIN 75 | PE | 3.653 | SIN | 5 578 | 70.5 (1.51) | 75 (2.15) | 72.6 (2.15) | -6.0% | -2.9% | -3.2% |
| DIFRES 4 SIN 105 | PE | 3.653 | SIN | 5 578 | 106.5 (1.20) | 109.7 (1.19) | 108.4 (1.15) | -2.9% | -1.8% | -1.2% |
| DVZ 4 DBL | PE | 3.976 | DBL | 6 953 | 81.0 (3.01) | 84.0 (2.65) | 83.1 (2.92) | -3.6% | -2.6% | -1.1% |
| DVZ 5 SIN | PE | 4.132 | SIN | 7 918 | 86.9 (1.90) | 90.9(1.79) | 89.6 (2.11) | -4.4% | -3.1% | -1.4% |
| IMR-N 10,8 UC | PE | 9.981 | SIN | 59 545 | 133.7 (1.28) | 137.6 (1.12) | 137.0 (1.41) | -2.8% | -2.4% | -0.4% |
| IMR-N 3,2 TRI | PE | 3.066 | TRI | 4 733 | 135.2 (2.16) | 141.8 (2.19) | 137.7 (2.27) | -4.6% | -1.8% | -2.9% |
| IMR-N 5 DBL | PE | 5.661 | DBL | 14 463 | 137.7 (2.99) | 141.4 (2.38) | 140.0 (2.60) | -2.6% | -1.7% | -1.0% |
| IMR-IS 6 DBL | PE | *6.0* | DBL | *10 800* | 134.1 (3.37) | 137.2 (2.99) | 136.3 (3.14) | -2.3% | -1.6% | -0.7% |
| IMR-N 7,1 UC | PE | 6.26 | SIN | 21 020 | 133.2 (0.81) | 137.2 (0.76) | 135.2 (0.94) | -3.0% | -1.5% | -1.5% |
| IMR-N 8 DBL | PA | 5.517 | DBL | 15 520 | 136.8 (2.03) | 138.9 (1.68) | 137.5 (1.89) | -1.5% | -0.5% | -1.0% |
| IMR-S 3,5 SIN | PE | 2.924 | SIN | 3 883 | 71.6 (1.38) | 74.8 (1.62) | 76.2 (1.47) | -4.3% | -6.0% | 1.9% |
| IMR-S 4 SIN | PE | *4.0* | SIN | *5 400* | 107.1 (1.27) | 107.3 (1.14) | 111.7 (1.13) | -0.2% | -4.1% | 4.1% |
| MARLAB 3 SIN | PE | 3.191 | SIN | 4 077 | 68.6 (2.78) | 76.1 (3.28) | 75.0 (2.95) | -9.9% | -8.6% | -1.4% |
| MARLAB 5 SIN | PE | 5.682 | SIN | 13 830 | 74.7 (1.73) | 81.2 (2.88) | 79.4 (2.54) | -8.1% | -6.0% | -2.2% |
| MARLAB 6 DBL | PE | 5.615 | DBL | 14 467 | 99.5 (2.19) | 104.6 (2.64) | 101.9 (2.94) | -4.9% | -2.4% | -2.6% |
| MDMF 6 DBL | PE | 6.083 | DBL | 13 333 | 149.8 (3.19) |  | 165.9 (3.19) |  | -9.7% |  |
| MDMF 8 SIN | PE | 7.662 | SIN | 27 028 | 184.6 (4.68) |  | 189.3 (6.81) |  | -2.5% |  |
| RIVO 4 DBL | PE | 3.944 | DBL | 5 998 | 75.2 (2.24) | 82.6 (2.01) | 80.9 (2.20) | -9.0% | -7.1% | -2.1% |
| RIVO 6 DBL | PE | 5.695 | DBL | 11 068 | 76.6 (3.60) | 89.4 (2.90) | 84.2 (3.08) | -14.3% | -9.0% | -5.8% |

a) ICES-WH +55 mm b) ICES-WH -55 mm



c) ICES-WW +55 mm d) ICES-WW -55 mm



e) WW-WH +55 mm f) WW-WH -55 mm

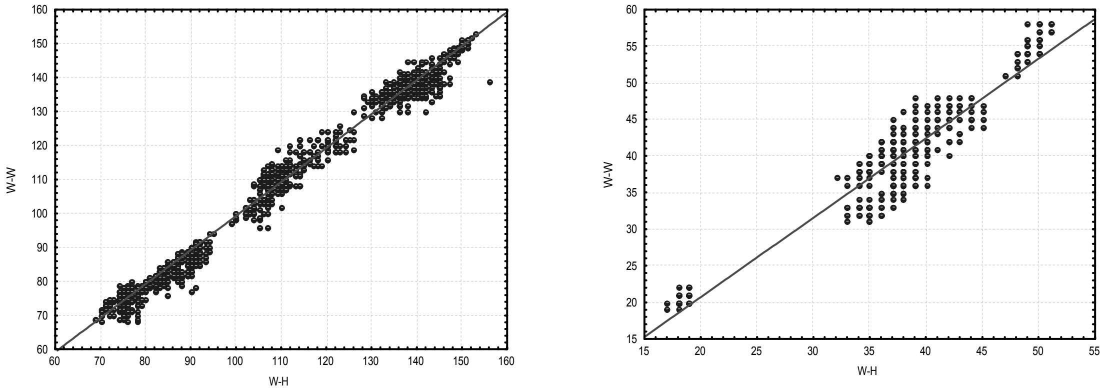


Figure 9. Comparison of existing methodologies – Scatter plots of individual measurements.

Table 8. Small mesh data analysis.

|  |  |  |  |  |  | 95% confidence intervals |  |
|---|---|---|---|---|---|---|---|
| Parameter | Estimate | Std. Error | df | t-value | p-value | Lo | Hi |
| ICES | 32.625 | 3.765 | 714 | 8.664370 | <0.0001 | 25.25 | 40.00 |
| WH | 32.213 | 3.765 | 714 | 8.554820 | <0.0001 | 24.84 | 39.59 |
| WW | 32.983 | 3.765 | 714 | 8.759534 | <0.0001 | 25.61 | 40.36 |

Table 9. Large mesh data analysis.

The results in the first 14 lines of following table gives the expected mesh sizes for the range of nominal mesh sizes represented in the data when measured with the ICES gauge. The last two lines gives the estimated contrasts (adjustments) when measured by the "WH" and "WW" method.

| Parameter | Estimate | Std. Error | df | t-value | p-value | Lo | Hi |
|---|---|---|---|---|---|---|---|
| Nom. Mesh 70 | 73.0856 | 1.038096 | 2748 | 70.4035 | <0.0001 | 71.055 | 75.116 |
| Nom. Mesh 74 | 67.9113 | 1.065989 | 2748 | 63.7073 | <0.0001 | 65.826 | 69.996 |
| Nom. Mesh 75 | 69.8879 | 1.065989 | 2748 | 65.5616 | <0.0001 | 67.803 | 71.973 |
| Nom. Mesh 80 | 81.9833 | 1.065989 | 2748 | 76.9082 | <0.0001 | 79.898 | 84.068 |
| Nom. Mesh 82 | 80.4773 | 1.030905 | 6 | 78.0647 | <0.0001 | 77.961 | 82.994 |
| Nom. Mesh 100 | 96.6947 | 1.065989 | 2748 | 90.7089 | <0.0001 | 94.610 | 98.780 |
| Nom. Mesh 105 | 105.3828 | 1.038096 | 2748 | 101.5155 | <0.0001 | 103.352 | 107.413 |
| Nom. Mesh 107 | 107.5210 | 1.065989 | 2748 | 100.8650 | <0.0001 | 105.436 | 109.606 |
| Nom. Mesh 135 | 132.6662 | 1.465892 | 6 | 90.5020 | <0.0001 | 129.088 | 136.244 |
| Nom. Mesh 138 | 136.4662 | 1.465892 | 6 | 93.0943 | <0.0001 | 132.888 | 140.044 |
| Nom. Mesh 140 | 130.4333 | 1.065989 | 2748 | 122.3590 | <0.0001 | 128.348 | 132.518 |
| Nom. Mesh 150 | 144.3000 | 1.065989 | 2748 | 135.3672 | <0.0001 | 142.215 | 146.385 |
| Nom. Mesh 152 | 155.5585 | 1.475414 | 2748 | 105.4338 | <0.0001 | 152.672 | 158.445 |
| Nom. Mesh 190 | 184.6721 | 1.475414 | 2748 | 125.1663 | <0.0001 | 181.786 | 187.558 |
| Method WH | 5.0518 | 0.143012 | 2748 | 35.3242 | <0.0001 | 4.772 | 5.332 |
| Method WW | 4.5997 | 0.137092 | 2748 | 33.5517 | <0.0001 | 4.332 | 4.868 |

Table 10. Small mesh model.

M: *fixed~ method+ method:sqrt(Rtex)*

| Parameter | Estimate | Std.Error | df | t-value | p-value |
|---|---|---|---|---|---|
| Intercept | 7.23799 | 9.547382 | 711 | 0.75811 | 0.4486 |
| WH | -4.88662 | 0.603206 | 711 | -8.10108 | <.0001 |
| WW | -10.30566 | 0.603206 | 711 | -17.08482 | <.0001 |
| ICES_sqrt(Rtex) | 0.65239 | 0.240077 | 711 | 2.71742 | 0.0067 |
| WH_sqrt(Rtex) | 0.76736 | 0.240077 | 711 | 3.19633 | 0.0015 |
| WW_sqrt(Rtex) | 0.92643 | 0.240077 | 711 | 3.85889 | 0.0001 |

Table 11. Large mesh model.

M: *fixed~ method*sqrt(dia)*Twine*

| Parameter | Estimate | Std.Error | df | t-value | p-value |
|---|---|---|---|---|---|
| Intercept | 158.3278 | 11.94311 | 2 749 | 13.25684 | <.0001 |
| WH | -16.0561 | 10.23822 | 2 749 | -1.56825 | 0.1169 |
| WW | -13.5162 | 9.76109 | 2 749 | -1.38471 | 0.1663 |
| Sqrt(dia) | -20.7422 | 3.48686 | 2 749 | -5.94868 | <.0001 |
| Twine | -132.2997 | 8.95710 | 2 749 | -14.77038 | <.0001 |
| WH_sqrt(dia) | 9.8903 | 4.57957 | 2 749 | 2.15965 | 0.0309 |
| WW_sqrt(dia) | 8.2788 | 4.33466 | 2 749 | 1.90990 | 0.0563 |
| WH_Twine | 35.8510 | 13.05468 | 2 749 | 2.74622 | 0.0061 |
| WW_Twine | 16.3268 | 11.46217 | 2 749 | 1.42441 | 0.1544 |
| Sqrt(dia)_Twine | 58.3751 | 3.98794 | 2 749 | 14.63790 | <.0001 |
| WH_sqrt(dia)_Twine | -18.1206 | 6.12022 | 2 749 | -2.96077 | 0.0031 |
| WW_sqrt(dia)_Twine | -7.7207 | 5.20246 | 2 749 | -1.48405 | 0.1379 |

Table 12. Comparison between ICES 4 kgf mesh gauge and TSF.

|  |  |  |  | Average Mesh Size (mm) |  |  |  |
|---|---|---|---|---|---|---|---|
| Sample designation | Material | Rtex | TSF x no of yarns (g) | ICES gauge 4 kgf | TSF | p | ICES/TSF |
| BFAFi 2,2 DBL | PA | *3 400* | 3 400 | 41.9 (1.54) | 42.8 (1.54) | 2.07653E-09 | 0.98 |
| BFAFi 2,6 SIN | PA | *4 800* | 2 400 | 47.1 (1.55) | 45.7 (1.82) | 7.14395E-06 | 1.03 |
| BFAFi 4 DBL | PA | *12 000* | 12 000 | 113.0 (3.57) | 118.8 (3.23) | 1.13873E-26 | 0.95 |
| BFAFi 6 DBL | PA | *20 000* | 2 000 | 132.1 (2.76) | 143.1 (2.52) | 2.5055E-39 | 0.92 |
| BFAFi 8 SIN | PA | *35 800* | 17 900 | 119.9 (3.56) | 127.0 (2.27) | 4.96539E-19 | 0.94 |
| DFO 1,8 SIN | PE | *1 700* | 850 | 50.9 (1.73) | 47.2 (1.67) | 8.21833E-50 | 1.08 |
| DFO 4 DBL | PE | 5 687 | 5 600 | 146.5 (2.22) | 147.1 (2.18) | 2.40847E-13 | 1.00 |
| DFO 5 DBL | PE | 8 197 | 8 100 | 82.3 (1.88) | 83.7 (1.95) | 7.46004E-30 | 0.98 |
| DFO 5,5 DBL | PE | 11 170 | 10 940 | 105.3 (2.76) | 108.3 (2.81) | 2.82555E-39 | 0.97 |
| DFO 6 DBL | PE | 11 175 | 11 140 | 131.6 (3.73) | 134.3 (3.71) | 3.39801E-46 | 0.98 |
| DIFRES 4 SIN 105 | PE | 5 578 | 2 735 | 106.5 (1.20) | 104.4 (1.61) | 3.07453E-11 | 1.02 |
| DIFRES 4 SIN 75 | PE | 5 578 | 2 735 | 70.5 (1.51) | 68.8 (1.76) | 1.30332E-07 | 1.02 |
| DIFRES1,5 SIN | PA | 1 414 | 698 | 34.1 (0.67) | 30.5 (0.75) | 2.81792E-36 | 1.12 |
| DVZ 4 DBL | PE | 6 953 | 7 174 | 81.0 (3.01) | 81.7 (3.14) | 1.3624E-09 | 0.99 |
| DVZ 5 SIN | PE | 7 918 | 4 000 | 86.9 (1.90) | 86.9 (1.98) | 1 | 1.00 |
| DVZ 1,2 SIN | PA | 812 | 406 | 21.5 (0.72) | 18.7 (0.77) | 4.16334E-36 | 1.15 |
| IMR-N 3,2 TRI | PE | 4 733 | 7 950 | 135.2 (2.16) | 142.2 (2.03) | 4.23493E-27 | 0.95 |
| IMR-N 5 DBL | PE | 14 463 | 13 900 | 137.7 (2.99) | 147.1 (2.60) | 6.38877E-28 | 0.94 |
| IMR-IS 6 DBL | PE | *10 800* | 10 800 | 134.1 (3.37) | 140.8 (3.56) | 1.95891E-29 | 0.95 |
| IMR-N 7,1 UC | PE | 21 020 | 10 600 | 133.2 (0.81) | 138.7 (0.80) | 2.287E-46 | 0.96 |
| IMR-N 10,8 UC | PE | 59 545 | 26 750 | 133.7 (1.28) | 143.1 (1.12) | 1.06979E-46 | 0.93 |
| IMR-N 8 DBL | PA | 15 520 | 15 400 | 136.8 (2.03) | 146.6 (2.09) | 1.84219E-43 | 0.93 |
| IMR-S 3,5 SIN | PE | 3 883 | 1 957 | 71.6 (1.38) | 71.0 (1.48) | 6.85818E-07 | 1.01 |
| IMR-S 4 SIN | PE | *5 400* | 2 700 | 107.1 (1.27) | 106.1 (0.99) | 2.23951E-12 | 1.01 |
| IMR-S 1,5 SIN | PA | 1 450 | 816 | 37.0 (0.57) | 35.6 (0.66) | 4.74876E-18 | 1.04 |
| MARLAB 3 SIN | PE | 4 077 | 2 030 | 68.6 (2.78) | 68.0 (2.62) | 1.68884E-06 | 1.01 |
| MARLAB 5 SIN | PE | 13 830 | 6 816 | 74.7 (1.73) | 78.8 (2.05) | 3.85695E-32 | 0.95 |
| MARLAB 6 DBL | PE | 14 467 | 14 225 | 99.5 (2.19) | 104.3 (2.72) | 1.59198E-31 | 0.95 |
| MDMF 6 DBL | PE | 13 333 | 12 813 | 149.8 (3.19) | 158.3 (3.21) | 2.27534E-41 | 0.95 |
| MDMF 8 SIN | PE | 27 028 | 12 255 | 184.6 (4.68) | 191.2 (4.98) | 8.78829E-32 | 0.97 |
| RIVO 4 DBL | PE | 5 998 | 5 200 | 75.2 (2.24) | 77.0 (2.61) | 1.79107E-18 | 0.98 |
| RIVO 6 DBL | PE | 11 068 | 12 500 | 76.6 (3.60) | 83.5 (3.50) | 1.41865E-29 | 0.92 |
| RIVO 2 SIN | PA | 2 650 | 1 225 | 37.8 (0.98) | 36.6 (1.06) | 8.3824E-27 | 1.03 |
| RIVO 2 DBL | PA | 2 650 | 2 450 | 35.2 (1.27) | 34.7 (1.14) | 0.00206892 | 1.01 |

