Guide pratique

Identification of fishes by their otoliths in 3D

English Channel and North Sea

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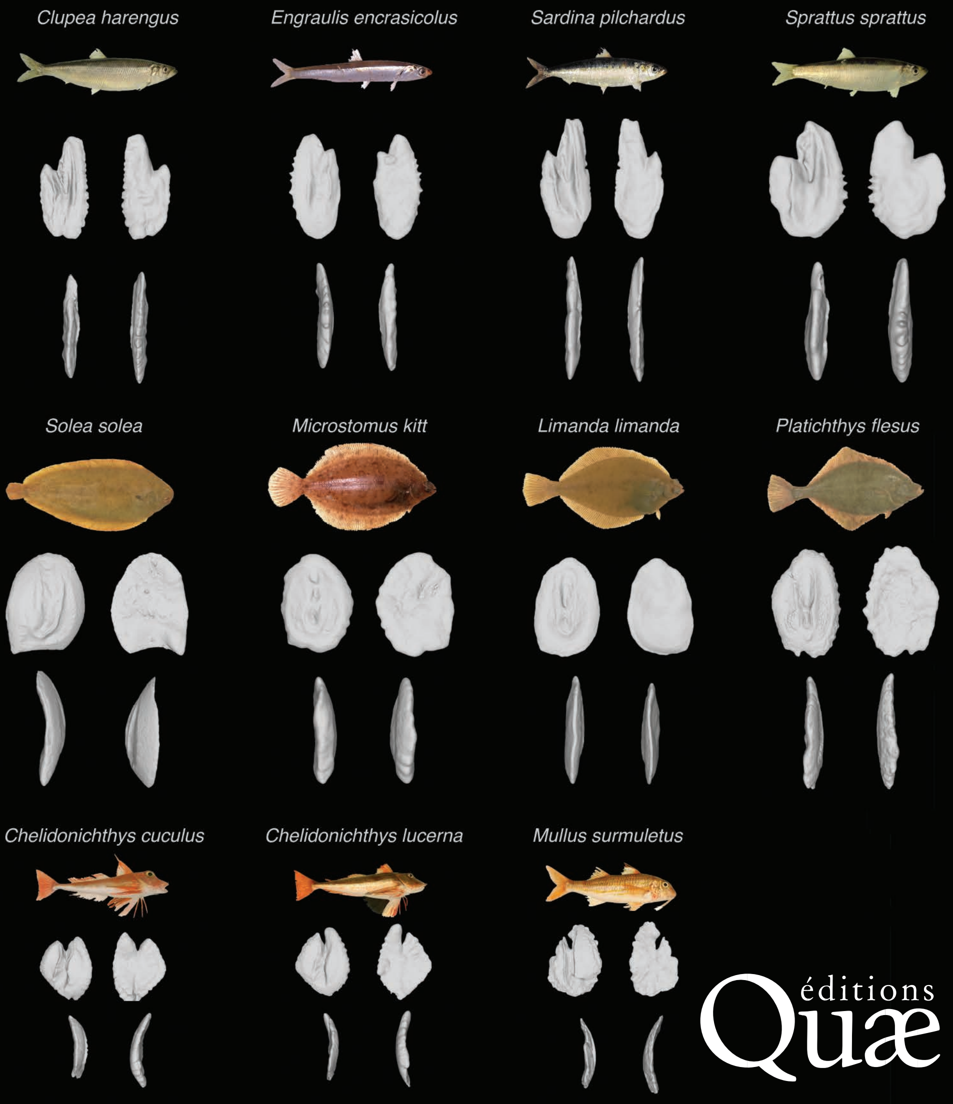

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With the collaboration
of Lauriane Poloni

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Content

Introduction

This identification guide to the main fish species of the English Channel and the North Sea covers 22 species. It is intended as an educational tool for students and the general public, and as a reference tool for scientific research studying the otoliths of these species, for example in archaeology, or for identifying the fishes present in the stomach contents of all species that eat fish (seals, birds, fish, etc.).

Study area

The English Channel and the North Sea form a strategic region in North-West Europe from a socio-economic and ecological point of view[1]. This is an important economic zone, with a wide range of human activities, including tourism and leisure, international ports and freight, and the exploitation of living and non-living resources. This maritime area carries almost 20% of the world's traffic, making it one of the busiest in the world. It harbours huge reserves of marine aggregates (sand, gravel) and gas, which resources are coveted by many industries. Other human activities are also developing around marine renewable energies, such as offshore wind and tidal turbines.

