Rapp. P.-v. Réun. Cons. int. Explor. Mer, 170: 130–135. Février 1977.

THE USE OF SWIMBLADDER RESONANCE IN THE SIZING OF SCHOOLED PELAGIC FISH

D. V. Holliday

TRACOR, Inc., 2923 Canon Street, San Diego, California 92106, USA

An acoustic method for remotely determining the presence and size of gas-filled swimbladders in schools of pelagic fish from a drifting ship has been extended to underway operation. Resonance structure was observed at ship speeds of up to five knots. In the absence of direct sampling of the schools studied, the underway results are compared with data for which samples of the school were available.

INTRODUCTION

Frequency-selective sound scattering from marine organisms has been principally used to study deep scattering layers (Hersey and Backus, 1962; Farquhar, 1970). Both acoustic theory and experiments, validated by net hauls, indicate a major role for the gas-filled swimbladders of mesopelagic nekton and plankton in the acoustic backscattering from deep scattering layers. An extension of the technology developed in the study of the deep scattering layers has led to investigations of the frequency distribution of energy in echoes from pelagic fish schools. Recent acoustic measurements indicate that the presence and average size of gas-filled swimbladders in a fish school can be remotely determined. In order to optimize the acoustic conditions and to maintain a lengthy contact with the fish schools studied, previous measurements (Holliday, 1972) were made from a drifting ship. This paper reports the results of an experiment designed to aid in the development of a system for making underway measurements of the acoustic transfer function of pelagic fish schools.

SUMMARY OF RESULTS FROM DRIFTING SHIP

During the period from January to June 1971, measurements were made of the square of the magnitude of the acoustic transfer function of several fish schools in the Los Angeles Bight (Holliday, 1972). The

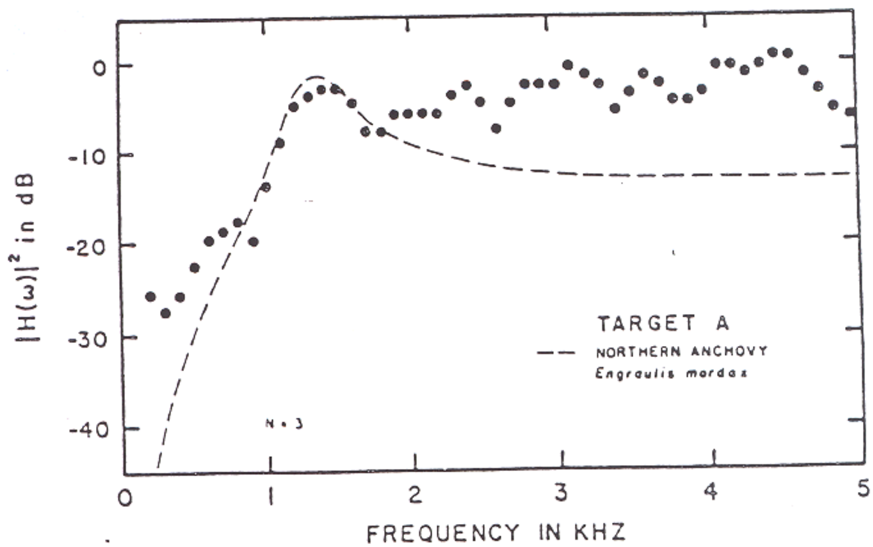

Figure 106. Acoustic data for target A, northern anchovy (*Engraulis mordax*). Dots represent experimental measurements; the broken line represents theoretical predictions.

