

## Review of mesh measurement methodologies

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### Abstract

Many technical measures aimed at the conservation and recovery of fish stocks are based on the implementation of minimum mesh sizes to guarantee a certain level of fishing gear selectivity. At present, different methods are used to measure mesh opening, according to whether the measurement serves fisheries inspection, fisheries research or the manufacturing of netting for fishing nets. At the very least, this causes confusion but can also have more serious consequences such as the criminalization of well intentioned fishermen or the setting of inappropriate mesh size regulations. For example, the measurements made by fishery inspectors using the wedge gauge are generally larger than those made by scientists using the ICES gauge. As a result the cod-ends used by fishermen to satisfy the fishery inspectors will have a selectivity lower than that anticipated by the scientists who provided the advice that informed the relevant legislation.

In 1999, owing to the wider range of twines and netting materials used by the fishing industry, ICES established the Study Group on Mesh Measurement Methodology (SGMESH) to refine mesh measurement procedures. At the same time the different stakeholders agreed that there was a need to consider the adoption of a standard mesh measurement method. A major step in the standardization of mesh measurement methodologies was the development of a new standard mesh gauge (2002–2005). In October 2005, it was adopted by ICES as the new standard for mesh measurements and in June 2006 the Northwest Atlantic Fisheries Organization (NAFO) recommended its use for scientific purposes.

This review paper critically examines the different mesh measurement methodologies and their related problems, and introduces and describes a new objective mesh gauge (OMEGA) to replace the former less satisfactory gauges. Its adoption will result in researchers, fisheries inspectors and the netting industry using one standard gauge and one set of standard protocols to achieve consistent mesh-size measurements.

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### 1. Introduction

Mesh measurement is inherent to technical measures based on minimum mesh sizes. Already 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 the predecessor of the present-day wedge gauge that is used by fisheries inspectors to check whether the meshes of fishing nets comply with modern technical regulations.

The wedge gauge has been in use for the enforcement of mesh size regulations since the signature of the International Fisheries

Convention in London in 1946 (Parrish et al., 1956). The wedge gauge is normally operated by hand force and this makes the measurements liable to human influence. If a fishing skipper contests the measurements, a 5 kg weight (2 kg for meshes under 35 mm) or dynamometer must be used to control the measuring force. Because this procedure generally yields lower mesh openings than the hand force, it is hardly ever requested by fishermen. The objectivity of the wedge gauge has regularly been questioned (Parrish et al., 1956; Post, 1987; Schwalbe and Werner, 1977) and lawyers have often raised these concerns in court to contest the outcome of a mesh inspection in which the wedge gauge has been used.

A mesh gauge developed by C.J.W. Westhoff under the auspices of the International Council for the Exploration of the Sea (ICES) became the standard gauge for research activities in 1962 (Anon, 1962) and became known as the ICES gauge. The ICES gauge exerts a fixed longitudinal measuring force on the mesh and when the gauge is used correctly the measurements

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are free of human influence. The recommended measuring force is 4 kgf.<sup>1</sup> From 1962 till 2005 the ICES gauge was commonly used in selectivity experiments, to provide scientific advice on minimum regulated mesh sizes. It is generally acknowledged that measurements made with the ICES gauge yield lower mesh openings than the wedge gauge (Ferro and Xu, 1996; Fonteyne and Galbraith, 2004). Consequently a cod-end with the legal minimum mesh size, as measured with the wedge gauge, will have a selectivity lower than that anticipated when the minimum mesh size was proposed. This is because any such proposal will have been based on scientific experiments where the ICES gauge will have been used.

Since the introduction of the ICES gauge in 1962 a wide range of new twines and netting materials have been used by the fishing industry. These modern twines vary significantly in thickness and stiffness, both of which have been shown to affect mesh size measurement and cod-end selectivity (Lowry and Robertson, 1996; O'Neill, 2003). The question of 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 in 1997 during the European Concerted Action Project MESH to evaluate mesh measurement methodologies. About the same time fisheries scientists, most European fisheries inspection services and the fishing industry (both fishermen and net makers) agreed that there was a need to consider the adoption of a standard mesh measurement method for use by the fishing industry, enforcement agencies and scientists. As a result of these discussions on modern twines and gauges ICES established the Study Group on Mesh Measurement Methodology (SGMESH) (Anon, 2000) to review current mesh measurement methodologies and to "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".

