A. General introduction

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Etymologically, the term "sclerochronology" is derived from the Greek roots sklêros "hard", khronos "time" and logos "reason". Literally, this science aims to reconstruct the past history of living organisms from the study of their calcified structures (CS). Its scope covers problems of age estimation as well as the estimation of the time and duration of life history events. Its methods are based on the study of various types of signals that provide temporal references, whether structural, chemical and/or optical.

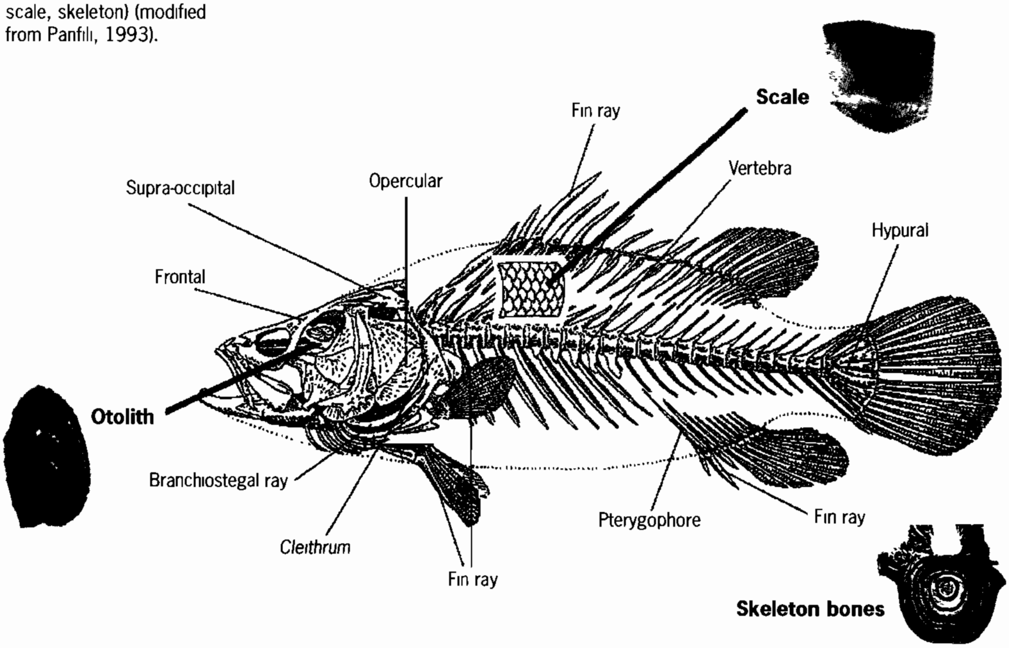
Data on the age and growth of fishes are essential for the understanding of vital traits of species and populations (e.g. lifespan, age at recruitment, age at sexual maturity, reproduction periods, migrations, mortality) and the study of population demographic structure and its dynamics (e.g. in age based stock assessment). The ecological and paleoecological applications of such data include the study of adaptive responses of populations to environmental pressures, whether natural (climatic variations) or anthropogenic (e.g. fishing, pollution, coastal zone development). Given the current poor state of many aquatic resources, the demand for reliable sclerochronological data for decision-making related to fishery management and sustainable exploitation of aquatic resources is growing.

As with the CS of some invertebrates (e.g. cephalopods, molluscs or hermatypic corals), it has long been observed that those of fish show roughly periodic structural patterns (fig. I.A.1) that are related to variations in growth rate induced by both environmental (biotic or abiotic) and endogenous factors such as ontogenic events (see Bagenal, 1974; Summerfelt & Hall, 1987). Sclerochronology has a great deal in common with dendrochronology, i.e. tree-ring science. The latter has developed, in a more easily studied environment (terrestrial environment and fixed site), an advanced methodology for the analysis of tree ring-climate relationships.

Calcified structures have the potential to grow throughout the life of the fish and act as a permanent record whose definition varies from one structure to another in relation to its specific biomineralisation processes and functional role. Three major types of mineralised parts have proved to be informative, resulting in the division of sclerochronology into three sub-disciplines (fig. I.A.1): scalimetry, which deals with scales, otolithometry, otoliths and skeletochronology, bones.

The assessment of individual age and growth through CS analysis rapidly proved to be much more informative and precise than statistical methods used at the population level (e.g. analysis of length-frequency data) or alternative individual methods such as metabolic pigment accumulation. In consequence, sclerochronology has emerged as a discipline capable of providing invaluable information to several fields of research, particularly in fishery sciences and marine ecology. To achieve this status, it had (and still has) to answer a number of very basic questions, many of which were (and still are) far from trivial:

Figure I.A.1
Various calcified structures that can be utilised for sclerochronological studies, and the three main types of structure (otolith, scale, skeleton) (modified from Panfili, 1993).