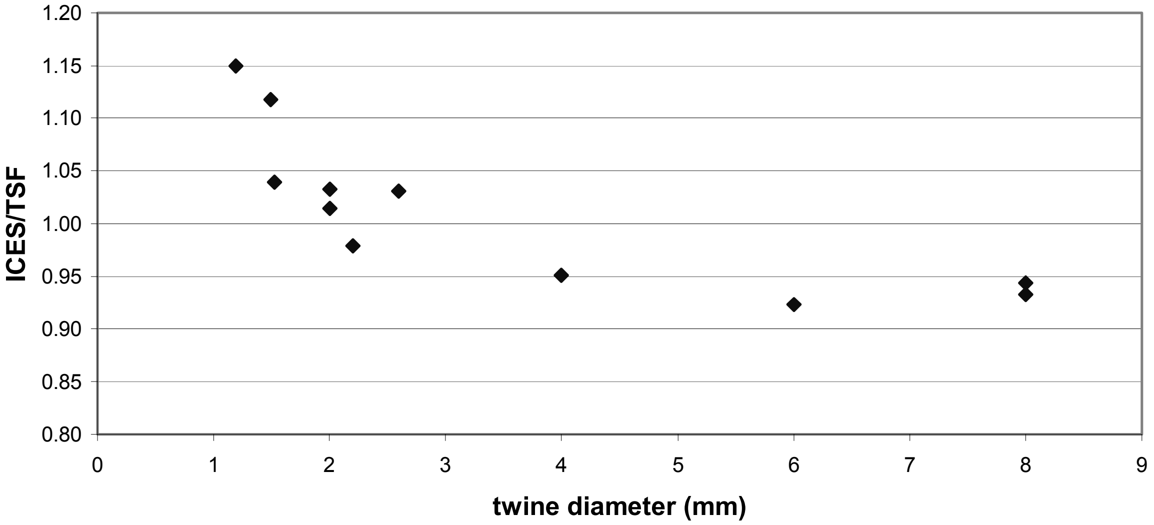


Figure 10. Ratio ICES/TSF in relation to the twine thickness for all PA nettings.

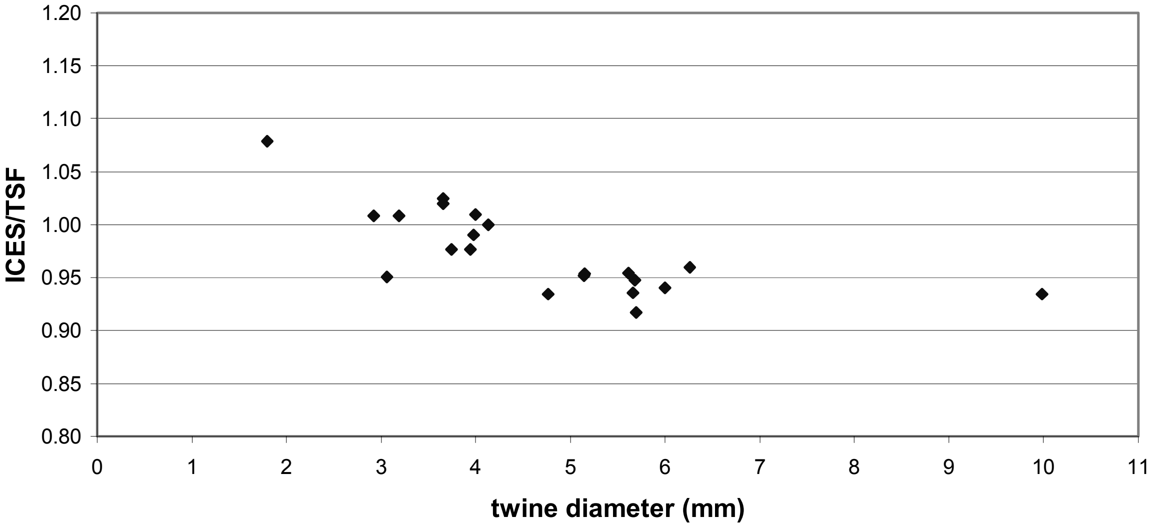


Figure 11. Ratio ICES/TSF in relation to the twine thickness for all PE nettings.

For PE nettings the upper group in the plot includes the samples from 1.8 mm single twine to 4.1 mm single twine. The lower group consists of the samples from 3.7 mm double (equivalent of 5.2 mm single) to 5.6 mm double twine (equivalent of 8.5 mm single).

*Mesh measurements with 10 and 13 kgf longitudinal measuring forces*

The average mesh openings obtained with 10 and 13 kgf measuring forces are given in Table 6. For reasons explained in Section 5.2, these measurements were only performed on the netting samples with a mesh opening > 55 mm.

The results from all measurements made with a longitudinal force (i.e. ICES 4 kgf, TSF, 10 and 13 kgf) were used to calculate for each sample the stretching force needed to obtain the same mesh opening as obtained with the wedge gauge, either operated by hand or with a 5 kgf weight. To make these calculations a linear relationship between mesh opening and measuring force was assumed. An example is given in Figure 14. A linear regression was calculated and by substituting the mesh opening from the wedge gauge measurements the “equivalent longitudinal force” was obtained. The results for all netting samples are given in Table 13.

Data variables: Var = (ICES – TSF)/TSF
RtexT= Rtex x N of twines

Number of complete cases: 10

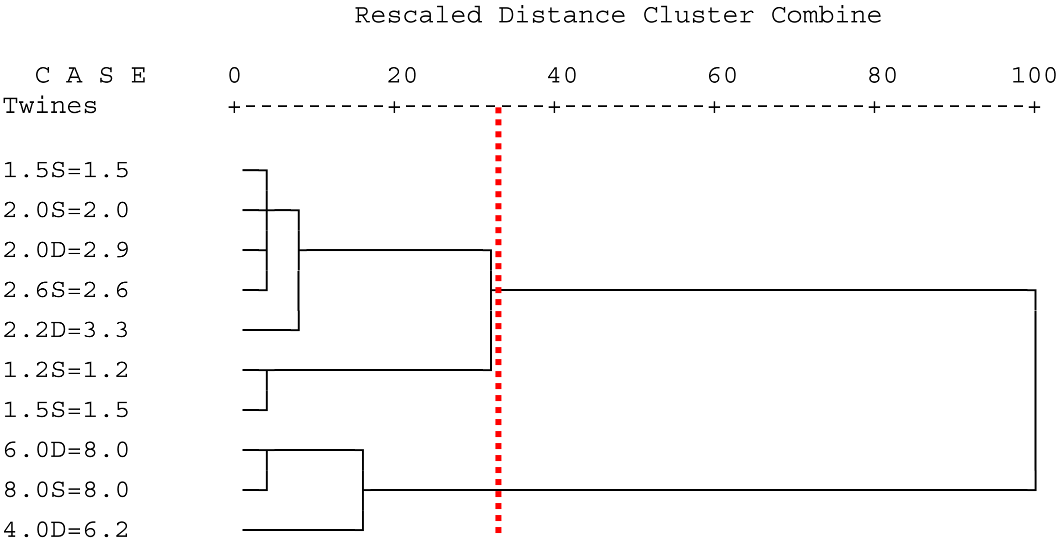


Figure 12. Hierarchical Cluster Analysis - Dendrogram for the PA netting samples.

The equivalent longitudinal force showed a great variability with 2.9 kgf as a minimum and 21.1 kgf as maximum value for the hand operated wedge gauge. Surprisingly the wedge gauge used with a 5 kg weight showed the same range of variability (3.5 kgf – 21.9 kgf).

The histograms in Figures 15 and 16 show the occurrence of the calculated longitudinal forces equivalent to the wedge gauge hand force and the wedge gauge 5 kgf respectively for all samples. The histogram based on the wedge gauge with 5 kgf force shows two peaks, one at 4-6 kgf and one at 8-10 kgf, in contrast with one peak at 10-12 kgf for the wedge gauge with hand force.

The occurrence of equivalent forces, for both wedge hand force and wedge with a 5 kg weight, covering 10, 11, 12, 13 and 15 kgf are presented in Table 14, together with median and mean for each case. As most large mesh codends (>55 mm) are made of PE yarns results for PE netting samples only are given separately.

The relationship between measurements made with longitudinal measuring forces of 10 kgf (Mesh10) and 4 kgf (ICES4) is dealt with in Annex 1.

The simplest model does not take account of the parameters linear density, twine thickness and netting material:

Mesh10KGF=11.440+0.8984*ICES4KGF+0.00034*ICES4KGF^2 (3)

Taking account of the twine thickness and netting material the model becomes:

Mesh10KGF=4.551+0.8977*ICES4KGF+0.0000334*ICES4KGF^2+8.6544*Mat+1.0265*dia-1.3297*mat*dia (4)

in which dia = twine thickness and ma t= 0 for PE and mat = 1 for PA.

By including the linear density and netting material the model now becomes:

Mesh10KGF=8.0499+0.8858*ICES4KGF+0.000414*ICES4KGF^2+5.01989*Mat+0.000114*Rtex-0.000217*Mat*Rtex (5)

The model using the twine thickness gives the best fit, but it is believed that for practical purposes the two models perform equally well.

## 5.5 Discussion

In general the nominal values of the twine thicknesses do not correspond well with the measured values. A similar result was obtained for the linear density: measured values tend to be larger than the nominal values. Unfortunately there is no uniformity in the determination of the linear density of netting twines and this makes it difficult to compare different values. According to ISO, netting yarns should be designated in the Tex System (Anon., 1973) but this system is rarely used by the netting industry.

Data variables: Var = (ICES – TSF)/TSF
RtexT= Rtex x N of twines

Number of complete cases: 20

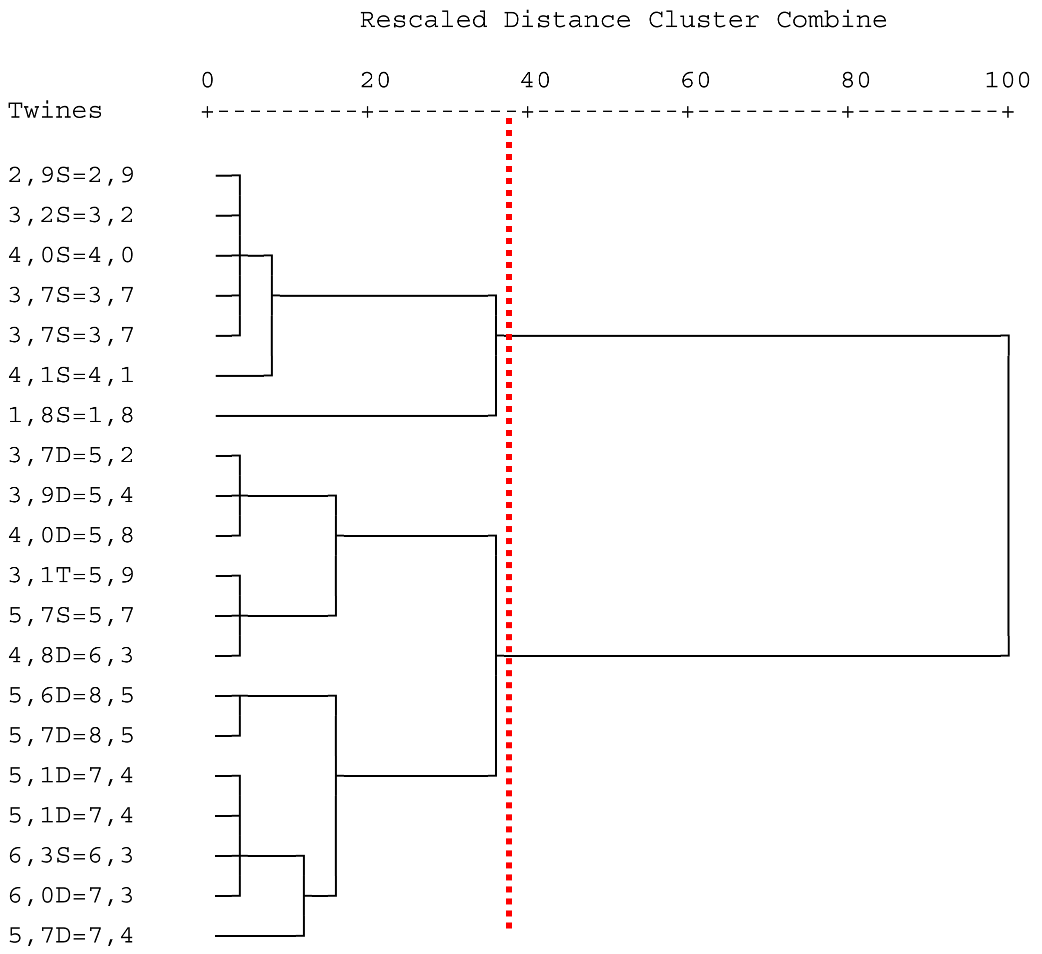


Figure 13. Hierarchical Cluster Analysis - Dendrogram for the PE netting samples

Other designations, such as the runnage (metres per kilogram) or the twine thickness are more frequently used. As a consequence care should be taken when using nominal values of twine thickness or linear density as a basis to calculate the pre-tension (i.e. the TSF) in certain tests (e.g., determination of elongation of netting yarns). Good correlation was found between the linear density and twine thickness and the formulas (1) and (2) can be used to convert one parameter to the other.