In 2002 a combined R&D and Demonstration project, known as the OMEGA project, was funded by the Fifth Framework Programme of the European Commission with the goal to develop a new and objective mesh gauge that was capable of performing mesh measurements according to the protocol recommended by the ICES SGMESH. The resulting OMEGA gauge is capable of making precise and objective measurements of mesh opening that are free of human influence, on a wide range of netting materials.

In this paper we review the wedge, ICES and OMEGA gauges, protocols for their use by researchers, fisheries inspectors and the fishing industry, and relevant current standards and legislation regarding mesh measurement methodologies.

## 2. Wedge gauges

### 2.1. Wedge gauges used by fisheries inspectors

Flat wedge gauges used for mesh size inspections are shown in Fig. 1. These gauges are usually made of 2 mm thick plates

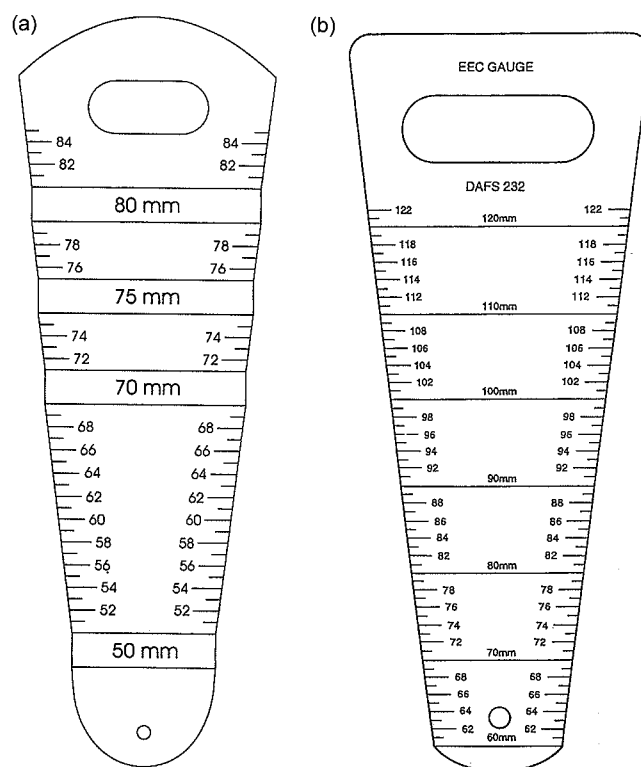


Fig. 1. Wedge gauges.

of durable material capable of retaining its shape. They have either a series of parallel edged sides connected by intermediate tapering edges (Fig. 1a), or tapering edges only (Fig. 1b). The taper is 1:8 on each side. The width is inscribed on the gauge at regular intervals.

To measure the opening of mesh the net is stretched in the N-direction of the meshes. The gauge is inserted into the mesh 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. 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.

The rules for determining the mesh size of fishing gears for inspection purposes are described in the regulations of the relevant national or international authorities. According to European regulation (Anon, 2003a) 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 measured again using a weight or dynamometer attached

<sup>1</sup> 1 kgf is defined to be the gravitational force exerted on a mass of 1 kg where the earth's gravity is 9.80665 m s<sup>-2</sup>. Hence, 1 kgf is 9.80665 N.

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 a 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 2 kgf is applied; for other nets the force is 5 kgf. The accuracy of the weights or the dynamometer is certified by the competent national authority.

## 2.2. Wedge gauges used by the fishing industry and netting manufacturers

Fishermen use a diversity of wedge gauges to measure the mesh opening of their nets. They are unlikely to use weights and generally will only use hand force. In addition to the wedge gauge they may also use rulers.

The measure used for indicating the mesh size during the manufacturing process is the length of mesh.<sup>2</sup> To check the opening of mesh a wedge gauge is used.

## 2.3. International standards

The international standard EN ISO 16663-Method of test for the determination of mesh size (Anon, 2003c,d) has two parts:

- Part 1—Mesh opening (EN ISO, 16663-1; Anon, 2003c).
- Part 2—Length of mesh (EN ISO, 16663-2; Anon, 2003d).

Part 1 specifies a method for the determination of the mesh opening of active fishing gears using a flat wedge gauge. The 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 between the specifications in the standard and the specifications in the legislation 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;
- 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 and
  - 8 kgf for mesh sizes above 120 mm.
- a minimum of 20 consecutive meshes (in the N-direction) shall be measured.