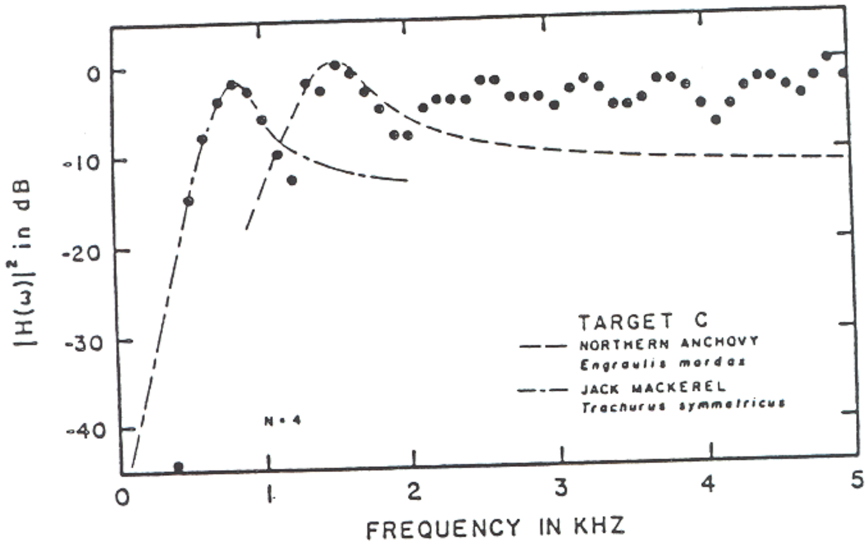

Figure 107. Acoustic data for target C, northern anchovy (*Engraulis mordax*) and jack mackerel (*Trachurus symmetricus*). Dots represent experimental measurements; the broken lines represent theoretical predictions.

quantity measured is proportional to the acoustic back-scattering cross-section and contains information on the presence and size of gas-filled swimbladders in a fish school.

The acoustic technique was analogous to the impulse response method of transfer function measurement widely used in linear circuit theory (Thomas, 1969). A small explosive charge was detonated near the ocean surface to provide the acoustic impulse. Since the formation of an echo from a fish school is a stochastic process, an ensemble average of the energy spectra of several (N) echoes from each target was used to calculate a transfer function for each school. Acoustic transfer functions for two of the schools (Targets A and C) are illustrated in Figures 106 and 107. Existing theory (Andreeva, 1964; Weston, 1967) was used to compare the experimental measurements with

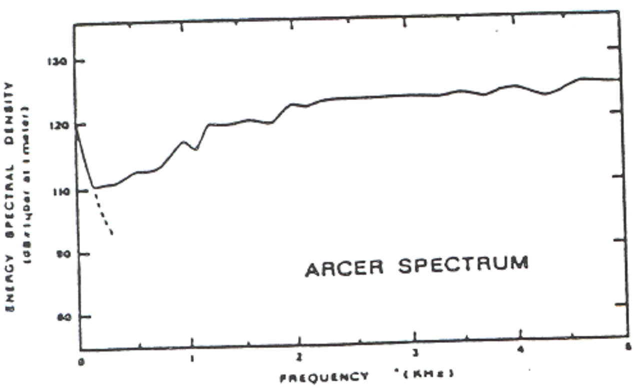

Figure 108. Power spectral density of arcer acoustic source. Average of three sequential shots.

theoretical predictions based on a sample of fish from each school. The theoretical curves were based on scattering from swimbladders only, and differences between these lines and the experimental points were attributed to scattering from scales, bones and flesh.

The fish schools were partially captured by a purse-seiner after the acoustic work was performed. The northern anchovy (*Engraulis mordax*) in a sample of 89 fish from Target A ranged in length from 99 mm to 137 mm with a mean standard length 116 mm. Target C contained both northern anchovy and jack mackerel (*Trachurus symmetricus*). In a sample of 90 anchovy the lengths ranged from 97 mm to 146 mm. The mean standard length of the jack mackerel was 180 mm.

ACOUSTIC TECHNIQUE FOR UNDERWAY OPERATION

Based on the results of experiments performed while drifting, an experiment was designed for making the same measurements from a ship which is underway at a speed of 3–5 kn. Several major modifications were made in the original data acquisition system. Explosive acoustic sources previously used were replaced by a towed arcer source originally developed for seismic profiling. The single omnidirectional hydrophone originally used to receive the echo was replaced with a 3 m long, one hundred element towed line array. The elements were wired in parallel, forming a 26° wide beam at 1 kHz. The arcer was towed near the centre of the line array at a depth of less than 1 m. The depth of the line array ranged between 0·5 m and 1 m, depending on the ship speed. A lateral separation of the