From the measurements with current mesh gauges and measuring forces on the netting samples with large meshes it was found that the mesh opening obtained with the ICES 4 kgf gauge is lower than wedge gauge measurements, whether they are made with hand force or a 5 kg weight. The difference is statistically significant. These conclusions confirm the results from earlier comparative studies (e.g., Ferro and Xu, 1996; Fonteyne *et al.,* 1998). The wedge gauge with a 5 kg weight is known to give smaller mesh openings than when operated by hand force (Fonteyne *et al.,* 1998). In the present series of measurements this difference was true for most netting samples but for seven samples the wedge gauge operated with a 5 kg weight yielded larger mesh openings. The difference between both methods was not significant. It is reasonable to assume that the latter results are biased by human influences when measuring with the wedge gauge by hand. An analysis of the forces exerted on the netting twines when using the wedge gauge showed a large variability for both hand force and the 5 kg weight. Differences in the value of the friction coefficient (between netting material and the wedge gauge) may also have played a role.

The small mesh netting samples gave a less clear picture for all three methods. The differences between methods was often quite large but without clear trends in the data. Former comparative mesh measurement studies on this type of nettings are unknown.

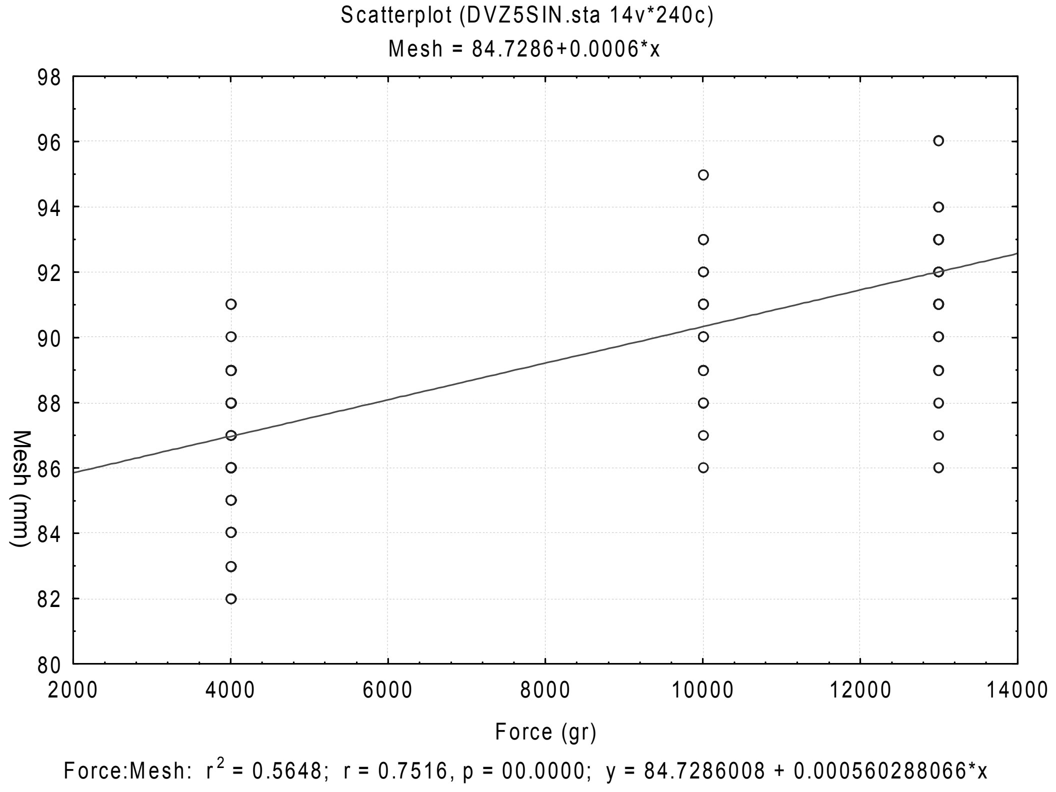


Figure 14. Linear relationship between mesh opening and measuring force (sample DVZ 5 SIN).

The standard deviation of the measured values differed from one sample to another, but seemed to be independent of the measurement method used. This result confirms the conclusion made by Ferro and Xu (1996) that the variance is caused less by the method and more by the characteristics of the netting and twine, e.g., variation in mesh size due to manufacture.

The hypothesis that the ICES gauge with a 4 kgf measuring force, compared with the Textile Standard Force, would overestimate the mesh opening of netting samples with small twine thicknesses and underestimate netting samples with large twine thicknesses proved to be true. This finding was to be expected since a 4 kgf measuring force corresponds to a TSF for netting made of single twine with a linear density of R8000tex. Consequently this force is too low to stretch modern netting made of heavier, often double, twines.

The measuring principle of the wedge gauge is based on a perpendicular measuring force transformed by the action of a wedge into a longitudinal force, which stretches the mesh to be measured. As set out in Section 5.2 a 5 kg weight attached to a wedge gauge with a taper of 1:8 will theoretically exert a longitudinal stretching force of 20 kgf, assuming that there is no friction between gauge and netting. The calculations of the longitudinal force exerted by a wedge gauge on the mesh showed a very large variation, apart from whether hand force or the 5 kg weight was used. This variation can be attributed to the human element, friction between gauge and netting and deviations from the vertical position of the gauge (Schwalbe and Werner, 1977; Post, 1987). The resulting longitudinal force may also have been influenced by movements of the netting and/or the mesh gauge with the attached weight. The results of the measurements made in the present study confirm the proposition that this instrument is unsuitable for scientific measurements of the opening of mesh. The international standard for the measurement of the opening of mesh (Anon., 2003c) makes severe reservations for the use of the instrument in non-laboratory conditions (see also Section 3.5). Recently the use of the wedge gauge for fisheries inspection has also been questioned from a legal point of view (Fonteyne *et al.,* 2002).

The ICES gauge uses a fixed longitudinal force to stretch the mesh and minimises human influence and effects of friction between gauge and netting. The Study Group was of the opinion that this principle should be maintained. The comparison with the Textile Standard Force showed that a 4 kgf measuring force is too small for modern netting. Ideally the measuring force should be related to the linear density or twine thickness of the netting material. However, such a methodology is impractical due to the difficulties related to the measurement of linear density and/or twine thickness, especially at sea. Nominal values are often imprecise and should not be used without verification. Furthermore, absorption of sediments in the netting of bottom trawls will change their physical dimensions with time. The present study justifies making a distinction between small mesh netting, made of thin twines and large mesh netting made of heavier twines. For the reasons set out above a division based on linear density or twine thickness is inappropriate. The international standard EN ISO 16663 (Anon., 2003c) set a division between small and large meshes

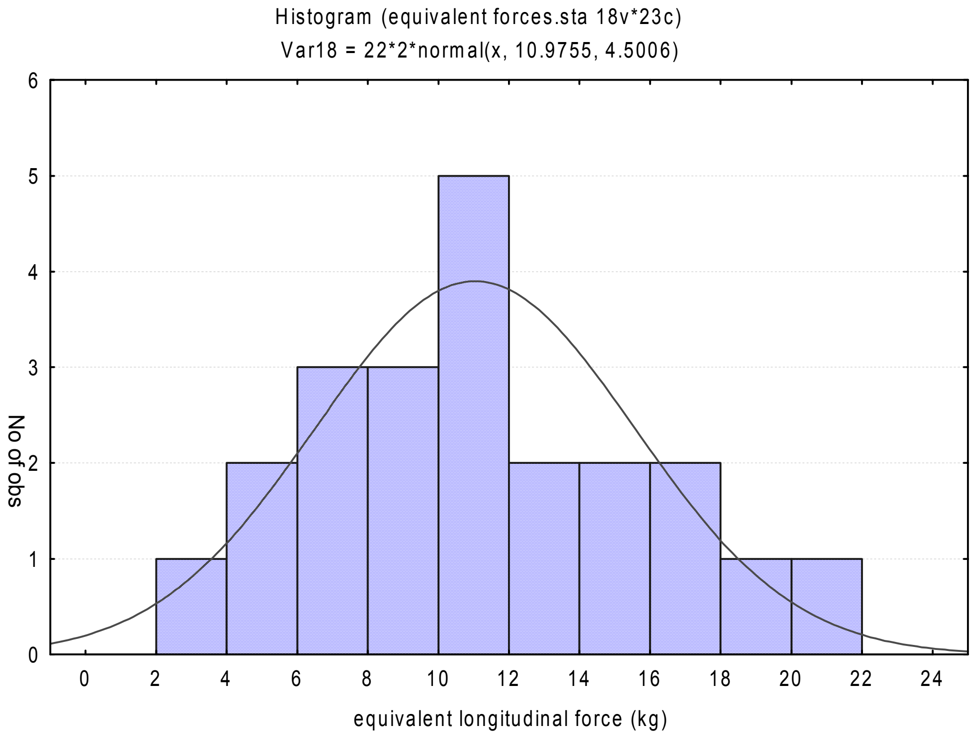


Figure 15. Occurrence of calculated longitudinal forces equivalent to wedge gauge hand force – all samples.

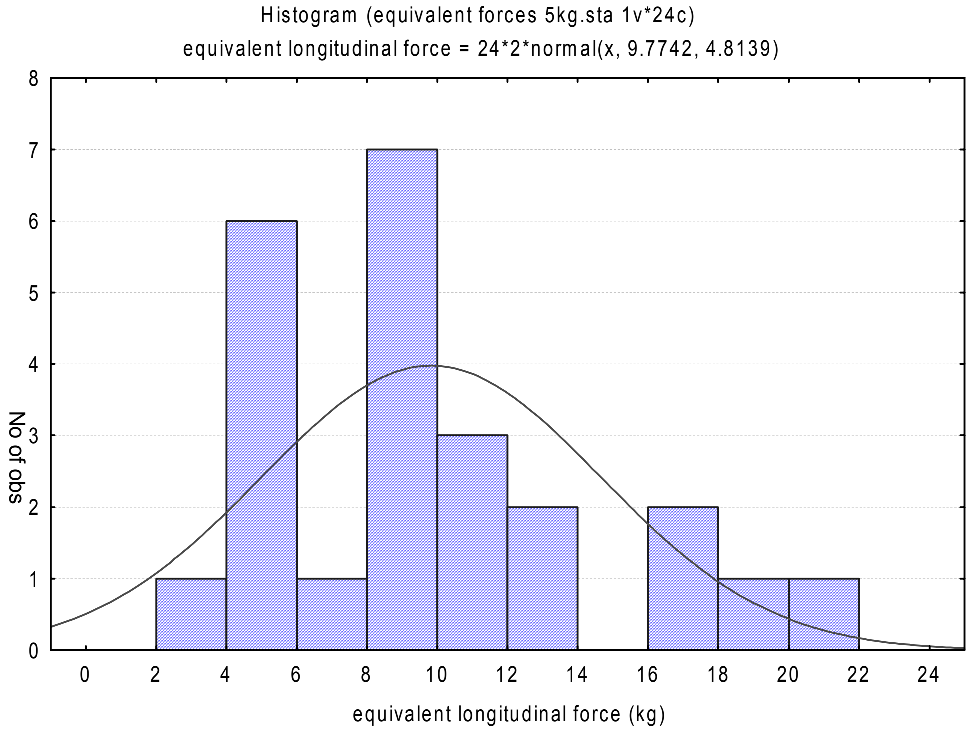


Figure 16. Occurrence of calculated longitudinal forces equivalent to wedge gauge 5 kgf – all samples.

Table 13. Longitudinal forces needed to obtain wedge gauge average mesh sizes.

| | | Equivalent Force (kgf) | |
|---|---|---|---|
| Sample | Material | Wedge hand | Wedge 5 kgf |
| BFAFi 4 DBL | PA | -16.89 | -0.75 |
| BFAFi 6 DBL | PA | 5.25 | 5.4 |
| BFAFi 8 SIN | PA | 2.91 | 3.5 |
| DFO 4 DBL | PE | 11.3 | 9.83 |
| DFO 5 DBL | PE | 21.08 | 18.23 |
| DFO 5,5 DBL | PE | 16.11 | 17.5 |
| DFO 6 DBL | PE | 11.51 | 17.13 |
| DIFRES 4 SIN 105 | PE | 12.29 | 9.60 |
| DIFRES 4 SIN 75 | PE | 14.66 | 9.58 |
| DVZ 4 DBL | PE | 12.42 | 10.02 |
| DVZ 5 SIN | PE | 10.29 | 8.12 |
| IMR-N 3,2 TRI | PE | 9.65 | 5.23 |
| IMR-N 5 DBL | PE | 7.11 | 5.71 |
| IMR-IS 6 DBL | PE | 6.92 | 5.00 |
| IMR-N 7,1 UC | PE | 8.73 | 6.50 |
| IMR-N 10,8 UC | PE | 6.54 | 4.81 |
| IMR-N 8 DBL | PA | 5.79 | 4.23 |
| IMR-S 3,5 SIN | PE | 8.53 | 10.75 |
| MARLAB 3 SIN | PE | 10.47 | 9.40 |
| MARLAB 5 SIN | PE | 10.72 | 8.62 |
| MARLAB 6 DBL | PE | 16.16 | 10.05 |
| MDMF 6 DBL | PE | | 21.90 |
| MDMF 8 SIN | PE | | 9.33 |
| RIVO 4 DBL | PE | 14.71 | 12.03 |
| RIVO 6 DBL | PE | 18.10 | 12.11 |

Table 14. Occurrence of equivalent longitudinal forces with respect to longitudinal measuring forces in the range 10–15 kgf.