The Channel and the North Sea also support a very significant commercial fishing industry, both in terms of the quantity of fish and the number of species exploited. Of the 120 species identified in this region, around 20 account for almost all of the commercial species.

Uses of otoliths in fisheries science

Fish populations are monitored every year to achieve the Maximum Sustainable Yield (MSY) required for a sustainable Common Fisheries Policy into the future. The statistical models used to monitor fisheries therefore require knowledge of the age structure of each management unit, known as a stock, and to assess the limits of each of these stocks (Cadrin and Dickey-Collas, 2015). Calcified parts (scales, vertebrae, fin rays, otoliths, etc.), which grow by successive concentric periodic accretion, are used to determine age. Of these calcified parts, only the otoliths, located in the inner ear cavity, are metabolically inert, i.e. they cannot be altered or resorbed (Casselman, 1987). Furthermore, observation of otolith internal structure shows that they develop according to a periodicity of calcium carbonate deposits ranging from daily to yearly.

The ears (right and left paired structures located on either side of the brain) are made up of a network of canals that connect three cavities (called otic sacs). This entire system is filled with a liquid called endolymph (Panfili *et al.*, 2002).

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[1] For more information on the area and the development of human activities, please refer to the strategic document for the Channel East-North Sea coastline finalised by France: https://www.dirm.memn.developpement-durable.gouv.fr/IMG/pdf/straegie_de_facade_maritime_memnor_synthese.pdf (consulted on 20/07/2025).

Otoliths are concretions formed largely of calcium carbonate that are present in each cavity. The largest of the cavities contains the largest otolith, called the *sagitta*. The *sagitta* is used for virtually all studies, and is thus the otolith presented in this book. The otolith exists in the otic cavity, and is connected to the brain by a membrane called the *macula* (Panfili *et al.*, 2002). This membrane is in contact with the otolith on its proximal surface (inner surface) in a groove called the *sulcus acusticus* (Figure 1). The *sulcus acusticus* is divided into three parts along an anteroposterior axis, with the *excisura* (the zone delimited by the *rostrum* and the *antirostrum*), the *ostium* and the *cauda*. The characteristics of this zone are closely linked to acoustic development (detection of sound waves) and angular development (detection of accelerations enabling the individual to balance). The shape of the otolith, although very different from one species to another, generally shows a convex proximal inner surface and a concave distal outer surface. Positioned on the inner face, the development of the otolith is often greater on the antero-posterior axis (where the length of the otolith is measured) than on the dorso-ventral axis (where the width of the otolith is measured) (Figure 1).

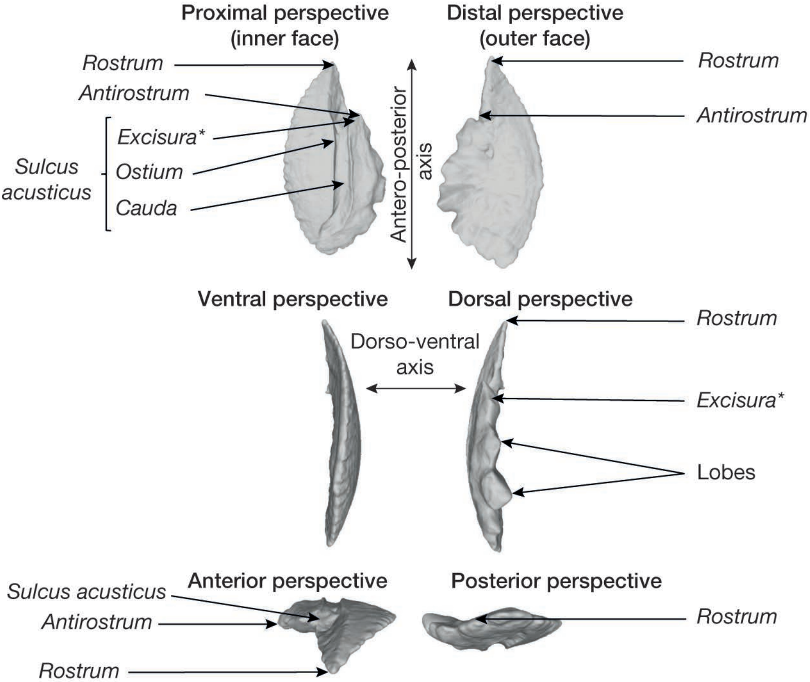

Figure 1. Presentation of a right otolith from the different perspectives extracted from a three-dimensional image.

