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Lidar TS measurements on Northeast Atlantic mackerel (Scomber scombrus)

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A green linearly polarized laser and a digital video camera were used to find the average reflectivity and lidar target strength of live mackerel. The light reflected from the fish was compared to that reflected from a target having a known total reflectivity of 20 %. The target was 50 % depolarizing, resulting in 10 % reflectivity in the co-polarized plane and 10 % in the cross-polarized plane. Using a lidar having two receivers with different polarization, one might be able to distinguish between the reflected laser light from mackerel and other fish (e.g. herring) as they depolarize the light differently. Mackerel was found to reflect 8.6 % of the light in the plane co-polarized with the laser and 6.1 % in the cross-polarized plane, giving a total average reflectivity of 14.7 %. A similar experiment on sardines gave a co-polarized return of 9.7 % and a cross-polarized return of 3.1 %. The large difference in depolarization between the two (41 % for mackerel and 24 % for sardines, respectively) can be used for species identification. The average reflectivity was combined with the size of the fish to find the lidar target strength of mackerel at 532 [nm]. When the video camera and laser were co-polarized, the target strength was found to be between 1.06×10^{-4} and 3.61×10^{-4} [$m^2 sr^{-1}$]. The cross-polarized setup resulted in a target strength between 8.92×10^{-5} and 2.21×10^{-4} [$m^2 sr^{-1}$]. Multiplying this by fish density, we get the lidar volume backscatter. Adding a second receiver gives the lidar great new species identification capabilities.

Keywords: Lidar, Mackerel, reflectivity, TS, polarization

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INTRODUCTION

Mackerel are difficult to assess using standard acoustic assessment methods due to their lack of swimbladder (MacLennan and Simmonds, 1991). During their summer feeding in the Norwegian Sea, they are distributed close to the surface, where vessel avoidance is a problem (Aglen, 1994, Misund 1993). Institute of Marine Research have started a program to find better assessment tools for mackerel. Part of this program is a multifrequency acoustic survey with the new silent research vessel R/V "G.O. Sars" (see Korneliussen and Ona, 2002). In addition we have started a lidar (LIght Detection And Ranging) project. In July 2002 IMR hired the NOAA Environmental Technology Laboratory's Experimental Oceanographic Fisheries Lidar (FLOE) to map the distribution and density of mackerel in the Norwegian Sea and to test the efficiency of the lidar as a survey tool.

In order to take full advantage of the lidar it is important to know the target strength of the fish and to be able to distinguish between different species. After finishing the flights in the Norwegian Sea, the lidar was brought to the IMR station at Austevoll, in the period from 26-28.07.2002, to find the reflectivity and target strength of live mackerel.

Lidar reflectivity of live fish has previously only been found for Sardines (Churnside et al, 1997). It was then found that sardines reflected 9.7 % of the light when the receiver was co-polarized with the laser and 3.1 % with a cross-polarized setup, giving a depolarization of 24%. The difference in depolarization, the ratio between cross-polarized and co-polarized return, between the species could be very beneficial for recognizing them.

Churnside et al (2001b) compared the scattering properties of sound and light from fish and found that echosounder measurements were much more aspect angle dependent than lidar measurements. In addition, acoustic backscattering depends on several internal anatomy properties that are difficult to model, e.g. swimbladder pressure, gonads, stomach content etc. Light backscattering only depends on external properties of the fish surface that are believed to be depth independent.

This study includes lidar reflectivity and target strength measurements on 185 mackerels of different sizes.

MATERIALS AND METHODS

The target measurements were conducted on live mackerel in a pen at Austevoll. The 12x12x10 m^3 experiment pen was partly covered to reduce direct sunlight and surface reflections. The 185 mackerel included in this study varied in size from 0.0042 m^2 to 0.0118 m^2. The size was calculated as the surface area of the fish visible to the lidar.