All samples

| | | Measuring Forces | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 10 kgf | 11 kgf | 12 kgf | 13 kgf | 15 kgf | Median | Mean |
| Equivalent force; wedge by hand | Numbers below | 41% | 55% | 64% | 73% | 82% | 10.6 | 11.0 |
| | Numbers above | 59% | 45% | 36% | 27% | 18% | | |
| Equivalent force; wedge 5 kgf | Numbers below | 63% | 75% | 75% | 83% | 83% | 9.5 | 9.8 |
| | Numbers above | 37% | 25% | 25% | 17% | 17% | | |

PE samples only

| | | Measuring Forces | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 10 kgf | 11 kgf | 12kgf | 13 kgf | 15 kgf | Median | Mean |
| Equivalent force; wedge by hand | Numbers below | 32% | 47% | 58% | 68% | 79% | 11.3 | 12.0 |
| | Numbers above | 68% | 53% | 42% | 32% | 21% | | |
| Equivalent force; wedge 5 kgf | Numbers below | 57% | 71% | 71% | 81% | 81% | 9.6 | 10.5 |
| | Numbers above | 43% | 29% | 29% | 19% | 19% | | |

at 50 mm using existing wedge gauges. European legislation related to twine thickness applies to netting of mesh size of 55mm and above. With a view to a future standardization between methodologies for science and inspection, the Study Group supports 55 mm as a borderline. The decision, for inspection purposes, on whether the meshes to be measured should be regarded as smaller or larger than 55 mm depends on the legislation on regulated mesh sizes for specified target species and on any declaration by the skipper concerning the species he is targeting.

As already mentioned in Section 5.2, the Study Group postulated that the transition to the use of a new measuring force should not be detrimental to codend selectivity and therefore should deliver results similar to the present procedures set down in technical measures legislation. Ferro and Xu (1996) suggested that a force of at least 8 kgf is required to achieve similar mesh openings in dry PE netting to a wedge gauge with a 5 kg weight, but this relationship was based on much thinner twines. Table 14 suggests that appropriate values for the longitudinal measuring force would be closer to 10 kgf if based on the wedge gauge with 5 kgf and 11 kgf if based on the wedge gauge with hand force. Fisheries inspectorates consider the wedge gauge with a 5 kg weight as the reference and this was also the opinion of the Study Group in the light of present conservation concerns. Taking further into account that the difference between 10 and 11 kgf would be minimal and that most existing selectivity data are based on measurements with the ICES gauge, which uses only 4 kgf measuring force, the Study Group agreed on 100 N (10.197 kgf) as the value for the new measuring force. The imposition of a 100 N measuring force may well result in some existing codends becoming illegal, and having to be removed from their respective fisheries. Based on the outcome of the measurements made in the present study, about 30% of the codends that pass the inspection with the hand operated wedge gauge will become illegal if the new force is used. This theoretical number is raised to 40% if the wedge gauge with a 5 kg weight is taken as a reference. In practice, codends are usually constructed from webbing with mesh sizes at least slightly larger than the minimum mesh size, as a prudent measure. Hence, the percentage of codends that will need to be replaced will be lower than suggested here.

The measuring force proposed for meshes less than 55 mm opening of mesh is 40 N (4.079 kgf). This choice is mainly based on theoretical assumptions. For the moment a 2 kg weight is used by inspectors for the measurement of small meshes using a wedge gauge. A 1:8 taper will convert this weight into an 8 kgf longitudinal force. It is reasonable to allow for a 50% reduction for friction forces as was done for a 5 kg weight. There were not enough measured netting samples to demonstrate this conclusively but a 40 N measuring force would retain the status quo with no detriment to selectivity.

The proposed measuring force of 100 N cannot be exerted by the present ICES gauge. The Study Group was notified that a new measuring gauge is being developed with a capacity of 150 N in the EU shared cost OMEGA project Q5CO-2002-01335, but this instrument will not be available until 2005. It was recommended that in the meantime for scientific work the ICES gauge with 4 kgf measuring force be used but the results should be converted to 100 N using conversion formulae (3), (4) or (5) given in Section 5.4.

# 6 Conclusions

The Study Group on Mesh Measurement Methodology formulated its response to the general Terms of Reference at its final meeting:

a) Advise on improvements and further standardizsation of current mesh measurement practices in view of the netting types now in use in ICES Member Countries

The Study Group recommends that all parties concerned should adhere to the specification of a suitable mesh measurement methodology set out in Term of Reference e) below, whether they are scientists, inspectors, netting manufacturers, net makers or fishermen. As advice derived from selectivity data determines mesh size regulations, it is logical that all stakeholders should use the same system of mesh measurement.

Until an instrument capable of making objective measurements, not subject to human influence, becomes widely available the Group recommends that for scientific purposes the existing ICES gauge with 4 kgf measuring force should continue to be used. In this interim period one of the following conversion formulas should be applied:

- when both the linear density and the netting material are known

Mesh10KGF=8.0499+0.8858*ICES4KGF+0.000414*ICES4KGF^2+5.01989*Mat+0.000114*Rtex-0.000217*Mat*Rtex

- when the twine thickness and netting material are known

Mesh10KGF=4.551+0.8977*ICES4KGF+0.0000334*ICES4KGF^2+8.6544*Mat+1.0265*dia-1.3297*mat*dia.

In these expression “dia” is the twine thickness and Mat = 0 for PE and Mat = 1 for PA.

- when the value of these parameters is unknown

Mesh10KGF=11.440+0.8984*ICES4KGF+0.00034*ICES4KGF^2.

These expressions deliver a mesh opening equivalent to that obtained using a longitudinal force of 100N. It should be noted that the conversion is based on the measurements with the ICES gauge with 4 kgf and 10 kgf measuring forces. 10 kgf corresponds to 98.07 N which is slightly lower than the proposed 100 N measuring force. This difference is considered insignificant for mesh measurements.

For inspection purposes use of the wedge gauge with 5 kg weight must continue until the necessary changes are made to regulations.

The Study Group also recommends that the same methods and conditions should be used for all areas of the gear as well as attachments, although this uniformity will not always be possible, e.g., for lifting bags with a limited number of meshes available for measurement. In some circumstances a certain amount of discretion will be required.

b) Consider whether the current definition of mesh size is still appropriate for scientific and industrial purposes

The Study Group considers the current definition of mesh size appropriate for scientific and industrial purposes. The Study Group agrees with the definition in the European Standard EN ISO 1107 standard on basic terms and definitions for fishing nets (Anon., 2003a). This standard defines the mesh opening for knotted netting as the longest distance between two opposite knots in the same mesh. This definition eliminates the difficulty encountered with the measurement of netting with large knots.

c) Compile an inventory of commercially available netting associated with the selectivity process, identifying the fisheries in which they are used

The inventory is presented in Table 1.

d) Consider the need to define groups of netting types for which the same measurement conditions (e.g., tension) can be applied

Ideally the measuring force for a specific netting twine should be related to the linear density. Alternatively twine thickness can be used to determine linear density using the relationships (1) or (2) in Section 5.4. However, both linear density and twine thickness can only be measured accurately under laboratory conditions. Since mesh measurements are generally carried out at sea, values of the linear density or the twine thickness are not easily obtainable. The measurements of linear density and twine thickness made by the Study Group indicated that nominal values are insufficiently precise. Therefore the Study Group is of the opinion that the best option is to base the mesh measuring force on single values for smaller and larger meshes. Based on mesh measurement data analysis and present legislation, a mesh opening of 55 mm is considered as the most appropriate value to separate these mesh size groups.

e) Propose the specification of a suitable mesh measurement methodology and the conditions under which mesh measurements for all fishing gears in ICES areas are made

The Study Group recommends:

1) A longitudinal force of either 40 or 100 N must be used, depending on whether the mesh opening is smaller than 55 mm or equal or larger than 55 mm. The decision, for inspection purposes, on whether the meshes to be measured should be regarded as smaller or larger than 55 mm depends on the legislation on regulated mesh sizes for specified target species and on any declaration by the skipper concerning the species he is targeting.

2) For scientific purposes a minimum of 40 meshes is required to be measured.

   For fisheries inspections the numbers of meshes to be measured may remain at 20 and 60 (as set out in e.g., Anon., 2003b).

3) When measuring codends or extensions care must be taken to observe previous recommendations (Wileman *et al.,* 1996; Anon., 2003b) with regard to nearness of selvedges, mendings, etc. For scientific purposes it is recommended that two rows of 20 meshes should be measured in an area where fish are known to escape, e.g., aft upper part of codend when targeting roundfish.

4) State whether netting is measured in a wet or dry state.

5) Meshes must be unfrozen.

6) For scientific work the area measured must be clean and as free from sediment as possible. For inspection such matters are left to the discretion of Fisheries Inspectors.

7) Netting must be stretched in the direction of the long diagonal of the meshes (as per Anon., 2003b).

8) Square mesh netting will be measured on the longest diagonal (as per Anon., 2003b).

9) 90° turned netting will be measured on the longest diagonal.

# 7 References

Anderberg, M. R. 1973. Cluster Analysis for Applications. Academic Press, Inc. New York.

Anon. 1966. I.C.E.S. Mesh Gauge. Observator, Rotterdam.

Anon. 1973. International Standard ISO 858. Fishing nets – Designation of netting yarns in the Tex System. Ref. No. ISO 858–1973 (E).

Anon. 1974. International Standard ISO 3090. Netting yarns – Determination of change in length after immersion in water. Ref. No. ISO 3090–1974 (E).

Anon. 1976. International Standard ISO 3790. Netting yarns – Determination of elongation of netting yarns. Ref. No. ISO 3790–1976 (E).

Anon. 1999. SPSS for Windows. SPSS Inc, Chicago.

Anon. 2000a. Commission Regulation (EC) No 2549/2000 of 17 November 2000 establishing additional technical measures for the recovery of the stock of cod in the Irish Sea (ICES area VIIa). Official Journal of the European Communities No L 292 / 5–6.

Anon. 2000b. PREMECS: Development of predictive model of codend selectivity. Final report FAIR study Contract FAIR-CT96–1555.

Anon. 2001a. Commission Regulation (EC) No 1162/2001 of 14 June 2001 establishing measures for the recovery of the stock of hake in ICES sub-areas III, IV, V, VI and VII and in ICES divisions VIIIa, b, d, e and of the connected regulations for the control of the activities of fishing vessels. Official Journal of the European Communities No L 159/4–9.

Anon. 2001b. Commission Regulation (EC) No 2056/2001 of 19 October 2001 establishing additional technical measures for the recovery of the stocks of cod in the North Sea and to the west of Scotland. Official Journal of the European Communities No L 277/13–16.

Anon. 2001c. Council Regulation (EC) No 2555/2001 of 18 December 2001 fixing for 2002 the fishing opportunities and associated conditions for certain fish stocks and groups of fish stocks, applicable in Community waters and, for Community vessels, in waters where limitations in catch are required. Official Journal of the European Communities No L 347/1–102.

Anon. 2002. Proposal for a Council Regulation for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms. COM(2002) 672 final.

Anon. 2003a. European Standard EN ISO 1107 Fishing nets – Netting – Basic terms and definitions (ISO1107:2003).

Anon. 2003b. Commission Regulation (EC) No 129/2003 of 24 January 2003 laying down detailed rules for determining the mesh size and thickness of twine of fishing nets. Official Journal of the European Communities No L 122/5–14.

Anon. 2003c. EN ISO 16663-1. Fishing nets – Method of test for the determination of mesh size - Part 1: Opening of mesh (ISO 1663–1:2003).

Anon. 2003d. EN ISO 16663-2. Fishing nets – Method of test for the determination of mesh size - Part 2: Length of mesh (ISO 1663–2:2003).

Caruso, P. G. and Carr, H. A. 1991. Comparative Testing of the Marfish Gauge, Weighted Wedge Gauge and Spring Wedge Gauge. Massachussetts Division of Marine Fisheries.

Ferro, R. S. T. 1983. Report by the Study Group on twine thickness measurement. ICES CM 1983/B:26.

Ferro, R. S. T. 1989. Objective measurement of the thickness of netting twine used in the fishing industry. Fisheries Research, 8: 103–112.

Ferro, R. S. T. and O'Neill, F. G. 1994. An overview of the characteristics of twines and netting that may change codend selectivity. ICES CM 1994/B:35.

Ferro, R. S. T. and Xu, L. 1996. An investigation of three methods of mesh size measurement. Fisheries Research, 25:171–190.

Fonteyne, R., Link, U., Stewart, P., and Ward, N. 1998. Evaluation of mesh measurement methodologies for fisheries inspection and research. Final report FAIR study Contract FAIR-CT96–1452.

Fonteyne, R., ten Have, H., and Stewart, P. 2002. Creating the conditions for a combined R&D and Demonstration Project for the development of an objective mesh gauge (PREMEGADEV). Final Report Accompanying Measure Project, Fifth Framework Programme – Quality of Life and Management of Living Resources, Contract No Q5AM–2000–00005.

Hovart, P. 1985. Zeevisserijbeheer in vroegere eeuwen. Mededelingen van het Rijksstation voor Zeevisserij, Publikatie nr. 206.

ICES. 1962a. Procés-Verbal de la Réunion 1961. Conseil Permanent International pour l'Exploration de la Mer. Recommendation B(2). pp.62–63.

ICES. 1962b. Prospectus of the I.C.E.S. Mesh Gauge. Conseil Permanent International pour l'Exploration de la Mer.

ICES. 1964. Report of the Mesh Selection Working Group, 1959–1960. Cooperative Research Report, International Council for the Exploration of the Sea, 2: 143–144.

ICES. 2000. Report of the Study Group on Mesh Measurement Methodology. ICES CM 2000/B:2.

ICES. 2002. Report of the Study Group on Mesh Measurement Methodology. ICES CM 2002/B:2.

Klust, G. 1982. Netting materials for fishing gears (2nd edition). FAO Fishing Manuals. Fishing News Books Ltd. Farnham.

Lowry, N. and Robertson, J. H. B. 1996. The effect of twine thickness on codend selectivity of trawls for haddock in the North Sea. Fisheries Research, 26:353–363.

O'Neill, F. G. 2003. A theoretical study of the factors which influence the measurement of fishing netting mesh size. Ocean Engineering 30: 2053–2063.

Post, H. 1987. Investigation into fishing nets and methods for measuring the mesh size. Netherlands Organisation for Applied Scientific Research. TNO Report No. 2066494/001.

Reeves, S. A., Armstrong, D. W., Fryer, R. J., and Coull, K. A. 1992. The effect of mesh size, codend extension and codend diameter on the selectivity of Scottish trawls and seines. ICES Journal of Marine Science, 49: 279–288.

Schwalbe, W. and Werner, M. 1977. Zur Problematik der Maschenöffnungsmessung an Netztuchen und des Trennversuches an PVC-Planenschichtstoffen. Technische Textillien 20(1977) 4:77–82.

Wileman, D. A., Ferro, R. S. T., Fonteyne, R., and Millar, R. B. 1996. Manual of methods of measuring the selectivity of towed fishing gears. ICES Cooperative Research Report, 215.