What does each CS record?

As permanent recorders, CS potentially constitute more or less precise individual biological archives which need to be decoded to extract the relevant and useful information. Visual signals present various kinds of periodicity which depend on both the CS and the scale of observation. For instance, while seasonal patterns may be observed on every CS, daily increments are only observable on otoliths at high magnification. Bones and scales act to different extents as reservoirs of calcium and phosphorus salts and thus undergo resorption and remodelling processes. Such properties have to be taken into account when interpreting the information provided by these structures. Disruptions in growth patterns are frequently observed and correspond to life events whose identity is sometimes anything but obvious. Moreover, information acquisition and interpretation are often complicated by the great plasticity of CS observable at various scales (individuals, populations, species). However, at the individual level, the interpretation of increments in CS can lead to a true chronological record of life events and growth.

What are the methods employed to reveal the information required?

Data provided by CS analysis result from an acquisition process in which methodology plays a pivotal role. Many methods of extraction, preparation and observation have been developed in the course of the 20th century, the choice of which depends fundamentally on the CS to be studied as well as on the level of information required (type and temporal precision).

Are the data obtained accurate and precise?

Data quality is a key issue in all sclerochronological studies. Age estimates that are neither accurate (i.e. close to the true value, which is essentially not known at least for wild fish) nor precise (i.e. presenting large disagreements between repeated measurements) would be of poor value for subsequent use.

Validation studies that aim to verify the presumed periodicity of a given signal are essential basis for sclerochronological studies. They are the only way to test the technology and the resulting accuracy of age estimation. It is also essential to assess data precision, i.e. variability between repeated interpretations (readings) of a given CS (either between or within readers) for revealing the most appropriate schemes for reading and interpretation. Recourse to computer vision techniques assists the reader at various levels of CS processing. Such techniques increase reading precision, provide unequalled measurement capability and allow interpretation data to be conserved.

Are the chemical patterns recorded informative and what do they reflect?

The idea that CS possess chemical tags or “chemo-prints” was recognised in the 1960s, opening another research field which is rapidly expanding thanks to the development of ever more sophisticated and sensitive analytical tools. The range of applications is potentially enormous, which explains the amount of research effort recently devoted to the field (more than 400 articles have been published during the past decade). The discipline also has to face questions of data quality, which is particularly difficult to assess, as well as those of interpretation of complex chemical signals that are under both environmental and physiological control.

How does this work?

Despite a rather long history and development, sclerochronology is far from being an exact science and, in many cases the decoding schemes for structures and chemistry remain incomplete and debatable, especially in some species. On-going experimental work in the laboratory and mesocosms provide strong sources of support for the validation of hypotheses drawn from field data. Ultimately, however, better understanding of the biomineralisation processes and regulation mechanisms is essential to the full interpretation of signals in CS.

The literature on fish CS is enormous: for instance the ASFA (Aquatic Sciences and Fisheries Abstracts) database contains more than 2 300 references on otoliths from 1978 to 2000. Although some specific topics have been dealt with in book reviews or symposium proceedings (e.g. Bagenal, 1974; Prince & Pulos, 1983; Casselman, 1987; Summerfelt & Hall, 1987; Baglinière *et al.*, 1992; Smith, 1992; Stevenson & Campana, 1992; Secor *et al.*, 1995a; Fossum *et al.*, 2000), none of these offers an overview of the current standing of methods, practices and applications of sclerochronology for new workers in the field or other interested end-users. This book is intended as an attempt to fill this gap.

The first part of the book deals with the basis of sclerochronological studies by providing descriptions of CS, their increments and the regulation of the incremental deposition process. The rationale behind sclerochronological studies and the uses of CS are mentioned in order to guide the reader for future analysis. A detailed description of the validation process is provided, as this is one of the most important steps in sclerochronology. Some uses of the data are then described in order to outline the most important applications of CS in research and fisheries assessment. As most laboratories involved in sclerochronology are now equipped with image analysis systems with capabilities ranging from fully interactive to automated data digitalisation, the basic principles of image processing of CS are also described. The book then provides a review of otolith microchemistry, which is a rapidly developing research field in sclerochronology. Finally, detailed descriptions of the numerous techniques for preparation and observation of CS are provided in order to help the reader to progress in this field.

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