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STIME DELLA BIOMASSA MARINA ATTRAVERSO IL METODO ACUSTICO: DISCERNIMENTO DELLE SPECIE E GESTIONE DELLE RISORSE ITTICHE

ACOUSTICAL ESTIMATION OF FISH BIOMASS: SPECIES IDENTIFICATION AND STOCKS MANAGEMENT

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RIASSUNTO

L'acustica è alla base delle più importanti tecnologie nelle telecomunicazioni subacquee, nonché nel rilevamento e nella determinazione dei target acustici nei mezzi acquatici. Le misure a multi-frequenza sono lo strumento principale per l'identificazione selettiva delle specie marine e per la pesca sostenibile. Lo sviluppo di sistemi a larga banda larga e le tecniche basate su sonar multi-beam costituiscono l'attuale sfida per gli scienziati e gli sviluppatori. Al contempo, sistemi più semplici ed economicamente efficienti, come boe satellitari, sono in grado di offrire informazioni per il monitoraggio degli ecosistemi o l'individuazione di specie bersaglio nella pesca marittima.

ABSTRACT

Acoustics is the basics of the most important technologies for underwater telecommunication, as well as for target detection and identification in the aquatic media. Multiple frequency measurements are the key for species discrimination and open the door for sustainable fisheries. The development of wider broadband systems and quantitative multi-beam sonars and processing techniques constitute the present challenge for scientists and developers. In parallel, simpler and cost-efficient systems like satellite buoys can offer clue information for marine ecosystem monitoring or target species fisheries.

Parole chiave: Acustica subacquea; Acustica della pesca; Ecosistemi marini, Acquacoltura
Keywords: Underwater acoustics; Fisheries acoustics; Marine ecosystems, Aquaculture.

1. Introduction

The most important technological revolution of the 20th century consisted probably in the use of electromagnetic (E-M) fields to communicate at long ranges, as well as to detect objects and to characterize them remotely through the space and the atmosphere. Nevertheless, the aquatic medium is almost impenetrable to E-M fields, just with the optical frequencies of sunlight vanishing at a depth of a couple of hundred meters, whilst radio- and micro-waves extinguish at some meters and centimetres ranges. In order to have an image of the underwater landscape and their inhabitants, the mankind started to mimic the natural tools of marine mammals and other species, developing hearing techniques to locate and to identify sound sources (passive acoustics) as well as emitting and receiving systems that could map the sea bottom an locate and characterise underwater sound scatterers (active acoustics). Active acoustics implies, first, the emission of a short ultrasonic pulse, formed by a determinate number of pressure wave oscillations, that can travel through the aquatic medium at a considerable speed (1500 m/s, three time faster than in air) and relative low attenuation (1000 times lower than in the atmosphere). Second, the echo, or backscattered signal, has to be detected. Depth of the sea bottom or of any mid-water object can be then calculated dividing by two the time of flight of the ultrasonic pulse, for a given sound speed in the medium that depends strongly on temperature, salinity and hydrostatic pressure (depth). Underwater acoustics techniques were boosted, like other branches of science, by the military effort of the two world wars and the following competition between blocks during the cold war, but their use in science and particularly fisheries research started from the very beginning of its technological implementation.

2. Fisheries acoustics

The first fish detection using active acoustics were reported in 1926 by the French explorer Rallier du Baty [1] detecting mid water column echoes on the Grand Banks that he attributed to fish school presence. In 1929, the Japanese scientist Kimura [2] observed that the amplitude detected by the transducer changed following the number of sea breams inside the ultrasonic beam in an aquaculture pond. Beginning the 30s, Ronald Balls, in England, and Reinert Bokn, in Norway, experimented independently with echosounders. The first echogram to be published was recorded by Bokn in Frafjord, showing sprat schools [3]. In 1935, the Norwegian scientist Oscar Sund reported his classical echogram of cod schools [4], marking the first use of echosounding for fisheries research.

After the Second World War in the 50s, there were major advances in fishing echo sounders applications that were used to estimate the relative abundance of fish by counting traces recorded in the printout from the echo sounder. In the decade of the 60's efforts to count and estimate the size of the fish from their acoustic echoes went on. The start of the quantitative assessment of fish stocks by acoustic techniques was marked by the use of an electronic integrator that processed fish echoes. The methods for estimating the stock of fish have been progressing in recent decades. There is currently more stable and reliable equipment, and signal processing of echoes from fish is much faster and more accurate. More and more studies of fish behavior, orientation, density, distribution and any other factors that may affect the results obtained by acoustic techniques [5, 6] are continuously performed.