# 8 List of participants

**IJmuiden Meeting (2000)**

| | |
|---|---|
| R. Fonteyne, *Chair* | Belgium |
| D. Galbraith, *Rapporteur* | UK |
| K. Gamst | Norway |
| W. Hickey | Canada |
| B. Isaksen | Norway |
| K. Lange | Germany |
| P.-O. Larsson | Sweden |
| B. van Marlen | The Netherlands |
| P. Stewart | UK |

**Seattle Meeting (2001)**

| | |
|---|---|
| G. Brothers | Canada |
| A. Carr | USA |
| E. Dahm | Germany |
| R. Fonteyne, *Chair* | Belgium, |
| D. Galbraith, *Rapporteur* | UK |
| J. Gramaxo | Portugal |
| B. Isaksen | Norway |
| P.-O. Larsson | Sweden |
| T. Moth-Poulsen | Denmark |
| B. van Marlen | The Netherlands |
| M. Pol | USA |

**Sète Meeting (2002)**

| | |
|---|---|
| G. Cosimi | Italy |
| E. Dahm | Germany |
| R. Fonteyne, *Chair* | Belgium |
| D. Galbraith, *Rapporteur* | UK |
| K. Gamst | Norway |
| J. Gramaxo | Portugal |
| B. Isaksen | Norway |
| P.-O. Larsson | Sweden |
| I. Leonori | Italy |
| T. Moth-Poulsen | Denmark |
| B. van Marlen | The Netherlands |
| M. Pol | USA |
| E. Puente | Spain |
| A. Sala | Italy |

**Ostend Meeting (2003)**

| | |
|---|---|
| G. Buglioni | Italy |
| I. Craig | UK |
| E. Dahm | Germany |
| R. Fonteyne, *Chair* | Belgium, |
| D. Galbraith, *Rapporteur* | UK |
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| P. de Graaf | The Netherlands |
| J. Gramaxo | Portugal |
| H. ten Have | The Netherlands |
| W. Hickey | Canada |
| J. del Hierro | Spain |
| B. Isaksen | Norway |
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| B. O'Shea | European Commission |
| S. Petre | Sweden |
| H. Polet | Belgium |
| L. Schach | France |
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| P. Stewart | UK |
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# Annex 1: Analysis of data obtained within the ICES SGMESH

*by*

*René Holst*
*ConStat*

**Objectives**

The analyses presented in this report aim to address the following questions:

- Compare the three main methods "ICES" "WH" and "WW"
- Assess main factors affecting the mesh measurements and potential differences between the three main methods
- Find an appropriate conversion formula between "ICES" and "ICES10KGF"

**Data**

The data consist of measurements of mesh sizes conducted by a number of institutes each using 6 different methods (ICES, WW, WH, TSF, ICES10KGF and ICES 13KGF). The analysis will primarily focus on the first three methods. The response variable is consequently considered a vector with dimensions corresponding to the number of methods. Each institute measured a number of samples of netting and 60 meshes were measured from each sample. Each mesh was only measured once by each method. The same pieces of netting were not measured by the different institutes. In effect this forms a hierarchical structure of measurements of Mesh within Sample and Sample within Institute. The Method variable is called the primary covariate and Mesh, Sample and Institute are classification variables. In addition the data contain other variables:

| Name | Type | Explanation |
|---|---|---|
| Rtex | Continuous | A measurement of the twine-density |
| Diameter | Continuous | Twine diameter |
| NomMesh | Continuous | Nominal mesh size |
| Twine | Factor | SINGLE, DOUBLE, TRIPLE |
| Material | Factor | PA, PE |
| Construct | Factor | BRAIDED, TWISTED, KNOTLESS |

See the main-report for further explanation of these variables. These can all potentially be entered into models for assessing the variability in the response variables. See however the note below on multi-collinearity.

Data are separated into two groups:

- "SMALL": Nominal mesh size <= 55 mm
- "LARGE": Nominal mesh size > 55 mm

The separate analysis of the two groups is motivated by the fact that they are essentially composed of different materials. Since the material is suspected to influence the measurements it would not make much sense to combine measurements from the two groups.

It could be considered to conduct a combined analysis of the two groups, in which interaction effects allow for differences between the two, wherever deemed relevant or necessary.

*SMALL*

Twine: single

| *Institute* | *braided* | *twisted* | *knotless* |
|---|---|---|---|
| BFAFi | 360 | 0 | 0 |
| DFO | 360 | 0 | 0 |
| DIFRES | 0 | 360 | 0 |
| DVZ | 0 | 360 | 0 |
| IMRIS | 0 | 0 | 0 |
| IMRNO | 0 | 0 | 0 |
| IMRS | 0 | 360 | 0 |
| MARLAB | 0 | 0 | 0 |
| MDMF | 0 | 0 | 0 |
| RIVO | 0 | 360 | 0 |

Twine: double

| *Institute* | *braided* | *twisted* | *knotless* |
|---|---|---|---|
| BFAFi | 360 | 0 | 0 |
| DFO | 0 | 0 | 0 |
| DIFRES | 0 | 0 | 0 |
| DVZ | 0 | 0 | 0 |
| IMRIS | 0 | 0 | 0 |
| IMRNO | 0 | 0 | 0 |
| IMRS | 0 | 0 | 0 |
| MARLAB | 0 | 0 | 0 |
| MDMF | 0 | 0 | 0 |
| RIVO | 0 | 360 | 0 |

There were no measurements of triple twine netting samples within the "SMALL" group and no samples made of knotless netting. It is seen that the data are unbalanced with the majority of measurements made on twisted single twine. There are very limited observations of both single and double twine with the same treatment within the same institute (only RIVO). No institute measured both "braided" and "twisted" and four institutes had no measurements at all in this group. Finally all nettings from the SMALL group were made of material of type PA (PolyAmide).

The analysis for this group will consequently be restricted to single twine, twisted PA netting samples. Only four institutes generated these data.

*LARGE*

Twine: single

| *Institute* | *braided* | *Twisted* | *knotless* |
|---|---|---|---|
| BFAFi | 360 | 0 | 0 |
| DFO | 0 | 0 | 0 |
| DIFRES | 720 | 0 | 0 |
| DVZ | 360 | 0 | 0 |
| IMRIS | 0 | 0 | 0 |
| IMRNO | 0 | 0 | 720 |
| IMRS | 720 | 0 | 0 |
| MARLAB | 720 | 0 | 0 |
| MDMF | 360 | 0 | 0 |
| RIVO | 0 | 0 | 0 |

Twine: double

| *Institute* | *braided* | *twisted* | *knotless* |
|---|---|---|---|
| BFAFi | 720 | 0 | 0 |
| DFO | 1440 | 0 | 0 |
| DIFRES | 0 | 0 | 0 |
| DVZ | 360 | 0 | 0 |
| IMRIS | 360 | 0 | 0 |
| IMRNO | 720 | 0 | 0 |
| IMRS | 0 | 0 | 0 |
| MARLAB | 360 | 0 | 0 |
| MDMF | 360 | 0 | 0 |
| RIVO | 720 | 0 | 0 |

Twine: triple

| *Institute* | *braided* | *twisted* | *knotless* |
|---|---|---|---|
| BFAFi | 0 | 0 | 0 |
| DFO | 0 | 0 | 0 |
| DIFRES | 0 | 0 | 0 |
| DVZ | 0 | 0 | 0 |
| IMRIS | 0 | 0 | 0 |
| IMRNO | 360 | 0 | 0 |
| IMRS | 0 | 0 | 0 |
| MARLAB | 0 | 0 | 0 |
| MDMF | 0 | 0 | 0 |
| RIVO | 0 | 0 | 0 |

Only one institute made measurements on triple twine and only on the "braided" type. Similarly only one institute made measurements on knotless netting. Single twine and double twine are both well represented. There were however only four institutes which took measurements on both. One institute only measured PA material. For this group the analysis will consequently be restricted to the braided netting of PE, single or double twine.

The total numbers of measurements distributed over institutes and twine-types is listed in the following table.

| *Institute* | *Single* | *Double* |
|---|---|---|
| BFAFi | 360 | 720 |
| DFO | 0 | 1440 |
| DIFRES | 720 | 0 |
| DVZ | 360 | 360 |
| IMRIS | 0 | 360 |
| IMRNO | 0 | 720 |
| IMRS | 720 | 0 |
| MARLAB | 720 | 360 |
| MDMF | 360 | 360 |
| RIVO | 0 | 720 |

## Statistical Models and Methods

*A statistical model for the data*

The modelling approach used here is commonly known as mixed effects models (or random effects models). See (Pinheiro and Bates, 2000) for a more quantitative description of the general modelling framework.

It is essential that a statistical model reflects the process by which the data has been sampled. To some extent the sampling process therefore drives the modelling. In particular it is important for proper inference that the model gives a realistic description of the random variation in the data.

For the present data the following assumptions and structures have been used:

Measurements of the meshes are assumed to be observations from independent normally distributed random variables. These are sampled in a hierarchical structure with 60 meshes measured from each of a number of samples of netting, each taken within a number of institutes. It is noted that the data are not balanced. The hierarchical structure of the random effects is presented as:

$$random\sim 1|Institute/Sample/Mesh$$

(read: Mesh within Sample, sample within institute and a random effect associated with each institute.) A variance component is associated with each level of this hierarchy. Variants of this structure can be argued (and will be used; see below) based on the data.

Another aspect of modelling concerns the objective of the analysis. In this respect the model is driven by the question which the analysis aims to answer. This is not always unambiguous and data sets may allow for a multitude of different models to be analysed. This part typically addresses the so-called fixed effects.

An example of the notation for the fixed effects part is:

$$fixed\sim Method+Rtex$$

with an obvious interpretation.

The data allow for a range of different models to be fitted. The variation of models mainly concerns the choice of fixed effects.

*A comment on fixed and random effects:*

Factors affecting the value of a response can be classified as either a fixed or a random effect. The actual choice is not un-ambiguous but depends on the question the analysis aims to answer. A factor for which the interest focuses on the effect of the actual levels will be classified as fixed. On the other hand a factor where the levels are not of specific interest, but (can be) considered a random sample from a larger population will be classified as a random effect. In other words a variable, which is suspected to influence the response but which is not of interest in itself, will be deemed random, provided its levels can be considered a random selection from a larger population.

For the particular case, consider the Institute variable. If the aim of a model is to describe the mesh size as provided by the various methods and to assess the levels and potential differences of the particular institutes represented in the data this variable would be considered a fixed effect. If however the particular institutes are of no interest by themselves, but merely considered a random selection from a larger population, the Institute variable would then be considered a random effect.

*A comment on multi-collinearity:*

Another ambiguous aspect of building a model is the selection of variables. Sometimes two or more background variables are strongly correlated, and hence essentially contain the same information about the variation in the data. Using more than one of these in a model leads to multi-collinearity: Overlap of information. Whenever one of them is included in the model, including another will not provide additional information to the model. The choice among the competing candidates depends on various issues: If one of the candidates can be considered the cause for the other it would be natural to choose this one. If however the interest is on assessing the effect of a particular variable, this one would obviously be chosen. In many cases there is however not an obvious preference to one of the candidates. The natural choice will then be to choose the one which provides the best fit. This can be determined by various statistics such as AIC (Akaike's Information Criterion) or BIC (Bayes Information Criterion). Both give preference to the model with smallest value of the statistics.

For this particular case, Rtex and dia are strongly correlated. There are no obvious reasons for choosing one in front of the other. Consequently this will be determined by the use of AIC and BIC.

### Results

The following sections contain a number of analyses, which aim to answer the questions described above. The focus has been on presenting the main results. Consequently intermediate models are described in less detail and results of model checks are omitted.

*Exploratory analysis*

Before addressing the particular questions of this analysis, it is of interest to do an exploratory analysis. This serves to provide an overview of the data and can help in guiding the subsequent modelling.

Plots of the mesh size measurements adjusted for nominal mesh size and grouped by Method obtain a first assessment of the variability in the data. These are given in Figures 1 and 2 for the SMALL and LARGE group respectively.

*SMALL*

The "ICES" and the "WH" methods appear to be similar in variation and with "WH" at a slightly higher level than the "ICES" method. The "WW" method seems to display a larger variation. All three methods seem to overestimate the mesh size in comparison with the nominal mesh size.

*LARGE*

The "ICES" method appears to be at a lower level than the two other methods and the plot indicates that this method measures below the nominal mesh size. The "WW" method seems to display a larger variation

These plots cover however the potential different levels at which the institutes measure. Figures 3 and 4 give the observed measurements grouped by Method and Institute. The larger variation within the "WW" group is now less apparent. Instead it is seen for groups that the Institute factor accounts for a considerable amount of the variation, both in levels and variation for the different methods.

A more quantitative assessment is provided by standard linear regressions for each institute. The two tables below give the estimated ratio of measurement to nominal mesh size.

*SMALL*

| | RIVO | DVZ | DIFRES | IMR-S |
|---|---|---|---|---|
| ICES | 1.081 | 1.1963 | 0.9748 | 1.0282 |
| WH | 1.0776 | 1.0139 | 0.9971 | 1.0551 |
| WW | 1.2143 | 1.1287 | 0.9343 | 1.0116 |

*LARGE*

| | RIVO | DVZ | MAR-LAB | DIFRES | IMR-S |
|---|---|---|---|---|---|
| ICES | 0.9257 | 1.0234 | 0.9937 | 0.989 | 1.0074 |
| WH | 1.0488 | 1.0662 | 1.0686 | 1.0297 | 1.0223 |
| WW | 1.0067 | 1.0533 | 1.045 | 1.0105 | 1.0568 |

| | IMR-IS | IMR-NO | DFO | MDMF |
|---|---|---|---|---|
| ICES | 0.9932 | 0.9977 | 0.9749 | 0.9771 |
| WH | 1.0165 | 1.0244 | 1.0039 | 1.0336 |
| WW | 1.0099 | 1.0145 | 1.0074 | NA |

The conclusions from these tables support the conclusions from the plots.

Plots of all combinations of factors continuous covariates and the response variable are given in Figures 5 and 6 for the SMALL and LARGE group respectively. A number of observations can be made from these figures and in particular from Figure 6 which present far more data:

- There is more overlapping of Nominal mesh sizes between the institutes for the "LARGE" data set than for the "SMALL" one.
- Rtex and dia are close to linearly related
- Nominal mesh size and observed mesh size are close to linearly related for all three methods
- Double twine tends to have a larger diameter (and Rtex-value) than single twine (not unexpected)
- A similar conclusion for the relation between Nominal mesh size and Twine

### Comparison of the three main methods "ICES" "WH" and "WW"

Considerations for incorporation of nominal mesh size into the model.

It is expected that the result of any reasonable mesh measurement method is closely related to the nominal mesh size of the meshes being measured. A given sample of netting is characterized by a nominal mesh size. When only a few samples are measured and they are almost all of different nominal mesh sizes, the nominal mesh size and sample become confounded effects. In this case it can become difficult or impossible to include both in the model.

*SMALL:* Each of the four institutes represented measured (effectively) only one sample each. It is therefore not possible to estimate a variance component for the sample. A total of 3 mesh sizes (18 mm, 35 mm, and 36 mm) were measured. The smallest was however only measured by a single institute. The majority of the measurements are consequently concentrated on two adjacent nominal mesh sizes. This may affect the possibilities of detecting an effect of nominal mesh size.

