# Abstract

Marine aquaculture production has increased considerably in recent years due to the scarcity of fisheries resources and increased demand. In 2013 world production reached 173,062 tons of gilthead sea bream (*Sparus aurata*) and 161,059 tons of European sea bass (*Dicentrarchus labrax)*, produced mainly in Greece, Turkey, Spain and Italy. Gilthead sea bream and European sea bass are among the most interesting species for cultivation in Spain. Its cultivation area is limited to temperate waters and is usually cultivated in floating cages systems. Fish growth and biomass estimations are essential to prepare the production plan of fish farms, as well as to organize and to perform management operations such as sorting and distribution of fish, downloading new lots, harvesting schedules, calculating daily feeding rates, etc. It is necessary to optimize these production processes, not only to improve economic profitability but also to minimize the environmental impact of the facilities. These processes include feeding strategy, growth and population monitoring. The daily dose of feed is estimated from the estimated biomass and different factors such as the average size of the fish, the season, the water temperature, etc. Therefore, size and number of fish estimations are crucial for the proper management of production.

Acoustic techniques are most appropriate for remote sensing in the water, because acoustic waves travel long distances compared with electromagnetic waves which are attenuated very quickly. Light does not penetrate more than a couple of hundred metres below the water surface, even less when the medium is loaded with suspended solids or biota such as plankton. Thus, acoustic instruments that transmit and receive sound waves are able to detect fish or other far objects that are beyond the field of view. For this

reason, acoustic technologies have had a major impact on the detection of fish. For several decades acoustic methods have been employed to detect shoals of fish, so that the information provided by sonars and echo sounders is an important factor in the efficiency of current fishing operations.

Today acousticians are investigating ways to accurately determine the biomass in cages by noninvasive techniques, which go through the estimation of fish abundance and size distribution. Similarly, these techniques can allow the study of the behavior school in floating cages, the control of the feeding process and even the species identification. The methodology of scientific or commercial echo sounders have been directed mainly towards pelagic fishing, and it is necessary to evaluate whether the equipment and algorithms can be applied in the control of marine aquaculture farms.

In order to evaluate the biomass of fish in cages, two techniques for estimating size are evaluated in this thesis, whilst the study of energy returned by the school of fish is addressed to estimate abundance, as discussed in Chapter 1. Also the acoustic response of pellets by size is characterized.

In Chapter 2 general information about gilthead sea bream and European sea bass and their farming in floating cages is included, in order to facilitate the understanding of the behavior of animals and the interpretation of the acoustic field scattered by their bodies. The basic concepts and formulations used in acoustics to estimate biomass are described in Chapter 3, which are useful for understanding this thesis. A homogeneous, isotropic and non-dispersive medium is assumed, in which pressure variations are of small amplitude, so that the nonlinear effects can be neglected. Sonar equation is approached from the study of the propagation of a sound wave in a fluid and from the dispersion of the sound field produced by a target. The electroacoustic transducer parameters are also discussed. The necessary concepts for size and abundance estimations from energy returned by fish are included. Besides the expressions used by two of the most commercialized scientific echo sounders, the Simrad EK60 and DT-X Biosonics, are summarized.

In Chapter 4 the suitability of using scientific sounders for estimating size from echo detection from individual targets is studied, with the peculiarity that fish are close to transducer. Ventral and dorsal aspects of the target strength (*TS*) are measured for five different sizes of gilthead sea bream at a frequency of 200 kHz. The measurements are carried out in a small distance range, similar to the distances involved under production conditions to detect single fish. *TS* measurements at close distances to transducer imply a series of complications and uncertainties primarily due to the near field of the fish, compensation of propagation losses of the acoustic wave, determination of incidence angle of the backscattered sound field and alteration of echo envelope caused by the finite size of fish. The relationship between *TS* and size will allow indirect estimation of fish size from acoustic measurements.

In Chapter 5, applicability of scientific echo sounders for estimation of average size and abundance of fish in cages of gilt head sea bream and European sea bass in production conditions, which are characterized by a reduced distance between transducer and fish as well as high densities, is evaluated. Two frequencies, 123 and 201 kHz, are used to evaluate dorsal aspect of *TS*. The study of *TS* for determining fish size is limited to the volume above the shoal where detections from isolated fish are obtained, being unviable the evaluation at greater distances where the high density of school hinters the echo detection from multiple targets. The abundance of fish is evaluated by integrating energy backscattered by the school.

In Chapter 6 an alternative method for estimating fish size is proposed, based on measurement of the difference of flight time between two peaks of the same echo, which correspond to reflections of the pulse transmitted in different parts of fish body. The method is evaluated for ventral and dorsal aspect of gilthead sea bream, using a single-beam transducer operating at 200 kHz.

Finally, in Chapter 7 the acoustic response of pellets versus their size is measured using a scientific echo sounder working at 200 kHz, enabling the detection and identification of pellets fall in cages under production conditions.