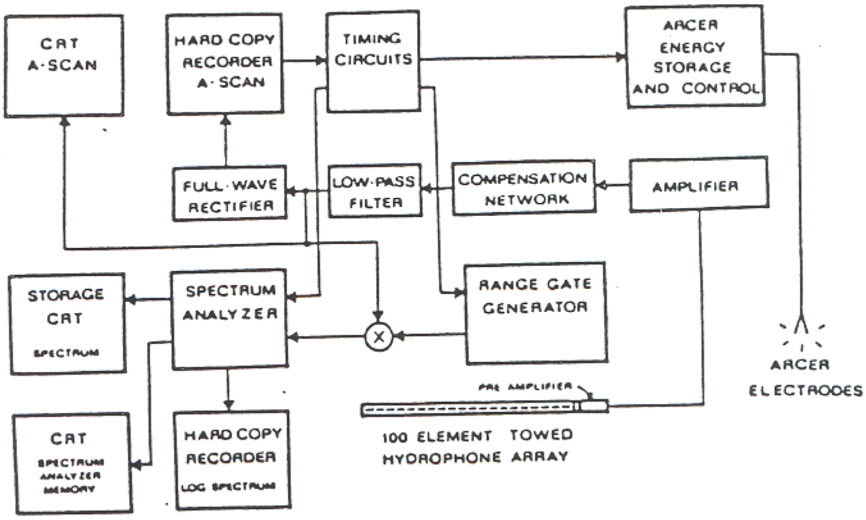

Figure 109. Data acquisition system for resonance research conducted while underway.

arcer and the hydrophone array was obtained by towing the two devices from different sides of the fantail.

The towing depths were chosen to minimize the Lloyd's mirror interference patterns in the frequency band of primary interest which was 1—5 kHz. Operating the arcer at depths of less than 1 m presented no problems in the calm seas encountered.

30 kJ of electrical energy was discharged through the arcer electrodes in less than 0·5 ms at 4 s intervals. The acoustic energy spectral density resulting from the discharge is illustrated in Figure 108 which is a graph of the average of the spectra of three sequential direct arrivals from the arcer acoustic source. The sharp rise in energy below 100 Hz is due to ship noise sources, principally the main propulsion system.

Figure 109 shows the data acquisition system used in the underway resonance research. After initial amplification of the echo from a volume of water at a preset range from the ship, detected by the towed hydrophone array, the signal was passed through a simple passive network to compensate for a lower acoustic source level at frequencies below 2 kHz (see Fig. 108). The transfer function for the compensation filter is illustrated in Figure 110. The consequence of compensation to provide a flat system response was to make the spectrum analyzer output equivalent to the transfer function of the fish school.

Continuous monitoring of the water slightly ahead of the ship's beam with an 11 kHz sonar allowed the system operator to set a school's range into the data acquisition system before the school was aligned with the acoustic beam of the towed array. The stylus on the hard-copy recorder (Fig. 109) was used to trigger the arcer discharge and a digitally controlled timing sequence. An analog range gate was generated on command from the timing circuits and an echo from the school under investigation was digitized and captured in the memory of a hybrid digital-analog spectrum analyzer. The captured echo was made available for examination on an oscilloscope display. This allowed the experimenter to make adjustments to input levels, in order to make maximum use of the limited dynamic range of the spectrum analyzer. During the charging time for the arcer capacitor bank, the spectrum of the captured echo was displayed repeatedly on a hard-copy recorder. A log transform of the spectrum was made before writing on the recording device in order to more closely match the dynamic range of the spectrum analyzer to the dynamic range of the paper display. The spectrum was also displayed on a storage scope for more detailed on-line analysis than is possible with the dynamic range of the paper display.

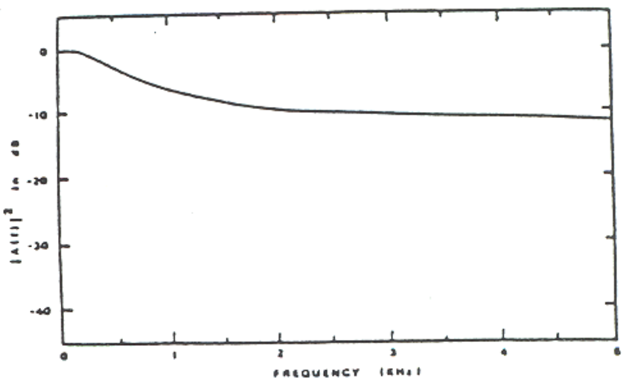

Figure 110. Transfer function for arcer source compensating network.

