Dissertations

Mechanisms of sound scattering by biological targets and their aggregates

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Post-doctoral (habilitation) thesis in underwater acoustics.

Natalia Gorska's thesis is based on a set of 9 papers published in scientific journals (Gorska & Klusek 1998, Gorska 2000, Gorska & Chu 2001a, b, Gorska & Ona 2003a, b) and conference proceedings (Gorska & Klusek 1994, Gorska 1999, Gorska & Chu 2000), which broadly summarise her integrated research achievements in underwater acoustics from 1994 to 2003. She is the sole author of two of the articles (Gorska 1999, 2000), and is the first co-author, taking a leading part, in the others (Gorska & Klusek 1994, 1998, Gorska & Chu 2000, Gorska & Chu 2001a, b, Gorska & Ona 2003a, b).

Her research objective was to work out the theoretical background to certain problems of sound scattering by biological targets – single individuals and aggregated layers of fish and zooplankton – in relation to environmental conditions in the sea. In the study she focused on acoustical extinction and backscattering, including the phenomenon of echo interference. In conjunction with the co-authors of papers Gorska & Ona 2003a, b, Gorska & Chu 2001a, b and Gorska & Chu 2000, she was able to apply and verify her theoretical results empirically.

In her thesis, the author addresses three problems, corresponding chronologically to the various stages in her research programme.

The first problem (1994–2000) (Gorska & Klusek 1994, 1998, Gorska & Chu 2000) concerns the backscattering of a plane monochromatic acoustical wave and rectangular pulse by a layer of zooplankton and its modelling by statistical analytical and numerical algorithms. The models she worked out apply to targets scattering sound isotropically and to others of various dimensions, and accidental spatial dispositions. Her results show that the echo interference in an extremely dense zooplankton layer is particularly significant. The effects of the bio-acoustical (density and sound velocity contrasts of biological tissue) and geometrical (average length, elongation coefficient, bending rate) characteristics of single scattering individuals are likewise significant. Her analysis of the probability density function's (spatial target distribution) effect on backscattering in the near and far acoustical fields has yielded important results. The echo-interference study is of practical importance as regards justifying the echo-integration method used to estimate biomasses of fish and zooplankton.

The second problem (1999–2001) (Gorska 1999, Gorska 2000, Gorska & Chu 2000, 2001a, b), a direct consequence of the development of the models mentioned above, relates to the role of acoustical extinction by biological targets and their assemblages in the measurement of ultrasonic signals and their application for the acoustical estimation of fish and zooplankton abundance in the sea. In systematic theoretical studies, the author derived analytical expressions for extinction cross-sections and obtained solutions for biological targets of various geometrical shapes (straight cylinder, bent cylinder and prolate spheroid); she also compared her results with experimental data. On the basis of the MB-DCM (Modal Based-Deformed Cylinder Model) approach, she obtained results for different species of fish and for conditions, hitherto unexamined, where acoustical extinction had not been taken into account (fluid-like zooplankton), demonstrating the significant influence of extinction by assemblages of such individuals. In her thesis, she compares her results obtained using the MB-DCM method with the results of parallel calculations employing the PC-DWBA (Phase Compensated-Distorted Wave Born Approximation) approach (originally applied by D. Chu) and demonstrates good agreement between the two approaches; she discusses the conditions of their applicability and their limitations. The results of her meticulous analysis of the sensitivity of the extinction cross-section to sound frequency and the geometrical shape of scattering targets within a significant range of variation of the $\boldsymbol{ka}$ parameter for zooplankton and fish are original and have important practical applications. The author also compares her results with the experimental data available in the literature: they stand up to scrutiny. There are interesting calculations of the relations between the extinction cross-sections of several species of krill, which could well have practical applications.

The third problem, covered by the papers from 2002–2003 (Gorska & Ona 2003a, b), refers to acoustical signal backscattering by single herrings and their aggregations in relation to an environmental factor (depth) and the morphology of these fish. The author developed a theoretical physical interpretation of the important experimental results obtained by Prof. E. Ona (Institute of Marine Research, Bergen, Norway). To do so, she modified the MB-DCM approach to take into account the behaviour of such a target under natural conditions. A matter of especial importance was to understand the experimental dependence, observed in the sea, of the target strength on hydrostatic pressure or on the depth at which a fish happens to be. Dr Gorska worked out analytical and numerical models for sound signal backscattering to consider the effects of hydrostatic pressure variations with depth resulting in fish swimbladder compression with depth during herring vertical migration, the different orientations of individual fish in their aggregations, and the morphology of the fish itself. The model took into account backscattering not only by the swimbladder but also by the fish's entire body. The backscattering by individual fish and fish in aggregations (mean backscattering cross-section) were considered. The impact of the contraction rate of the swimbladder, the frequency of the acoustical signal, the orientation of the fish in space, and backscattering by the fish's body on the total backscattering turned out to be significant. Comparison of the theoretical results with the experimental data in the case of the herring indicated that the variations in target strength with depth were caused by swimbladder compression. It also showed that calculated and experimental data agreed more closely when the length of the swimbladder varied with depth (introduced to the model) more slowly than its width. This led to the conclusion on how the shape of the swimbladder contracts with depth. This study has contributed to the development of the target strength – length relationship for Norwegian spring-spawning herring, as recommended by ICES for the acoustical estimation of its abundance.

By improving the understanding of scattering mechanisms of biological targets, the results presented by Natalia Gorska in her thesis are valuable contributions to marine science. Her theoretical analytical and numerical study has enriched the cognitive and methodological aspects of underwater acoustics. The practical application of her results will lead to more exact and more effective acoustical monitoring methods for determining the abundance and species composition of biological resources in the sea.

The list of publications on which this post-doctoral (habilitation) thesis is based:

Gorska N., 1999, *On sound extinction by zooplankton*, Proc. 2nd EAA Int. Symp. on Hydroacoustics, 45–50.

Gorska N., 2000, *Evaluation of sound extinction and echo interference in densely aggregated zooplankton*, Oceanologia, 42 (3), 315–334.

Gorska N., Chu D., 2000, *Some aspects of sound extinction by zooplankton*, Proc. 5th Eur. Conf. on Underwater Acoustics, ECUA, 2, 1467–1472.

Gorska N., Chu D., 2001a, *Some aspects of sound extinction by zooplankton*, J. Am. Acoust. Soc., 110 (5), 2315–2325.

Gorska N., Chu D., 2001b, *On sound extinction by biological targets*, Hydroacoustics, 4, 69–80.

Gorska N., Klusek Z., 1994, *Possibilities of acoustical diagnostics of plankton space distributions*, Proc. 11th Symp. on Hydroacoustics, 143–148.

Gorska N., Klusek Z., 1998, *Dependence of scattered acoustical signal intensity on the form of distribution of plankton concentration*, J. Am. Acoust. Soc., 104 (1), 141–145.

Gorska N., Ona E., 2003a, *Modelling the acoustical effect of swim bladder compression in herring*, ICES J. Mar. Sci., 60 (3), 548–554.

Gorska N., Ona E., 2003b, *Modelling the effect of swimbladder compression on the acoustical backscattering from herring at normal or near normal incidences*, ICES J. Mar. Sci., 60 (6), 1381–1391.

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