The laser was the one used with the NOAA fish lidar, a Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) laser. This is equipped with a Q-switch that is opened after the crystal is fully charged, so that all the energy is extracted in a 12 nsec pulse (Churnside et al. 2001a). The light is converted from an infrared wavelength (1064 nm) to visible green (532 nm) through a non-linear optical crystal. A negative lens in front of the laser increased the beam divergence. The receiver was a regular of the shelf Panasonic digital video camera fitted with a rotatable polarizing filter. The laser and video camera were mounted 2 meters above the surface with a 15 degrees tilt angle to decrease surface reflections. The laser beam diverged into a disk of approximately one square meter on the surface and this was well within the camera field of view.

A 40 cm^2 square target with a known total average reflectivity of 20 percent was lowered into the pen within the laser beam. The target was 50 percent depolarizing giving 10 percent reflectivity in the plane co-polarized with the laser and 10 percent in the cross-polarized plane. The reflected light was then recorded for both polarizations and at two different target depths, 30 cm and 80 cm below the surface, respectively.

Post processing of the videotapes involved extracting images from the videotapes where there was at least one mackerel within the laser beam and no fish covering the target. The fish also had to be at the same depth as the target to avoid attenuation differences for the two paths. This was done manually and was straightforward when the target was in the shallow position, whereas the deeper target position involved more shadowing of both the target and fish by shallower swimming fish. The entire target and fish were then extracted and the average reflectivity of the two compared see figure 1. By selecting the entire fish and target, the size of the fish could be calculated since the target size is known.

Images where the target was saturated, i.e. the highest pixel in the green image was higher than 255, were discarded. If target areas of more than 5 to 10 pixels are saturated, the center value could be substantially higher than 255, whereas single saturated pixels only results in small errors.

The average reflectivity R_f is calculated by

$$R_f = 0.2\frac{I_f}{I_t}$$

where I_f and I_t is the average intensity of the fish and target, respectively. The co-polarized and cross-polarized reflectivities are then found to be

$$R_{f,co} = 0.1\frac{I_f}{I_t}, \text{ and}$$

$$R_{f,cross} = 0.1\frac{I_f}{I_t}$$

due to the 50 percent depolarization of the target.

The reflectivity per unit solid angle is R_f/π and the contribution of the fish to the volume backscatter is the reflectivity per unit solid angle times the area of the fish. Given that the target size is 0.04 m^2 we get the TS or backscattering cross section

$$TS = 0.04\frac{R_f N_f}{\pi N_t}$$

where R_f is equal to $R_{f,co}$ for the co-polarized or $R_{f,cross}$ for the cross-polarized case, and N_f and N_t are the number of fish pixels and target pixels, respectively. As defined TS has the units of m^2sr^{-1}. The total volume backscatter is the product of this and the number density of fish, which has units of m^{-3}. The total backscatter volume is then given in units of $m^{-1}sr^{-1}$.

RESULTS

When the frames extracted from the videotapes were tested for saturation, it was found that the target was saturated most of the first day, and the frames had to be discarded. The second day, the camera was adjusted so that saturation was not a problem.

The target strength and reflectivity were calculated for each of the two polarizations. For the co-polarized case, the reflectivity was found to be 0.0861+/-0.0150 or about 8.6 percent and this is plotted versus fish size in figure 2. The correlation between fish size and reflectivity is found to be as large as 0.39.

The cross-polarized setup, which is the one NOAA usually use in their field experiments due to better contrast between fish, water, and other small scatterers in the sea (see Churnside et al.1997), gave a reflectivity of 0.06127+/-0.0090 or about 6.1 percent. This is plotted versus fish size in figure 3. Here the correlation is found to be smaller than for the co-polarized case, although still positive (0.21).

The average reflectivity of mackerel, which is the light reflected in all directions, is the sum of the two polarizations, which is 14.7 %.

The backscattering cross section or target strength (TS) in the co-polarized case varied from 1.06×10^{-4} to 3.61×10^{-4} [$m^2 sr^{-1}$] or –39.76 dB to –34.42 dB. Target strength versus fish size for the co-polarized setup is plotted in figure 4. The fish size is chosen as the area of the fish visible to the lidar rather than the fish length as is common in acoustic measurements. This was partly done because it is convenient when comparing the number of target pixels and fish pixels and partly because the lidar depends on light reflections from the whole surface of the fish. A relationship between fish size and fish length should be possible to find, so that an equation of the form commonly used for target strength in acoustics could be derived, although this was not done in this study.