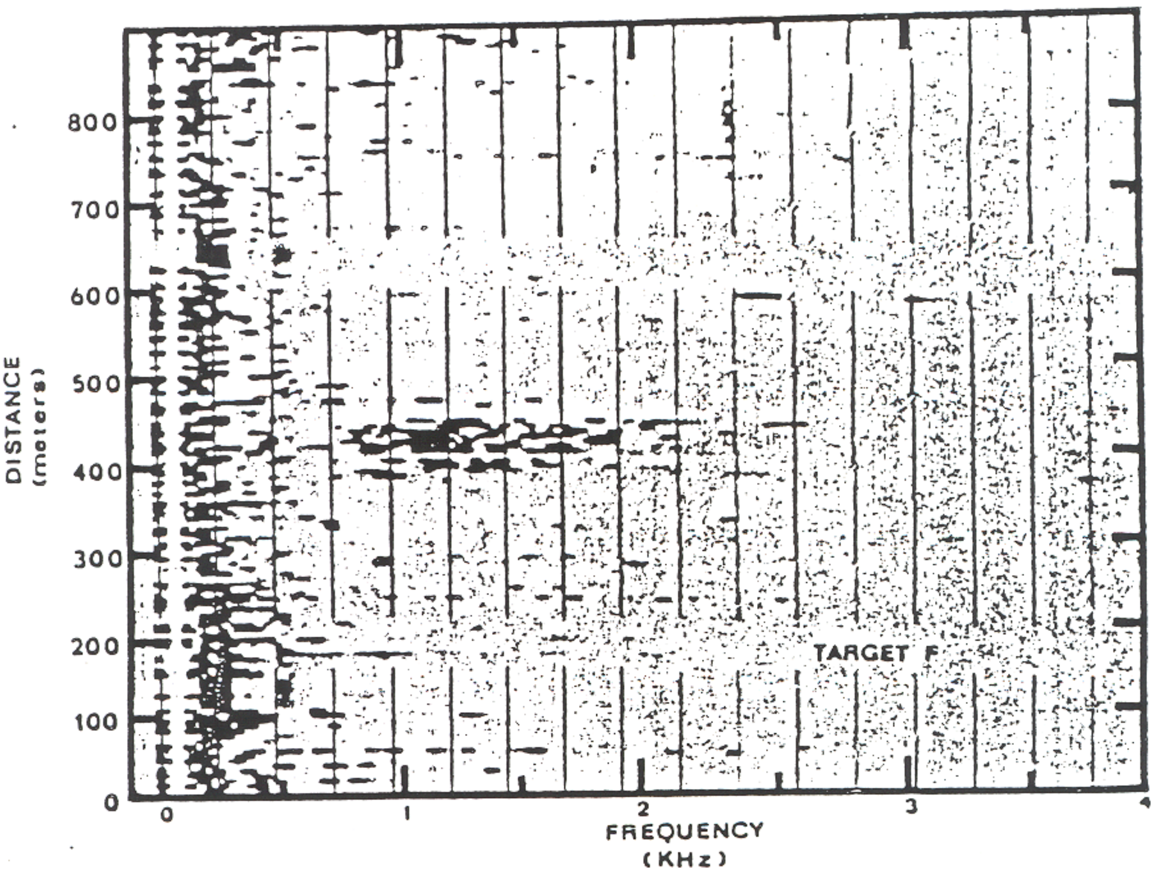

Figure 111. Acoustic signature for target F.

ACOUSTIC DATA

The acoustic transfer functions for two fish schools, designated targets F and G, are shown in Figures 111 and 112 respectively. The ordinate is distance along the track of the ship. The ship was underway at a speed of 3 kn. Frequency is displayed on the abscissa and the energy spectrum (fish school transfer function) is displayed as marking intensity, light marks representing less energy than dark marks.

ANALYSIS AND DISCUSSION

For many epipelagic marine fish, school depth and the distribution of fish in depth are not readily measured with current active sonars. Use of an echo-sounder to obtain school depth has frequently not proved practical because, in attempts to position the ship over shallow schools, the fish swim out of the track of the approaching ship or split into two schools. Consequently, accurate data for school depth, one of the parameters necessary for the precise interpretation of the data in Figures 111 and 112, are not available. The best estimate of depth for targets F and G comes from the observation that both schools were seen from the ship as areas of slightly different colour from that of the surrounding water. This observation places the upper boundary of the school in the upper 10 m.