Today, scientific echo sounders are used for stock assessment in fisheries, mainly for pelagic species, like the small ones in the Mediterranean sea, the sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*), and are the reference method to tune other classical estimation methods [7], even becoming one of the most important tools for the ecosystems description and management, one step beyond the classical concept of natural resources exploitation [9].

In their basic scheme, an acoustic pulse is emitted and backscattered sound waves by shoals of fish are recorded and processed by the echo sounder. For estimates of fish abundance (density), the acoustic energy backscattered by unit volume (or S_v) inside the beam is evaluated, while for the estimation of the fish size, the sound returned from individual specimens (the so-called *target strength*, *TS*) is studied and evaluated. *TS* is the clue for biomass estimation, applying linear superposition principles; the total backscattered energy by the school or aggregation is integrated together, and this total is divided by the (previously determined) backscattering coefficient of a single animal, giving an estimate of the total number [8]. The capability of single fish echo detection, of discriminating the species of each single trace in the echograms, and to establish accurate relationships between *TS*, size and individual weight are the clue for acoustical estimates.

2.1 The scientific echosounder and the multi-frequency approach

Scientific echosounders are calibrated electro-acoustical systems that allow to estimate unbiased (or at least with accurately determined error levels) *TS* values from single fish detections. The vertical echosounders evolved during the 80's with the use of split transducers that allowed the single target trajectory tracking from the phase differences between receiving transducer sectors, improving the single fish identification in the echograms, and introducing the compensation of the beam directivity in the calculation of the *TS*; this parameter is evaluated as the ratio of backscattered intensity (I_{back}) to the incident on the evaluated object (I_{inc}), and expressed, as it is common in acoustics, in decibels:

$$TS = 10 \log(I_{back}/I_{inc}) \quad \text{[dB]} \tag{1}$$

When a object is not placed just in the centre of the acoustic beam (scientific echosounders emit beams between 7 and 15 degrees of aperture), the incident intensity is lower and the received backscattered energy is lower too, resulting in an underestimation of the *TS*. Split beam echosounders can compensate this effect, “limiting” the *TS* variability to the fish orientation, size, species (anatomical and physiological factors that vary with depth, season, spawning time, condition, ...), which are no minor effects, together with a fundamental element: the acoustic frequency. The ratio between the organism size (and of its inner structures) to the wavelength of the ultrasonic pulse governs the *TS* value. The presence of gas-filled inclusions can suppose 90% of the backscattered energy from a living organism, that is, a difference of 10-15 dB in the *TS* from similar size fishes, with and without swimming bladder [10]. This is an inverse problem, and different solutions are available for the same input: a small swimbladdered fish can have the same acoustic response that a big fish without it. The only alternative is the multi-frequency measurement of the *TS* that can give more information about the particular species/size curve. This has been done until now with multiple transducers and echosounder electronics, and a new generation of broadband echosounders with frequency sweeping capabilities aspire to cover the colour vision needs of fisheries research [11, 12].

Parametric echosounders, formerly used to explore the subbottom properties, since they produce low frequency emission inside the same beam volum of the emitted high frequency ultrasonics beam, have been proposed for multi-frequency biomass estimation and constitute a promising tool for long range detection and dense schools [13].

2.2 Multi-beam systems

Vertical echosounders provide biomass data in the water column, and their estimates are offered in terms of kilograms per square nautical miles, that is, per sea surface unit area covered by the vertical projection of the acoustical beam. Statistical approaches and specific design of the acoustical transects to be covered in a sea campaign, based in the knowledge of the ecosystems and species object of study, are the clue to obtain good estimates of fish populations [14].

The limitation to the down-looking perspective, the search for better spatial description of the size and structure of fish schools, has led to the development of scientific multibeam echosounders and sonars. These systems are array-based devices with the capability of forming very narrow beams (about 1 degree) and steering them in wide angles (up to 90 degrees) covering large volumes below or to one side or in front of the ship (typical 60x45 degrees). The difference with the traditional 360 degrees long range sonars is their quantitative character, subjected to scientific calibration, and the capability of synchronized use with vertical echosounders for a better description of the detected schools composition [15]. The large amount of information provided, together with the need of new methodologies and software for plotting and analysing, and the general lack of 3D information of different species have limited their present use in populations assessment. New efforts on *TS* modelling to interpret multi-beam measurements are under development [16], and the number of applications and advantages of the new multi-beam systems will grow together with its increasing availability from the budget point of view and its generalisation in the scientific and commercial communities.