<sup>2</sup> European Standard EN ISO 1107 (Anon, 2003b) defines “length of mesh” for knotted netting as “the distance between the centres of two opposite knots in the same mesh when fully extended in the N-direction”. “Opening of mesh” is defined as “the longest distance between two opposite knots in the same mesh when fully extended in the N-direction.” The difference between “length of mesh” and “opening of mesh” is one knot.

Part 2 of the standard deals with the determination of the length of mesh using a ruler and is applicable to passive fishing gears only.

## 2.4. Problems encountered with wedge gauges

The above standard has an important informative annex recognising the limitations of the use of the wedge gauge:

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.

The main problem is the uncertainty of the measurements due to variability of the measuring force. When used manually the mesh measurements are dependent upon the force applied by the operator but even with a weight or dynamometer the lateral stretching force will not be constant due to the varying friction force between the gauge and the netting material. Calculations carried out during the OMEGA project showed that the stretching force exerted by the wedge gauge is uncertain and very variable (Fonteyne et al., 2007). When used manually the stretching force varied from 56 to 215 N with an average of 126 N. When a 5 kg weight is used the stretching force is likely to be between 24 and 114 N with an average of 83 N.

There are also concerns with regard to gauge design and inconsistent measurement procedures. Post (1987) showed that different measurements are obtained by different fisheries inspection services using different versions of the EU wedge gauge. In Europe little use is made of the 2 or 5 kg weight or a dynamometer, whereas, the standard measurement procedure of the US Coast Guard requires the insertion of the wedge gauge with a 5 kg weight. In general European 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. Furthermore, 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 and where it does, the frequency of re-calibration differs between countries.



Fig. 2. ICES gauge.

### 3. The ICES mesh gauge

#### 3.1. Description and measurement procedure

For more than 40 years the ICES mesh gauge (Fig. 2) has been the standard gauge for research activities, recommended by ICES (Anon, 1962). The two jaws are inserted into the diagonal of the mesh to be measured. The sliding jaw is then pulled steadily away from the fixed jaw by the handle, thus stretching the mesh. The moment that the load on the movable jaw exceeds the force exerted by a spring in the device, a blocking mechanism is activated and the mesh opening can be read on the upper side of the bar. The tension at which the gauge operates, i.e. the stretching force on the mesh when its size is measured, is determined by the degree of compression of the spring, which can be adjusted. ICES has recommended a measuring force of 4 kgf. The precision of the length measurement 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. A more detailed description of the gauge is given in Westhoff et al. (1962).

To test the gauge, a short, rigid test spring is used. This spring is of a known length when under a tensile force of 4 kgf. The eyes of the test spring are fitted on the jaws and the gauge is operated in the normal way. The length read on the scale should correspond with the predetermined length of the spring under a force of 4 kg. 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 compression of the spring in the device, and hence, the force applied by the gauge can be corrected by means of a screw. The scale reading can be checked by a simple standard measure to ensure 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.

#### 3.2. Problems encountered

Measurements made using the ICES gauge are close to being free of human bias due to the fact that the applied force is con-

stant. Its major drawback is that the measuring force is controlled by the compression of a spring, the characteristics of which may change over time. This makes the instrument unsuitable as a legal mesh gauge and is the main reason that it has not been adopted by the International Organization for Standardization (ISO) to be the standard gauge for measuring fishing nets. Moreover, the ICES gauge is not considered to be robust enough for use under the severe environmental conditions during fisheries inspections at sea.

An inquiry made within the framework of the European Concerted Action Project MESH revealed that mesh measurements for scientific purposes are characterised by a lack of uniformity. This is true for both the measuring instruments and the measurement procedures. The only existing recommendations for measuring the mesh opening of cod-end meshes using the ICES gauge can be found in the report of the ICES Mesh Selection Working Group 1959–1960 (Anon, 1964). These recommendations, however, leave room for interpretation and are usually not followed nowadays.

Another outcome of the MESH project was that the procedure for selecting the meshes to be measured differs from one country to another. Wileman et al. (1996) suggest that the meshes should be chosen from the area where most escapes occur. In general this is what happens although the number of meshes measured is variable and often depends on the time that is available. More meshes are measured on board research vessels than on board chartered commercial vessels and the number of meshes measured during scientific experiments is usually much larger than that during fishery inspections. Additionally, some users do not operate the gauge twice in succession.