* *Excisura*: notch separating the *rostrum* from the *antirostrum*.

Otoliths, which evolve throughout the life of a fish, have chemical and physical signatures that correspond to the biological and environmental conditions in which the fish has lived (Casselman, 1987). It was not until the end of the 19th century that scientists observed these otoliths and counted periodic growths on their external surface, making it possible to estimate the age of the fish (Reibish, 1899). Since then, the scientific use of otoliths has continued to grow.

While age and growth are the primary information to be extracted from otoliths, much other scientific research uses the shape and chemical composition of the otolith to discriminate between populations within a species or to trace the geographical movements of individuals. There is also a significant relationship between the growth of fish and that of their otoliths (Lagardère and Troadec, 1997; Fossen *et al.*, 2003; Mahé *et al.*, 2017). By measuring an otolith of a fish, it is therefore possible to estimate the size of the individual to which it belonged. Campana and Thorrold (2001) estimated that nearly 800,000 otoliths were used worldwide in 1999 alone to determine the age structures of commercial fish species, representing a sum of around 8 million Canadian dollars. Similarly, in 2010, 759,403 calcified parts were supplied by various countries to monitor stocks in European waters (ICES, 2011). Every year, more than a million calcified samples, mainly otoliths, are analysed worldwide.

The use of the external shape of the otolith within a species has been developed strongly in research to better understand fish populations and their geographical limits. This shape incorporates all of the variations in environmental conditions and climatic forcing during the life of the fish, alongside the genetic characteristics of the parents. Differences in otolith shape can therefore be attributed to geographical differences linked to the metabolic activity of the organisms, itself being the result of environmental factors and genetic components specific to each individual (Gauldie and Nelson, 1990; Smith, 1992; Begg and Brown, 2000). This use of otolith shape as a method of discriminating between stocks has developed since the 1990s, in particular with the studies by Pontual and Prouzet (1987) and Campana and Casselman (1993). Since then, scientists have developed a keen interest in using otolith shape as a tool for discriminating between fish stocks, with nearly 50 scientific articles published each year over recent years. Annual monitoring by a group of international experts (the Stock Identification Methods Working Group, set up by the International Council for the Exploration of the Sea, ICES) shows that otolith shape analysis is becoming the main method used to define and validate stock limits, ahead of genetic analysis. This predominance can be explained by recent advances in image analysis and data processing, in particular with the development of statistical tools such as R (R Core Team, 2023), or Shape (developed by Iwata and Ukai, 2002). These tools make it possible to carry out studies in larger numbers and at lower cost than the genetic tracer approach, while showing generally comparable results. Since the early 1980s, otoliths have also been used to understand the ecology of fish, based on their chemical composition. Otolith chemistry reflects both exogenous factors (water chemistry, depth, temperature, trophic availability, stress factors, chronic or accidental pollution, etc.) and endogenous factors (ontogeny, metabolism, reproduction, health, etc.) (Radtke and Shafer, 1992). By comparing the chemistry of the otolith with the chemical composition of the water in different places, it is possible to retrace the geographical route taken by the fish during its life, with understanding of the time spent in each place, if the chemical compositions are sufficiently distinct.

1. Species differentiation by otolith morphological characteristics

The external shape of otoliths makes it possible to identify the different fish species to which they belong. Analyses of shape are used in archaeological studies (Disspain *et al.,* 2016; Agiadi, 2022) or targeted at prey-predator relationships within a food web (Lowry, 2011; Stock *et al.*, 2021; Quigley *et al.,* 2023). Between species (i.e. at the interspecific level), there is no link between the size of individuals and the size of their otoliths (Campana, 2005). For example, pelagic fishes[2] such as tuna or swordfish may have small otoliths, while some small reef species may have large otoliths (Campana, 2005). Similarly, fast swimming fishes tend to have more elongated otoliths than those of bentho-demersal species[3] (Volpedo *et al.*, 2008; Tuset *et al.*, 2015).