*LARGE*: Nine institutes are represented in the “LARGE” data set. Only two of these made repetitive measurements of the same nominal mesh size on two different samples. For the remaining institutes different netting samples represented different nominal mesh sizes. Consequently the nominal mesh size (within institute) is considerably confounded with the sample (within institute). Since the nominal mesh sizes span a considerable range it will be incorporated into the fixed effects part of the model. This enables us to isolate the effect caused by the choice of method. The nominal mesh size will enter the model as a factor. This way the estimates associated with the method parameters can be interpreted as method specific adjustments to the nominal mesh sizes at any particular level.

*SMALL*

The fixed effects part used in this part of the analysis is given by:

*fixed~method-1*

The *-1* removes the intercept. This fits an estimate for each method rather than a base level (= the “ICES” method) and fitting the other methods by contrasts to the base level.

First a simple model was fitted including only the “Method” as fixed effect and with random~1|Inst/Mesh. This was compared with a model with a more simple random effects structure: random~1|Inst. A likelihood ratio test gave preference to the simpler model. (Note however that by convention random effects are normally not tested for, but in this particular case the variance component attributed to the mesh within institute was very small. Furthermore inclusion of this component impeded the estimation of confidence intervals).

| Parameter | Estimate | Std.Error | df | t-value | p-value |
|---|---|---|---|---|---|
| ICES | 32.625 | 3.765 | 714 | 8.664370 | <0.0001 |
| WH | 32.213 | 3.765 | 714 | 8.554820 | <0.0001 |
| WW | 32.983 | 3.765 | 714 | 8.759534 | <0.0001 |

$$\hat{\sigma}_{Inst} = 7.51 \text{ and } \hat{\sigma} = 1.64$$

These variance components are estimates of the between-Institute and within-Institute variances.

The 95% confidence intervals for the fixed effects parameter estimates are:

| | Lo | Hi |
|---|---|---|
| ICES | 25.25 | 40.00 |
| WH | 24.84 | 39.59 |
| WW | 25.61 | 40.36 |

It is seen that there is a considerable overlap between the confidence intervals and it is not possible to detect any difference between the three methods. With the overall objective in mind (and because the data cover a relatively wide range of nominal mesh sizes) it does however not serve any purpose to fit a common level for the three methods.

Instead it could be asked if the variation and imbalance in nominal mesh sizes prevents the detection of differences. A model based on a data set with the smallest nominal mesh size removed was fitted. It did however not detect any difference. Finally a model was fitted with separate levels for each combination of nominal mesh size and method. This model could also not detect any difference between methods within any of the three levels of nominal mesh size.

*LARGE*

For the large mesh data the fixed effects part used is given by:

*fixed~NomMesh+method-1*

The results in the first 14 lines of the following table gives the expected mesh sizes for the range of nominal mesh sizes represented in the data when measured with the “ICES” gauge. The last two lines give the estimated contrasts (adjustments) when measured by the “WH” and “WW” method.

| Parameter | Estimate | Std.Error | df | t-value | p-value |
|---|---|---|---|---|---|
| Nom. Mesh 70 | 73.0856 | 1.038096 | 2748 | 70.4035 | <0.0001 |
| Nom. Mesh 74 | 67.9113 | 1.065989 | 2748 | 63.7073 | <0.0001 |
| Nom. Mesh 75 | 69.8879 | 1.065989 | 2748 | 65.5616 | <0.0001 |
| Nom. Mesh 80 | 81.9833 | 1.065989 | 2748 | 76.9082 | <0.0001 |
| Nom. Mesh 82 | 80.4773 | 1.030905 | 6 | 78.0647 | <0.0001 |
| Nom. Mesh 100 | 96.6947 | 1.065989 | 2748 | 90.7089 | <0.0001 |
| Nom. Mesh 105 | 105.3828 | 1.038096 | 2748 | 101.5155 | <0.0001 |
| Nom. Mesh 107 | 107.5210 | 1.065989 | 2748 | 100.8650 | <0.0001 |
| Nom. Mesh 135 | 132.6662 | 1.465892 | 6 | 90.5020 | <0.0001 |
| Nom. Mesh 138 | 136.4662 | 1.465892 | 6 | 93.0943 | <0.0001 |
| Nom. Mesh 140 | 130.4333 | 1.065989 | 2748 | 122.3590 | <0.0001 |
| Nom. Mesh 150 | 144.3000 | 1.065989 | 2748 | 135.3672 | <0.0001 |
| Nom. Mesh 152 | 155.5585 | 1.475414 | 2748 | 105.4338 | <0.0001 |
| Nom. Mesh 190 | 184.6721 | 1.475414 | 2748 | 125.1663 | <0.0001 |
| Method WH | 5.0518 | 0.143012 | 2748 | 35.3242 | <0.0001 |
| Method WW | 4.5997 | 0.137092 | 2748 | 33.5517 | <0.0001 |

$\hat{\sigma}_{Inst} = 1.435$, $\hat{\sigma}_{Sample} = 0.8864$ and $\hat{\sigma} = 3.265$

The 95% confidence intervals for the fixed effects parameter estimates are:

| Parameter | Lo | Hi |
|---|---|---|
| Nom. Mesh 70 | 71.055 | 75.116 |
| Nom. Mesh 74 | 65.826 | 69.996 |
| Nom. Mesh 75 | 67.803 | 71.973 |
| Nom. Mesh 80 | 79.898 | 84.068 |
| Nom. Mesh 82 | 77.961 | 82.994 |
| Nom. Mesh 100 | 94.610 | 98.780 |
| Nom. Mesh 105 | 103.352 | 107.413 |
| Nom. Mesh 107 | 105.436 | 109.606 |
| Nom. Mesh 135 | 129.088 | 136.244 |
| Nom. Mesh 138 | 132.888 | 140.044 |
| Nom. Mesh 140 | 128.348 | 132.518 |
| Nom. Mesh 150 | 142.215 | 146.385 |
| Nom. Mesh 152 | 152.672 | 158.445 |
| Nom. Mesh 190 | 181.786 | 187.558 |
| Method WH | 4.772 | 5.332 |
| Method WW | 4.332 | 4.868 |

Only the last two lines are of interest in terms of the objective. They demonstrate that the "ICES" is significantly smaller than both the "WH" and "WW" method. These two methods, on the other hand, do not appear to be significantly different.

It should be noted that these models (SMALL and LARGE) were designed to assess potential differences between the three measurement methods rather than for the purpose of describing actual mesh sizes. The models are fitted across different magnitudes of actual mesh sizes and thereby average the differences across these spans. Consequently they should not be used for predicting actual mesh size measurements with any of the three methods.

## Main factors affecting the mesh measurements

The analyses conducted here take the models used in the previous section as an offset. The purpose is to describe the variability observed in the data by including additional (fixed) effects. "Rtex" and "diameter" will not enter the models simultaneously (c.f. notes above). The plots in Figures 5 and 6 suggest that the observed mesh size be described by a non-linear relationship with either of the two variables. Preliminary tests showed that the square root of Rtex (or diameter) provided a better fit. "Twine" will be tested for in the "LARGE" data set.

### *SMALL*

First, two models were fitted to identify which of the two competing covariates to include for further analysis:

M1*: fixed~ method*sqrt(Rtex)*
M2: *fixed~ method*sqrt(dia)*

(Note that these models include both main effects as well as interaction effects.) Rtex was chosen based on a lower value for both the AIC and the BIC statistics.

Next it was investigated if M1 could be reduced. The results of fitting M1 is given in the following table:

| Parameter | Estimate | Std. Error | df | t-value | p-value |
|---|---|---|---|---|---|
| Intercept | 7.23799 | 9.547382 | 712 | 0.75811 | 0.4486 |
| WH | -4.88662 | 0.603206 | 712 | -8.10108 | <.0001 |
| WW | -10.30566 | 0.603206 | 712 | -17.08482 | <.0001 |
| Sqrt (Rtex) | 0.65239 | 0.240077 | 2 | 2.71742 | 0.1129 |
| WH_sqrt (Rtex) | 0.11497 | 0.015168 | 712 | 7.58003 | <.0001 |
| WW_sqrt (Rtex) | 0.27404 | 0.015168 | 712 | 18.06691 | <.0001 |

The Intercept corresponds to the "ICES" method, whereas "WH" and "WW" are contrasts. The table suggests that the main effect of Sqrt(Rtex) is insignificant. A likelihood-ratio test for removing the effect of Sqrt(Rtex) altogether was rejected. Therefore a model with only interaction effects (and individual levels for the three methods) was fitted:

M3: *fixed~ method+ method:sqrt(Rtex)*

With the following result:

| Parameter | Estimate | Std. Error | df | t-value | p-value |
|---|---|---|---|---|---|
| Intercept | 7.23799 | 9.547382 | 711 | 0.75811 | 0.4486 |
| WH | -4.88662 | 0.603206 | 711 | -8.10108 | <.0001 |
| WW | -10.30566 | 0.603206 | 711 | -17.08482 | <.0001 |
| ICES_sqrt (Rtex) | 0.65239 | 0.240077 | 711 | 2.71742 | 0.0067 |
| WH_sqrt (Rtex) | 0.76736 | 0.240077 | 711 | 3.19633 | 0.0015 |
| WW_sqrt (Rtex) | 0.92643 | 0.240077 | 711 | 3.85889 | 0.0001 |

The model could not be reduced any further.

The interaction terms imply that Rtex (or rather sqrt(Rtex) acts differently upon the three methods. By way of example consider a sample of netting with an Rtex value of 1325. The expected mesh size measurement given by the three methods would then be:

ICES: 7.23799+0.65239*sqrt(1325)=30.99
WH: 7.23799-4.88662+0.76736*sqrt(1325)=30.28
WW: 7.23799-10.30566+0.92643*sqrt(1325)=30.65

### *LARGE*

Similarly to the "SMALL" data set two models were fitted. This time however also including the "Twine" effect

M1: *fixed~ method*sqrt(Rtex)*Twine*
M2: *fixed~ method*sqrt(dia)*Twine*

Contrary to the "SMALL" data set the AIC and BIC statistics gave preference to "Diameter" as explanatory variable. The results of fitting M2 are given in the following table:

| Parameter | Estimate | Std. Error | df | t-value | p-value |
|---|---|---|---|---|---|
| Intercept | 158.3278 | 11.94311 | 2749 | 13.25684 | <.0001 |
| WH | -16.0561 | 10.23822 | 2749 | -1.56825 | 0.1169 |
| WW | -13.5162 | 9.76109 | 2749 | -1.38471 | 0.1663 |
| sqrt(dia) | -20.7422 | 3.48686 | 2749 | -5.94868 | <.0001 |
| Twine | -132.2997 | 8.95710 | 2749 | -14.77038 | <.0001 |
| WH_sqrt (dia) | 9.8903 | 4.57957 | 2749 | 2.15965 | 0.0309 |
| WW_sqrt (dia) | 8.2788 | 4.33466 | 2749 | 1.90990 | 0.0563 |
| WH_ Twine | 35.8510 | 13.05468 | 2749 | 2.74622 | 0.0061 |
| WW_ Twine | 16.3268 | 11.46217 | 2749 | 1.42441 | 0.1544 |
| sqrt (dia) _Twine | 58.3751 | 3.98794 | 2749 | 14.63790 | <.0001 |
| WH_sqrt (dia) _Twine | -18.1206 | 6.12022 | 2749 | -2.96077 | 0.0031 |
| WW_sqrt (dia) _Twine | -7.7207 | 5.20246 | 2749 | -1.48405 | 0.1379 |

Tests for removing the triple interaction effect Method:Sqrt(dia):Twine were rejected. This was also the case for a test for removing one of the dual interaction effects Method:Twine and Sqrt(dia):Twine and Method:Sqrt(dia):Twine.

## To find a suitable conversion formula between measurements with "ICES" and "ICES10KGF"

Some exploratory plots first assess the relation between measurements taken with the "ICES" and the "ICES10KGF" method. A histogram of all differences between the two methods suggests an asymmetric distribution (Figure 7). This plot makes no distinction between the Institutes. When plotting histograms for each institute, the distribution within these seems however closer to normal, but with considerable variation in location and variance. In analogy with the above analyses it is therefore reasonable to use the institute as a random effect. The variation between samples is mainly accounted for by the mesh size measurements themselves and therefore deemed unnecessary here:

$$random \sim 1|Institute$$

In Figure 9 the measurements taken with "ICES10KGF" are plotted against measurements taken with "ICES" along with the identity line. It is seen that for the vast majority of measurement the "ICES10KGF" measurement is larger than the "ICES" measurement. In Figure 10 the same plots are done by Institute. These plots also contain simple linear regression lines along with the estimated coefficients. These plots reveal a considerable variation in the regressions and in particular for the slopes. Regression lines parallel with the identity line suggest the difference between the two models to be modeled as a constant. Institutes with measurements well represented over a larger range show regression lines close to parallel with the identity line, whereas the cases with larger departure from parallelism all cover a very narrow range. These cases should therefore not disturb a hypothesis of a constant difference. A closer inspection of Figure 9 reveals a slight curvature, with larger differences for both small and large values. A second order polynomial relation will therefore be used as a starting point:

$$ICES10KGF \sim ICES+ICES^2$$

The following table lists the results of fitting this model:

| Parameter | Value | Std. Error | df | t-value | p-value |
|---|---|---|---|---|---|
| Intercept | 11.44031 | 1.642558 | 1288 | 6.96494 | <.0001 |
| ICES | 0.89837 | 0.026501 | 1288 | 33.89884 | <.0001 |
| ICES^2 | 0.00034 | 0.000112 | 1288 | 3.01690 | 0.0026 |

$$\hat{\sigma}_{Inst} = 2.137\,, \hat{\sigma} = 3.012$$

Likelihood ratio tests for reduction of the model by removing one of the three terms one at a time were all rejected. This will therefore also be the final model:

$$ICES10KGF=11.4403+0.8984*ICES+0.00034*ICES^2$$

The curve predicted from the model is plotted with the observed measurements in Figure 11.

## An extended conversion formula with additional variables

For the purpose of obtaining a more precise conversion formula, it was assessed whether additional variables could improve the model. Three candidates were tested in two separate competing models, which are extensions of the model above. The first includes "diameter" and "Material" and the second includes "Rtex" and "Material". The models will have both main effects as well as interaction effects. Likelihood ratio test were used for potential reductions of the models:

*Diameter and Material:*
The fit provided by this model is given in the following table:

| Parameter | Value | Std.Error | df | t-value | p-value |
|---|---|---|---|---|---|
| Intercept | 4.550772 | 1.890687 | 1285 | 2.40694 | 0.0162 |
| ICES | 0.897686 | 0.025918 | 1285 | 34.63595 | <.0001 |
| ICES^2 | 0.000334 | 0.000110 | 1285 | 3.04658 | 0.0024 |
| Material | 8.654418 | 1.171618 | 1285 | 7.38672 | <.0001 |
| dia | 1.026483 | 0.134343 | 1285 | 7.64077 | <.0001 |
| Material: dia | -1.329681 | 0.187891 | 1285 | -7.07688 | <.0001 |

$$\hat{\sigma}_{Inst} = 2.581, \hat{\sigma} = 2.930$$

PE is used as the default level for the "Material" factor. By way of example a measurement of 80 mm taken with the standard ICES gauge on a mesh made of PA with a diameter of 3.5 mm is expected to give a value of:

$$4.550772+0.897686*80+0.000334*80^2+8.654418+1.026483*3.5-1.329681*3.5=86.10$$

with the ICES10KGF gauge.