The target strength in the cross-polarized case was found to be between 8.92×10^{-5} and 2.21×10^{-4} [$m^2 sr^{-1}$] or between –40.50 and –36.55 dB. This is plotted versus fish size in figure 5.

DISCUSSION

The results show that mackerel reflects 8.6 % in the plane co-polarized with the laser and 6.1 % in the cross-polarized plane, giving a depolarization of 41 %. Churnside et al (1997) have previously shown that sardines give a co-polarized return of 9.7 and cross-polarized return of 3.1 %. This gives a depolarization of 24 %.

The large difference in depolarization between mackerel and sardines gave rise to the idea of using this for species detection. Recording both the co-polarized and cross-polarized lidar return needs two receivers, one for each polarization. The receiver optics are inexpensive compared to the cost of the lidar, but having two telescopes might cause some space problems because of the limited size of the camera port on the aircraft.

Adding a second receiver should also be beneficial when using the lidar in areas with great amounts of plankton, as is the case in the Norwegian Sea in July. Plankton tend to depolarize the light to a smaller degree than fish (Churnside et al. 1997), so that the plankton layers can be found as areas with little depolarized return.

The correlation between reflectivity and size requires some attention. The reflectivity is calculated as the mean backscattering from all the pixels on the fish surface, which one would expect to be size independent. However the correlation is quite large, particularly in the co-polarized case. It appears that larger fish to some degree are more reflective than small fish. One explanation could be small differences in the attenuation between the fish and target. Fish that are swimming slightly shallower than the target will appear larger and the attenuation will be smaller, making the fish look bigger and more reflective. However, the difference in correlation between the two polarizations is difficult to explain with this theory.

The difference in depth between fish and target should be small, but in future experiments greater care should be taken when deciding if the fish is at exactly the same depth as the target. A camera mounted in the water filming horizontally both the fish and target could be a solution.

The effect of tilt angle was not treated in this study, although this certainly is an issue as it is with acoustics. The side of the mackerel is quite different from the top in color and will probably give other values for the reflectivity. However, the fish included in this experiment were swimming as natural as possible in a schooling like manner. Frames containing fish that were swimming on the side due to injuries or other factors were not included.

Recording the lidar return for both polarizations seems to be a great improvement of the lidar as a survey tool.

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FIGURES

Figure 1. Typical frame from the videotape containing both target and mackerel.

Figure 2. Reflectivity plotted versus fish size with a co-polarized setup.

Figure 3. Reflectivity plotted versus fish size with a cross-polarized setup.

Figure 4. Target strength plotted versus fish size with a co-polarized setup.

Figure 5. Target strength plotted versus fish size with a cross-polarized setup.

Figure 1.