Economic considerations precluded the capture of targets F and G. A comparison with targets A and C referred to above (Holliday, 1972) is of some value, however. Even in the absence of accurate information on school depth, the similarities between the spectral signature of target F (Fig. 111) and target A (Fig. 106) are apparent. Target A was principally northern anchovy. The top of target A was 10 m below the surface. Likewise, a comparison of the signatures of target G (Fig. 112) and target C (Fig. 107) reveals a marked similarity in the location of the principal scattering as a function of frequency. Further examination of Figure 107 indicates that the scattering from target G (Fig. 112) above 2 kHz was probably the result of non-resonant scattering such as was attributed previously to contributions from scales, bones and flesh.

Clearly, less information is available in the format used in Figures 111 and 112 than in the plots of the magnitude squared of the acoustic transfer function

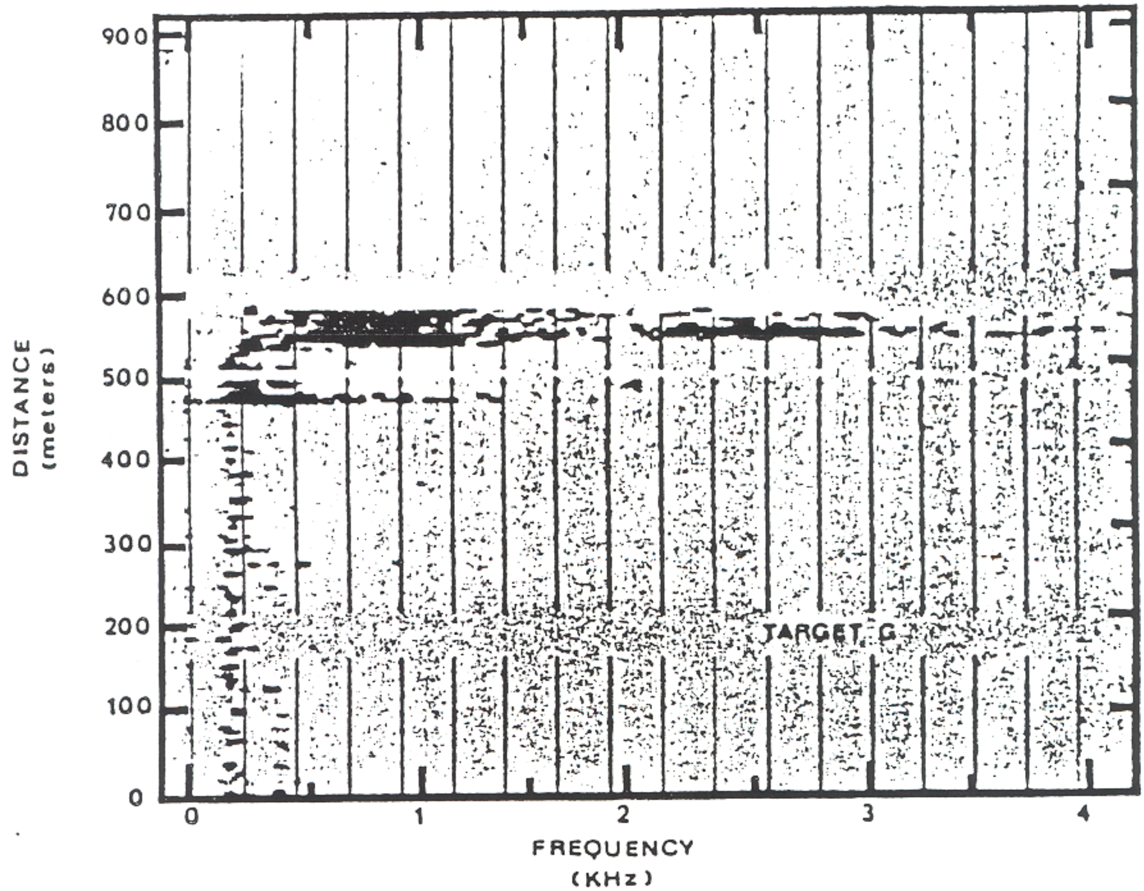

Figure 112. Acoustic signature for target G.

from the drifting ship work. This is due chiefly to the limited dynamic range of the paper display. Nevertheless, the format of Figures 111 and 112 contains useful information and did not require the computer processing necessary to produce the format of Figures 106 and 107.