### 4. The OMEGA gauge

#### 4.1. Description and measurement procedure

The OMEGA gauge (Fig. 3) was developed within the European Research and Demonstration Project “Development and testing of an objective mesh gauge” during the period 2002–2005. The main aim of this project was to build and test a new, objective mesh gauge, according to the specifications of SGMESH, and that would be suitable as a standard gauge for all user groups. The partners in the project were fisheries inspection services and fisheries research institutes from Belgium, France, Germany, Italy, the Netherlands, Spain and the United Kingdom. The instrument was built by a consortium of two private companies specialized in measurement equipment.

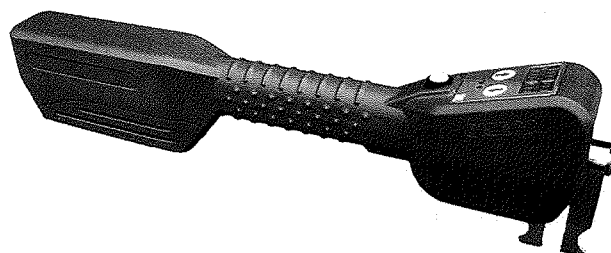


Fig. 3. The OMEGA gauge.

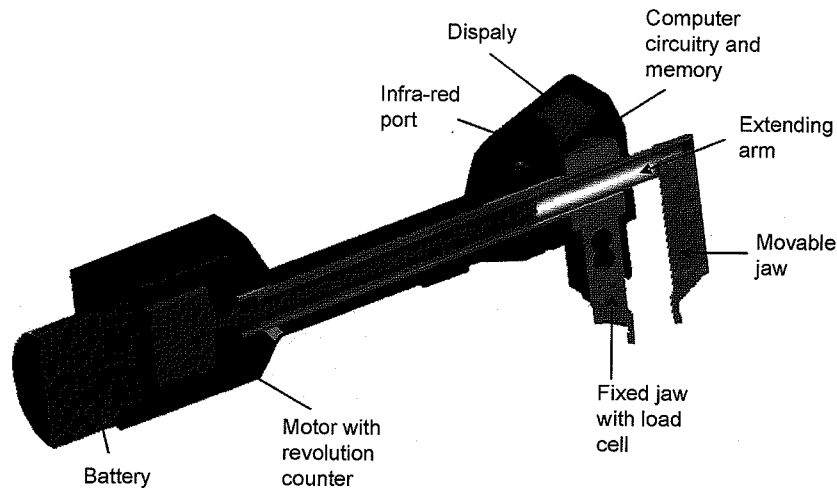


Fig. 4. Conceptual design of the objective mesh gauge.

The OMEGA gauge is a battery-powered instrument (Fig. 4) that applies a pre-set longitudinal force to the mesh to be measured. The two jaws are inserted into the diagonal of the mesh to be measured. The movable jaw, driven by an electrical motor, stretches the mesh until the pre-set longitudinal force, measured by the built-in load cell in the fixed jaw, is reached. The distance travelled by the movable jaw is derived from the number of revolutions of the motor. The mesh opening and the measurement force are shown on a digital display. A series of measurements can be performed and the data are stored in an integral memory. At the end of the operation the number of measurements made and the average mesh size are shown. Stored data can be transferred to a computer via an infrared link.

The design of the instrument is such that the measuring force is entirely controlled by the instrument. This ensures that measurements are free of human influence and are reproducible and consistent between operators. The technical specifications of the OMEGA gauge are given in Table 1.

Table 1  
Technical specifications of the OMEGA gauge

Temperature range: $-10$ to $40$ °C (operating)
Length measurement range: 10–300 mm
10–70 mm: small jaws
40–200 mm: standard jaws
140–300 mm: extended jaws
Precision: $\pm 1$ mm
Display resolution: $\pm 1$ mm (internal resolution 0.2 mm)
Force measurement
Range: 0–180 N
Precision: 1 N
Fixed measuring forces available
Data storage
Memory of 1000 measurements
Calculation of average and total number of measurements
Download via an infrared transmitter
Weight: 2370 g