2.3 Fishing target species with satellite buoys and DFADs

In recent years, single beam echosounders (operating at single, two or three frequencies) have been introduced in satellite buoys associated to drifting fish aggregation devices (DFADs) used by purse seiners of tropical target species of tuna. DFADs are floating structures that aggregate marine life with the aim of attracting tuna schools. In spite of the negative impacts of DFADs described in the literature, the role of acoustics can mitigate and change some of them, avoiding by-catch of non-target species, identifying best fishing practices and applying decision criteria depending on detected fish size, that could be even of mandatory application like in the regulation of bluefin tuna (*Thunnus thynnus*) fishing in the Mediterranean [17].

The strategy in this low-cost systems must be necessarily different to that applied by oceanographic vessels equipment: they can include more than one frequency, but every acoustical information should be pre-processed and sent minimized information through satellite links. The mentioned objectives could be fulfilled if they are transformed in small scientific stations, that can run decision algorithms on-board their processors.

Wider band transducers and electronics, pulse compression, single target strength evaluation, echo characteristics, school size, depth, behaviour,..., all these elements should be included in the next generation of satellite buoys for tuna fishing.

3. Cost effective acoustical monitoring of marine ecosystems

3.1 Cost effective scientific echo sounders in buoys, moorings, landers and ROVs

Everything that has been exposed for the echosounders on board satellite buoys has a great potential for scientific use in behavioural studies or in long term habitat monitoring. The application of the European directive for marine strategy implies the monitoring of several indicators of the good environmental state of our seas, including biodiversity, non-indigenous species, etc. The active acoustics tools are a crucial element to combine with video tools in every selected study platform (buoys, moorings, landers automated or remote operated underwater vehicles (AUVs/ROVs). It is necessary to expand the acoustic knowledge of non-commercial and protected species, in order to feed the processing capabilities of the automated monitoring systems, and therefore reducing the transmission and power budget needs of the scientific networks.

3.2 Passive acoustics for stock assessment

Together with the classical and innovative use of active acoustics as described above, passive techniques have been proposed to complete the acoustic picture of ecosystems.

Herring (*Clupea pallasii* and *C. harengus*) have been observed to release gas from their bladders during vertical migration likely to adjust buoyancy and also when under strong predation pressure. Field measurements of potential gas-release events agree with models predictions for a compact school with regard to levels and spectral shape and indicate that passive acoustic monitoring is feasible and could be a prime tool to study predator-prey interactions [18]. Also bluefin tuna (*Thunnus thynnus*) and yellowfin (*Thunnus albacares*) vocalisations have been described in [19].

4. Acoustic control of aquaculture installations

In the last decades aquaculture has become a fundamental activity to cover the human needs of food, providing today the 50% of the products with aquatic origin, and having an increasing demand, supposed to reach the 65% in 2030 [20]. Fish farming constitutes almost the half of the aquaculture effort, and several of the most important commercial fish species, like Atlantic salmon (*Salmo salar*), Gilthead sea bream (*Sparus aurata*) or sea bass (*Dicherantus labrax*) are intensively cultivated in floating sea cages, where juvenile stocks are introduced to be fed until they reach the desired commercial sizes. A critical aspect of the production process, both from the economical and the environmental impact point of view, is the adequate dosage of pelleted food, which is calculated as a function of the fishes biomass, in order to achieve optimal growing rates. Fish size monitoring tools are then crucial to improve the farms management, and different sampling methods have been developed, being the stereoscopic optical image recording the most successful non-invasive one, since it provides fish size measurements (length and height) which are the input for biometric relationships to obtain fish weight.

Nevertheless the estimation of total biomass in the cage remains as an open problem and the use of acoustics have been proposed to cover the limitations of optical techniques. Acoustical target strength (*TS*) measurements from single fish tracks for size monitoring and volume backscattering strength (S_v) scaling for fish density and total biomass estimations are the common proposed approaches, like in fisheries acoustics. Research addressed to the biomass estimation in aquaculture floating cages evidenced the problems associated to near range measurements and dense aggregations, but they offered important tools for sustainable (both economically and ecological) aquaculture management with the existing technologies [21, 22].

Conclusions

Acoustics has played a fundamental role in the exploration of the seas and their fisheries resources. The change in the man concept, from stocks to ecosystem based management, constitutes a new opportunity for more complex tools both passive and active, given response to the challenge of sustainable exploitation of wild resources and of aquacultured species.

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