A comparison of Figures 111 and 112 will reveal a measurable difference in the position of the apparent peak scattering of acoustic energy. The peak in Figure 111 is at about 1·2 kHz while the peak in Figure 112 can be interpreted as either a single broad peak near 900 Hz or as two peaks, one near 700 Hz and the other at about 1·1 kHz. Interpretation as a single peak leads to a group quality factor of approximately 1·0. The group quality factor is the ratio of the centre frequency of a resonance peak to the —3 dB width of the peak. A low quality factor, such as 1·0, would indicate a wide range of swimbladder sizes in the school. Calculations based on the distribution of fish sizes in a school dominated by a single species indicate a group quality factor for the swimbladder resonance of about 3·0. In addition, experience indicates that a group quality factor of at least 3·0 is observed when one species is dominant. Finally, fish catch records indicate that mixed schools are the rule rather than the exception among small fish in the area in which the study was conducted. For these reasons, the multiple peak interpretation, indicating a mixed school, is considered more likely than the single peak concept. A peak in scattered sound intensity is also apparent between 2·1 and 3 kHz. Marks at low frequencies, below 200 Hz, are due principally to ship-generated noise.

Approximately twenty species of pelagic fish are common in the Los Angeles Bight. One estimate of relative abundance (Squire, 1972) indicates an order of magnitude more biomass of northern anchovy in the area than of the second most abundant species, the jack mackerel. Pacific bonito were observed in slightly less quantity than jack mackerel. The quantity of Pacific mackerel was placed at about half the tonnage of bonito. The next most abundant species, yellowtail, was observed in quantities almost two orders of magnitude lower than those of Pacific mackerel. Of the number of surface schools observed in the Los Angeles Bight during the same period (1962–1966), 48 % were northern anchovy, 21 % were Pacific bonito, 17 % were Jack mackerel and less than 6 % were Pacific mackerel.

Although the similarity between the acoustic signatures discussed above leads us to the conclusion that the fish in targets F and G were about the same size as the fish in targets A and C, this data alone is clearly insufficient for the identification of the species of fish in the schools. It is equally clear, however, that if remote identification is to become a reality, the determination of fish sizes in a school will play a significant role.

ACKNOWLEDGEMENTS

This research programme was supported jointly by NOAA/NMFS La Jolla and by the Sea-Grant Program of the University of California, San Diego. The latter support was under NSF Grant GH-112 and NOAA Grant No. 2-35208.

Special thanks are due Dr V. C. Anderson of the Marine Physical Laboratory and to Dr P. E. Smith of the Population Dynamics Group of the National Marine Fisheries Service, La Jolla, for their interest, support and advice.

I would also like to thank J. Brown, R. Counts and J. Metoyer of NMFS, La Jolla, and I. E. Davies of the Naval Undersea Center, San Diego, and W. Huckaby for their assistance in execution of this work.

REFERENCES

Andreeva, E. B. 1964. Scattering of sound by air bladders of fish in deep sound-scattering ocean layers. Akust Zh. 10 (1): 20–24. (English Transl.: Sov. Phys. Acoust. 10 (1): 17–20).

Farquhar, G. B. 1970. Proceedings of an International Symposium on Biological Sound Scattering in the Ocean. Ed. by G. B. Farquhar, U.S. Dept. Navy, Maury Center for Ocean Science, Rep. MC 005, Washington, D.C.

Hersey, J. R. & Backus, R. H. 1962. Sound scattering by marine organisms. Chap. 13 *In* The Sea, Vol. 1. Ed. by M. N. Hill. Interscience, New York.

Holliday, D. V. 1972. Resonance structure in echoes from schooled pelagic fish. J. Acoust. Soc. Am., 51: 1322–32.

Squire, J. L., Jr. 1972. Apparent abundance of some pelagic marine fishes off the Southern and Central California coast as surveyed by an airborne monitoring program. U.S. Nation. Mar. Fish. Serv., Fish. Bull., 70: 1005–19.

Thomas, J. B. 1969. An introduction to statistical communication theory. Wiley, New York.

Weston, D. E. 1967. Sound propagation in the presence of bladderfish. Chap. 5. *In* Underwater Acoustics, Vol. 2. Ed. by V. A. Albers, Plenum Press, New York.

Printed in Denmark by Bianco Luno A/S