The OMEGA gauge is basically equipped with jaws for mesh sizes in the range of 40–200 mm. For smaller mesh sizes a set of smaller jaws must be fitted, enabling measurements in the range of 10–70 mm. For meshes over 200 mm an extending jaw must be fitted. The measuring range with extending jaws is 140–300 mm. The gauge has a rigid structure and does not distort under load. The gauge is water resistant and unaffected by dust to standard IP56.<sup>3</sup> The operation of the gauge is controlled by software. As some netting may creep under load, the controlling software contains a suitable algorithm to re-apply the measuring force if within 1 s the stretching force drops under 80% of the pre-set measurement force. For square meshes the software contains a function to select automatically the largest diagonal of each mesh to calculate the mean mesh opening of the square mesh netting. The menu is accessed via touch buttons. The gauge can be operated with one hand and is well balanced. When designing the gauge special care has been given to the ergonomics.

Initial calibration is done at the factory. For official use, the instrument will have to be re-calibrated once a year by an authorised technician. Check cycles enables witnessed checking of the instrument calibration:

- when starting up the instrument, the movable jaw automatically shifts to a reference position to calibrate the length measurement;
- a check plate with fixed opening lengths should always show the exact distance;
- calibrated weights allow to check the force measurement.

A protocol for mesh measurement with an objective mesh gauge contains detailed instructions for the design, construction and operation of the OMEGA gauge and aims to ensure uni-

<sup>3</sup> IP stands for internal protection. The IP codes define the degree of protection of electrical equipment against penetration of foreign particles including dust (first numerical) or ingress of water (second numerical). IP56 means that the equipment is dust protected (5) and protected against powerful water jets (6). IP codes are specified in the international standard IEC 60529 (Anon, 2001).

formity in the measurement procedure (Fonteyne, 2005). The measurement protocol is based on the mesh measurement procedure recommended by the SGMESH. The measuring forces, however, were modified after extensive laboratory and field tests performed to compare the new objective OMEGA gauge with both the former ICES gauge and the wedge gauge used by fisheries inspectors (Fonteyne et al., 2007). The measuring forces for cod-ends are: 20 N for mesh sizes <35 mm; 50 N for mesh sizes  $\geq$ 35 mm and <55 mm; 125 N for meshes  $\geq$ 55 mm. For set nets the measuring force is 10 N for all mesh sizes. For scientific purposes 40 meshes in two or more parallel lines of up to 20 meshes are measured.

#### 4.2. Current status of OMEGA gauge

The OMEGA gauge became commercially available in 2005. The ICES/FAO Working Group on Fisheries Technology and Fish Behaviour (WGFTFB) (Anon, 2005) and subsequently the ICES Fisheries Technology Committee (FTC), recommended the OMEGA gauge and its associated protocol (Fonteyne, 2005) as the new standard for mesh measurements to replace the former ICES gauge. The ICES Council formally adopted the resolution in October 2005. In June 2006 the Northwest Atlantic Fisheries Organization (NAFO) recommended that the OMEGA gauge be adapted as a standard for scientific purposes (Anon, 2006).

The Directorate General of Fisheries and Maritime Affairs of the European Commission has initiated a revision of Commission Regulation (EC) no. 129/2003, which lays down detailed rules for determining the mesh opening and twine thickness of fishing nets (Anon, 2003a). A review has also begun of the international standard EN ISO 16663-1 on mesh measurement. The intention of both these reviews is to replace the wedge gauge with the OMEGA gauge.

### 5. Conclusion

As advice from selectivity experiments determines mesh size regulations it is logical that all parties concerned adhere to the same measurement methodology, whether they are scientists, inspectors, netting manufacturers, net makers or fishermen. Such a standardisation is an essential condition to assure that the minimum mesh selectivity aimed at by these mesh size regulations is obtained. The lack of an objective standard mesh measurement methodology is often the reason for questioning the results of mesh inspections when a case is brought to court. Standardisation is economically important since it will reduce disputes between fishermen and the netting manufacturers about the mesh size of netting materials.

The OMEGA gauge meets the criteria of an objective mesh gauge and is also likely to be acceptable in court. It is capable of making precise measurements of mesh opening that are free of human influence, on a wide range of netting materials. The performance of the gauge has been extensively tested in many countries by fisheries inspectors, scientists and netting manufacturers, both at sea and in the laboratory and has been found to be accurate and reliable (Fonteyne et al., 2007). For the first time a standard instrument is available for use in all branches of the

fishing industry. This should assist in the integration of scientific, industrial and enforcement aspects of fishery management.

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