Whereas the same measurement on a PE mesh with the same twine-diameter is expected to give:

$$4.550772+0.897686*80+0.000334*80^2+1.026483*3.5=80.22$$

*Rtex and Material:*

The fit provided by this model is given in the following table:

| Parameter | Value | Std. Error | df | t-value | p-value |
|---|---|---|---|---|---|
| Intercept) | 8.049990 | 1.797714 | 1285 | 4.47790 | <.0001 |
| ICES | 0.885842 | 0.026356 | 1285 | 33.61055 | <.0001 |
| ICES^2 | 0.000414 | 0.000113 | 1285 | 3.66244 | 0.0003 |
| Material | 5.019889 | 0.821939 | 1285 | 6.10737 | <.0001 |
| Rtex | 0.000114 | 0.000022 | 1285 | 5.07902 | <.0001 |
| Material: Rtex | -0.000217 | 0.000038 | 1285 | -5.67832 | <.0001 |

$$\hat{\sigma}_{Inst} = 2.512\,, \hat{\sigma} = 2.960$$

In both cases the additional term showed a significant improvement by likelihood-ratio test against the previous model. Tests for reduction of the models were also rejected. A comparison of the two extended model, by the use of AIC and BIC statistics gave preference to the model using diameter. For practical purposes it is however believed that the two models perform equally well.

## References

Pinheiro, J. C. and Bates, D. M. 2000. Mixed-Effects Models in S and S-PLUS. Springer. pp.529.

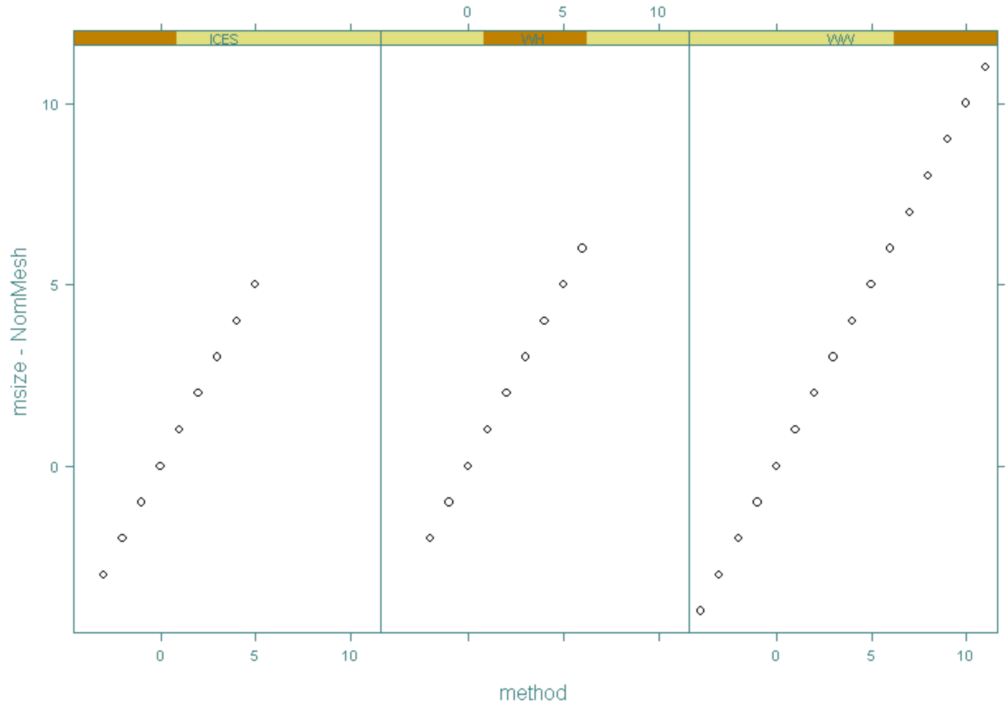

Figure 1. Panel plots of observed measurements adjusted for nominal mesh sizes and grouped by methods. SMALL group.

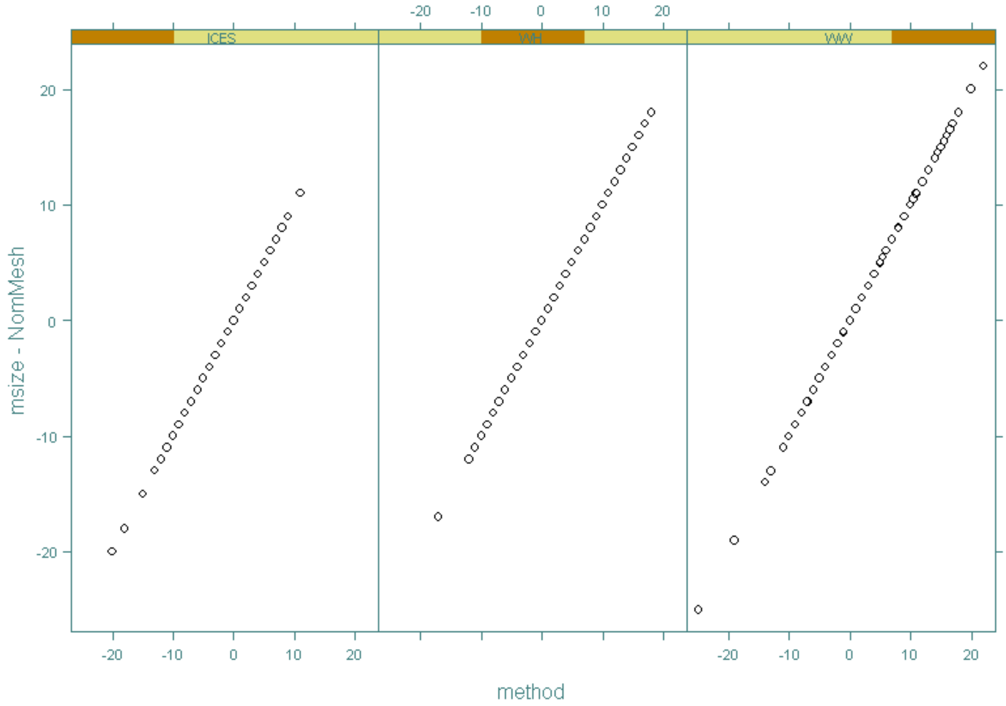

Figure 2. Panel plots of observed measurements adjusted for nominal mesh sizes and grouped by methods. LARGE group.

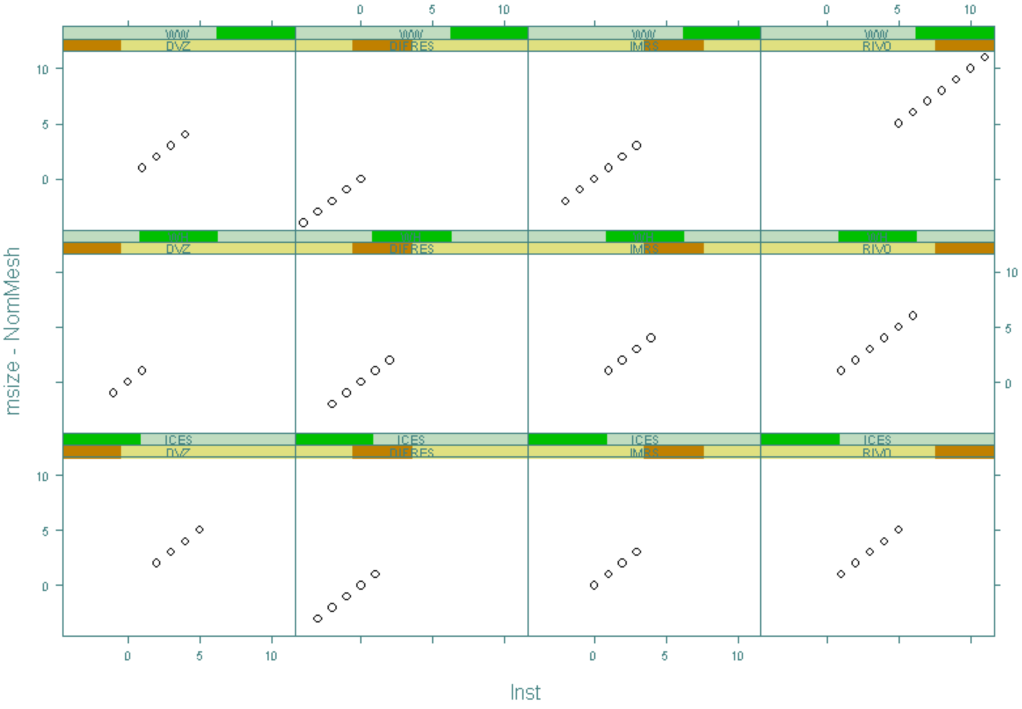

Figure 3. Panel plots of observed measurements adjusted for nominal mesh sizes and grouped by methods and institutes. SMALL group.

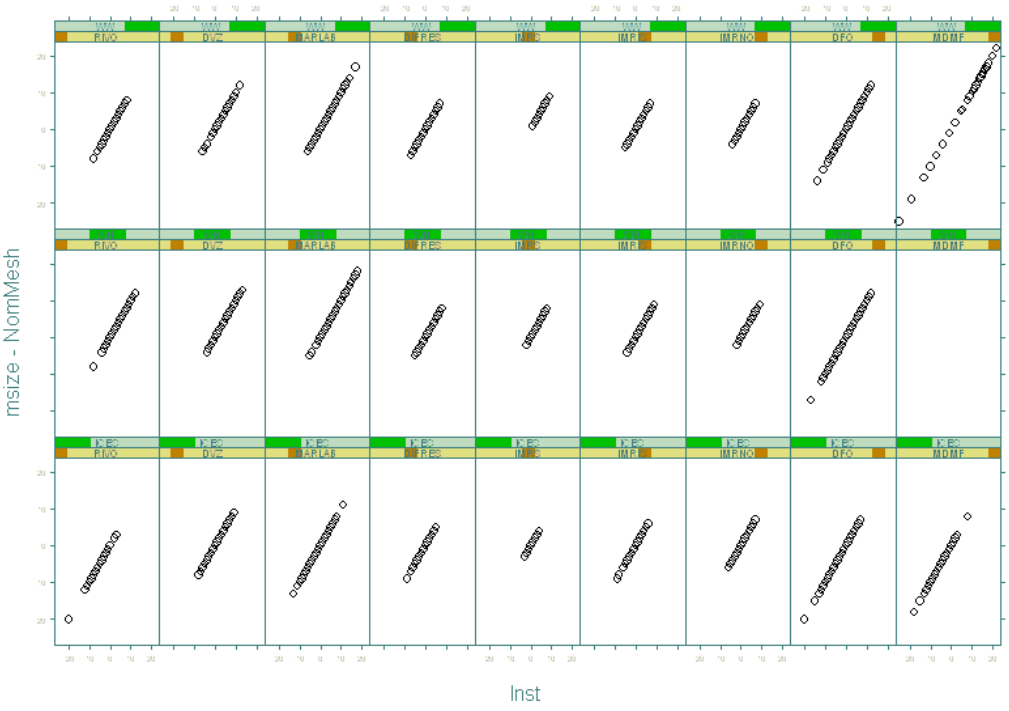

Figure 4. Panel plots of observed measurements adjusted for nominal mesh sizes and grouped by methods and institutes. LARGE group.

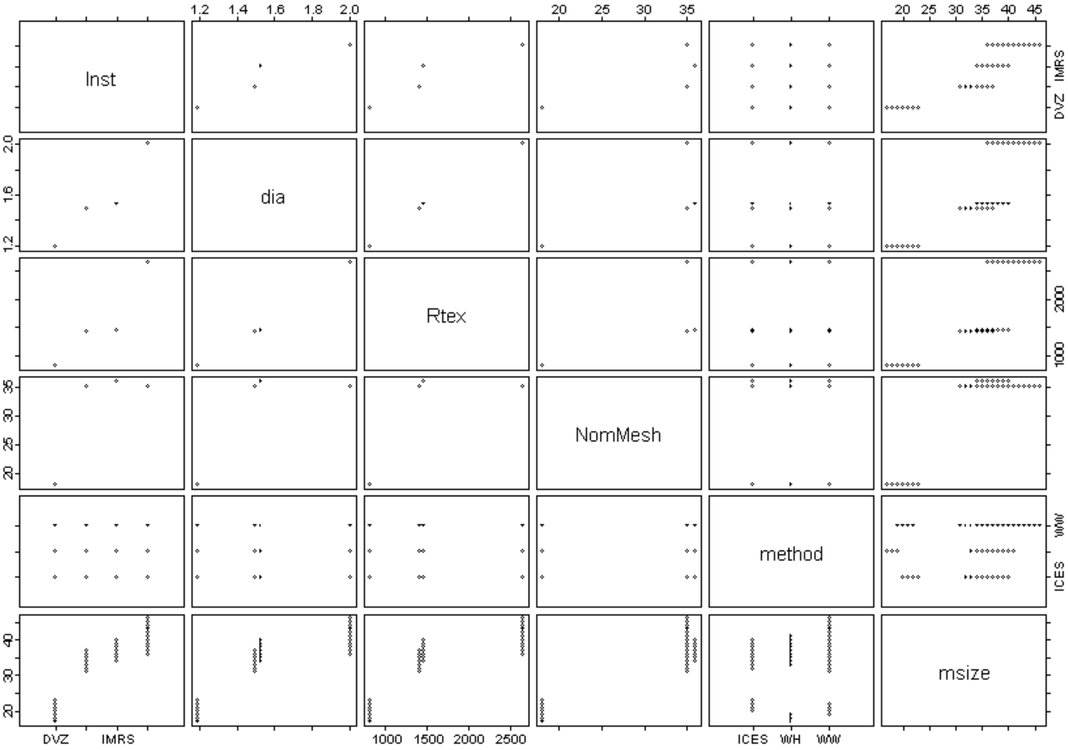

Figure 5. Scatterplots of response variables and covariates for the SMALL group.