The external shape of a fish changes from egg to adult. Its morphology therefore changes over the course of its life. This developmental process is called ontogeny. While genetic and environmental factors are sources of explanations for the shape of the otolith, the principle of ontogeny also plays a role. For the same individual, the shape of the otolith evolves over the course of its life, thus the life stage must be taken into account. In this book, several individuals of each species, distributed along a gradient of sizes observed in the natural environment, covering the different life stages (juveniles, young adults, adults who have already reproduced, etc.) are presented and analysed (Figure 2).

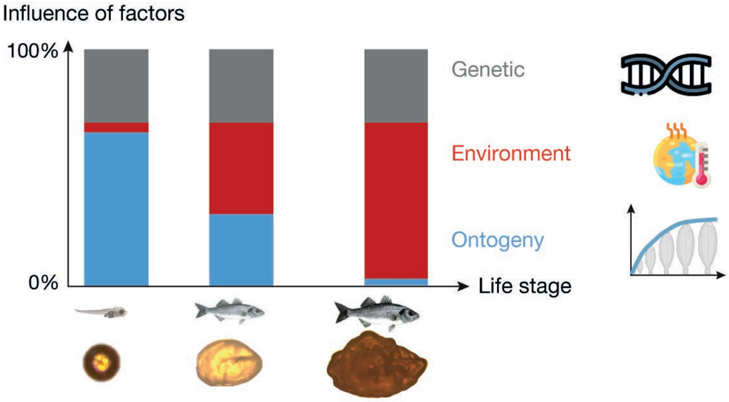

Figure 2. Influence of potential factors (ontogeny, environment, genetic inheritance) on the shape of the fish and its otolith at each life stage.

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[2] Pelagic fish live mainly at the top of the water column, close to the surface.

[3] Benthic species live at the bottom of the water column, i.e. close to the bottom, and feed mainly on animals in or on the bottom. Bentho-demersal species live close to the bottom, but may also spend part of their time in the middle of the water column.

Choice of species and harvesting

Only around 20 of the 120 species identified in the Channel and North Sea are currently exploited commercially, therefore the 22 most commercially exploited fish species were selected for this guide, taking three to five individuals per species for comparison of otoliths within or between species. The choice of the number of individuals enables the entire size range of each species to be accurately represented. For the adult stages, we discuss individuals of different sizes, without differentiating males and females. Among the species, there are two different morphotypes: flatfish, which interact strongly with the bottom, and roundfish, which interact less strongly with the bottom. In addition, these species live differently in the water column: some are pelagic and others benthic. All samples were taken by the Ifremer Institute, in particular by the team from the Channel and North Sea Fisheries Unit, during scientific campaigns carried out on the oceanographic vessel Thalassa. These samples were taken in the Channel and the North Sea as part of the international monitoring of fish populations to assess the state of health of commercial fish populations. Two scientific campaigns conducted by Ifremer each year for France covering the Channel and North Sea were used: the International Bottom Trawl Survey (IBTS, in January and February) and the Channel Ground Fish Survey (CGFS, in September and October).

Methodology

3D image acquisition

General principle of X-ray microtomography

The technique used to acquire images of the various otoliths is called X-ray microtomography[4]. This is a non-destructive and non-invasive technique used to characterise the microstructure of dense and porous materials. The technique is used in a variety of sectors, including medicine, materials, archaeology and the food industry. X-ray microtomography provides access to the 3D geometry of a sample from images acquired in 2D. The device acquires multiple X-ray images when the object is rotated a certain number of revolutions. Reconstruction software then transforms the 2D images into a 3D volumetric image.

Figure 3 shows the principle of X-ray microtomography acquisition. The sample is placed in the acquisition chamber and X-rays pass through the sample. Depending on the density of the sample, these rays are attenuated to a greater or lesser extent and are collected at the output by a detector, which produces an X-ray image of the sample. By rotating the sample, it is possible to acquire multiple X-rays taken from different angles.

Microtomography acquisition is defined according to a number of specific parameters.

The voltage (in kilovolts) and current (in milliamperes) parameters of an X-ray generator control the maximum energy and quantity of X-ray photons emitted by the source. The power of the X-rays emitted is determined by the voltage/current combination as a function of the density of the sample. The greater the density, the greater the power of the X-rays required to detect the object with the sensor.

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[4] The term “microtomography” comes from the X-ray source, a sealed tube with a focal spot of the order of a micrometre in diameter.