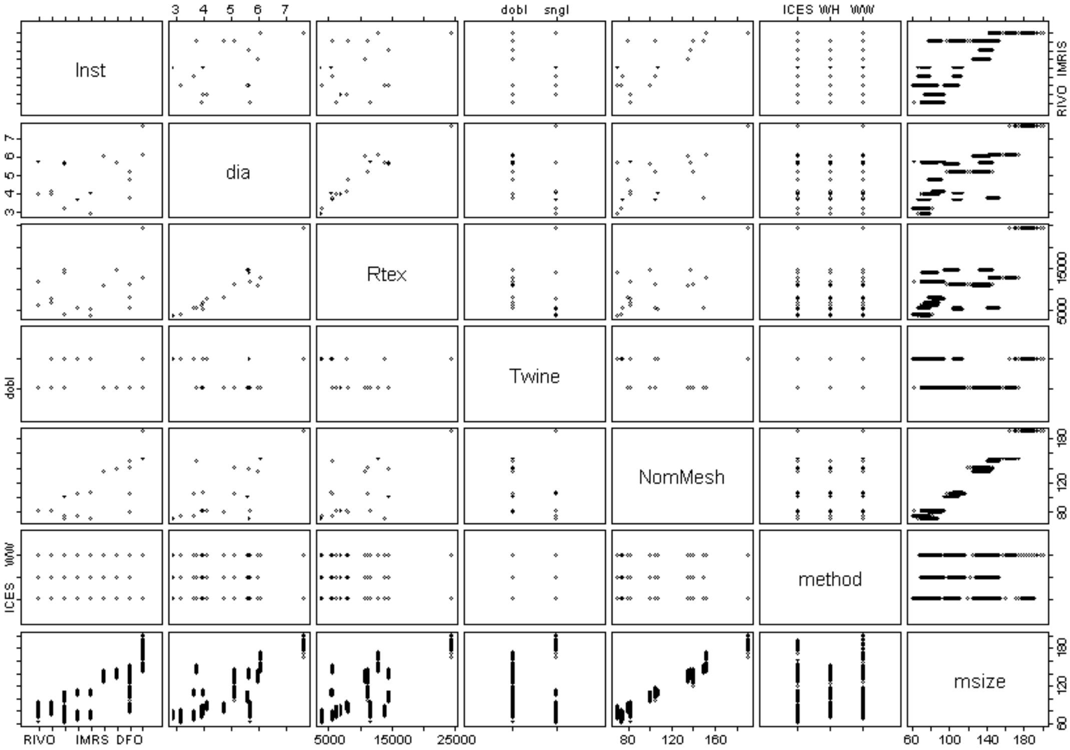

Figure 6. Scatterplots of response variables and covariates for the LARGE group.

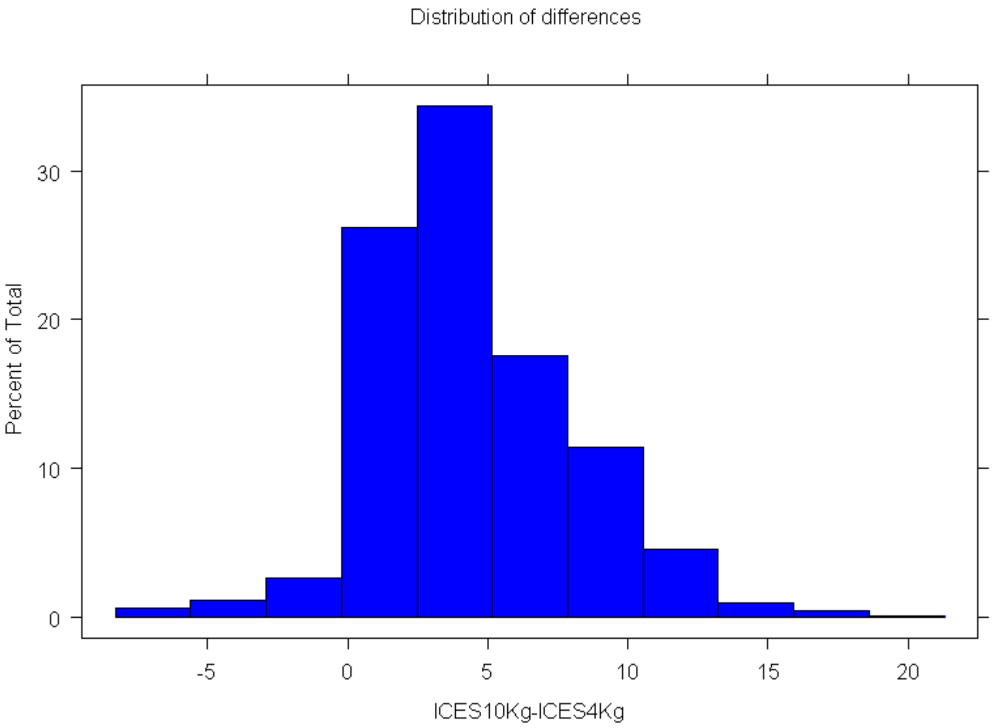

Figure 7. Histogram of all differences between ICES10KGF and ICEKGF measurements. LARGE group.

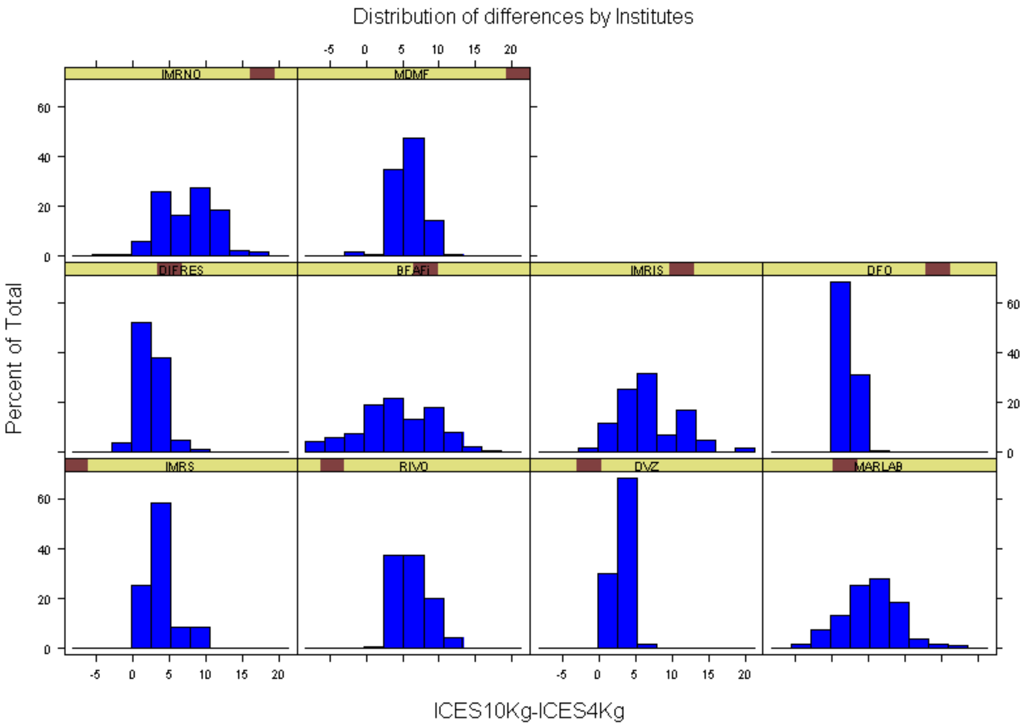

Figure 8. Histogram of all differences between ICES10KGF and ICEKGF grouped by institute. LARGE group.

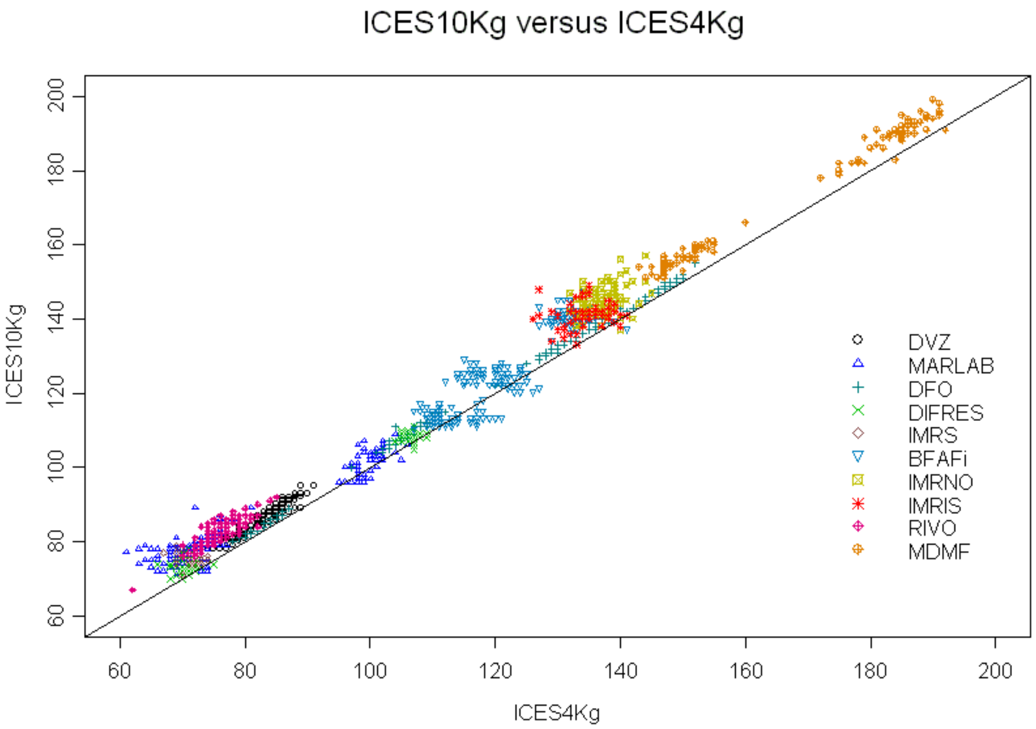

Figure 9. ICES10KGF measurements plotted against ICES4KGF measurements along with the identity line.

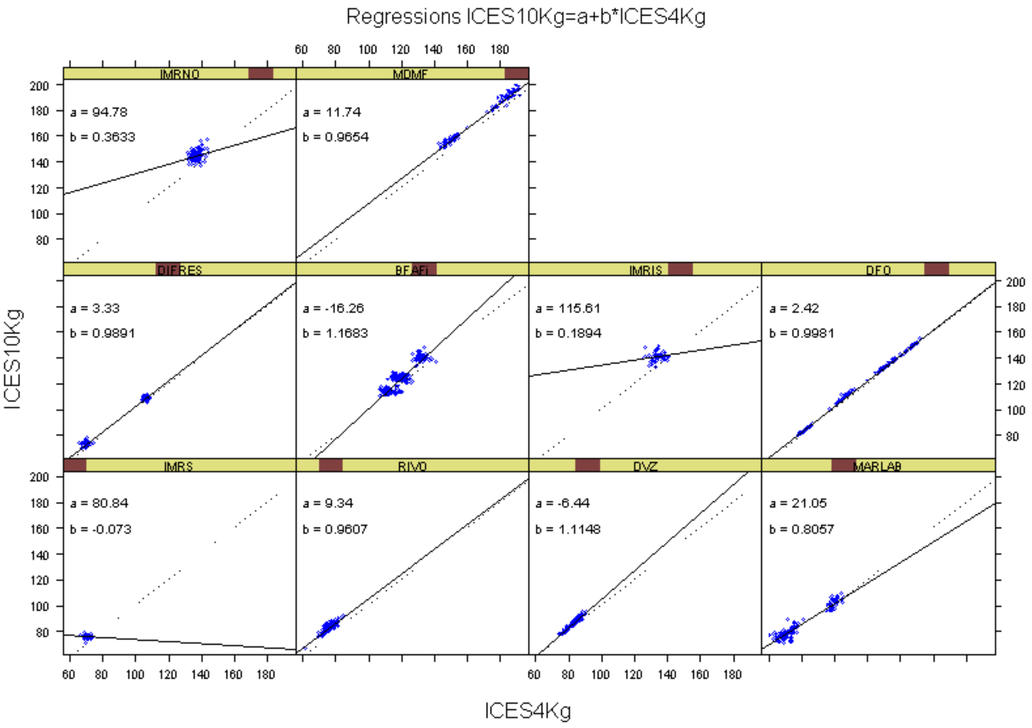

Figure 10. Observations of ICES10KGF against ICES4KGF measurements with simple regressions and grouped by institutes. LARGE group.

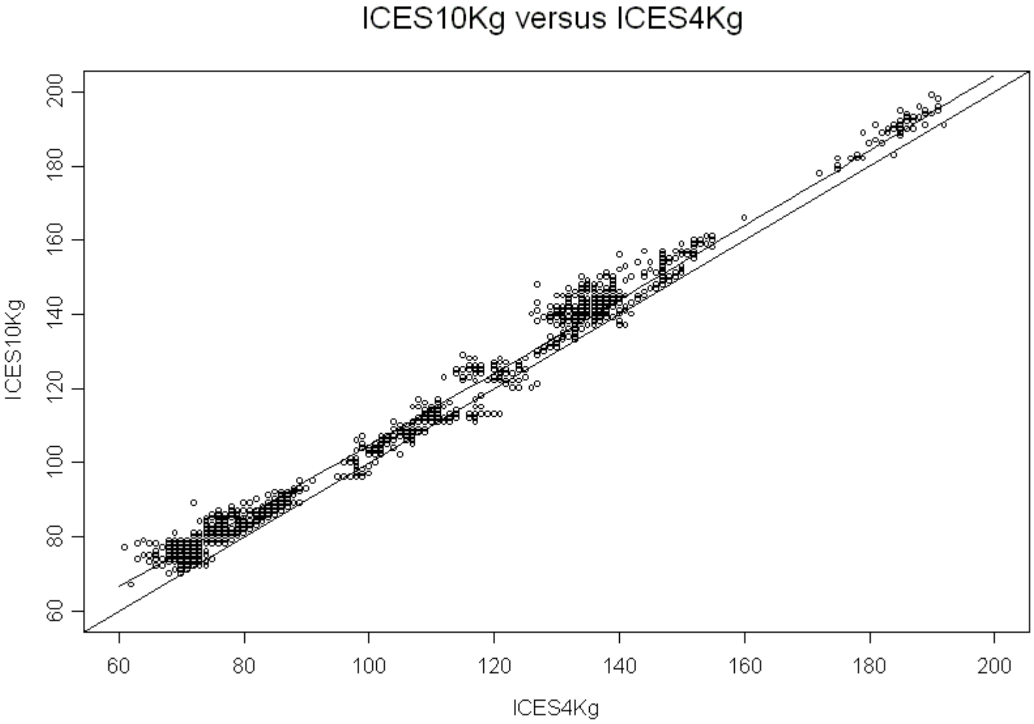

Figure 11. Observed values along with the identity line and the fitted regression curve.

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