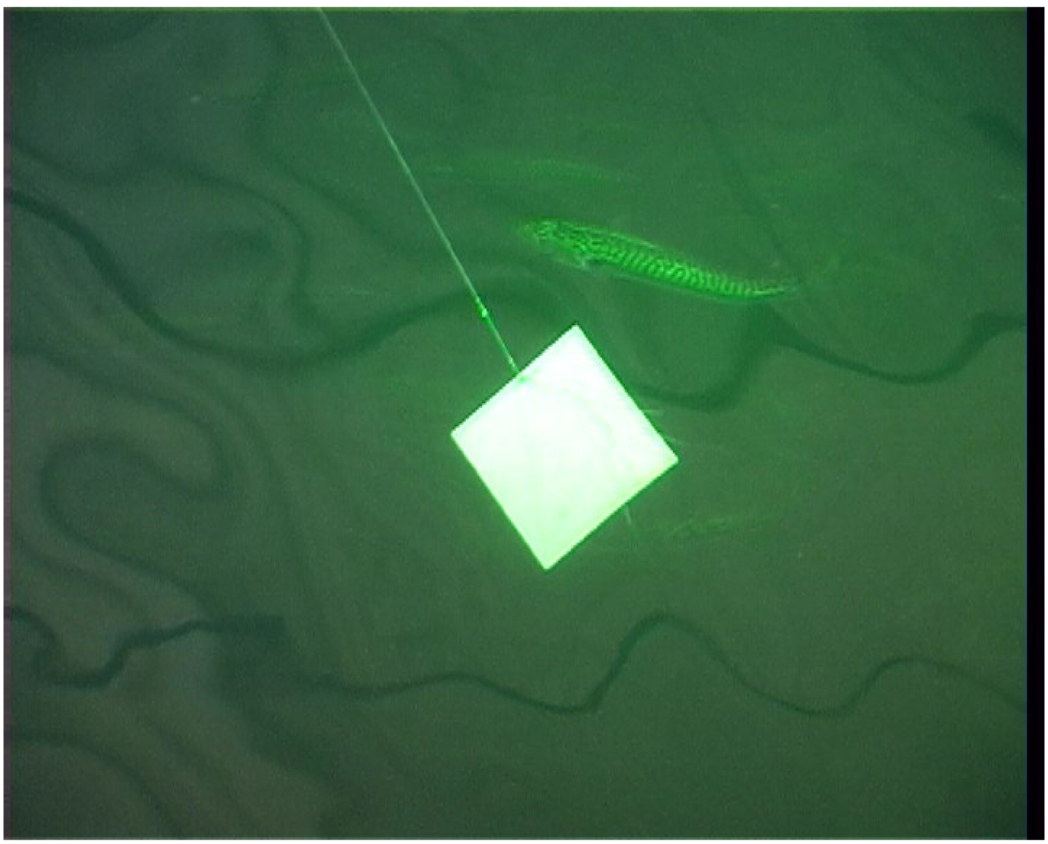

Figure 2.

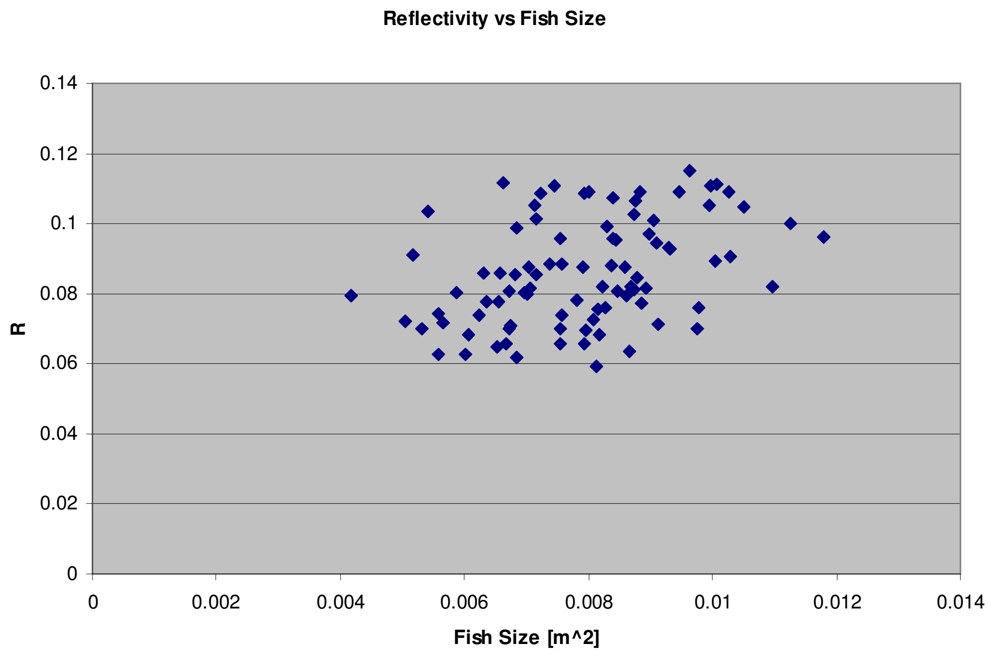

Figure 3.

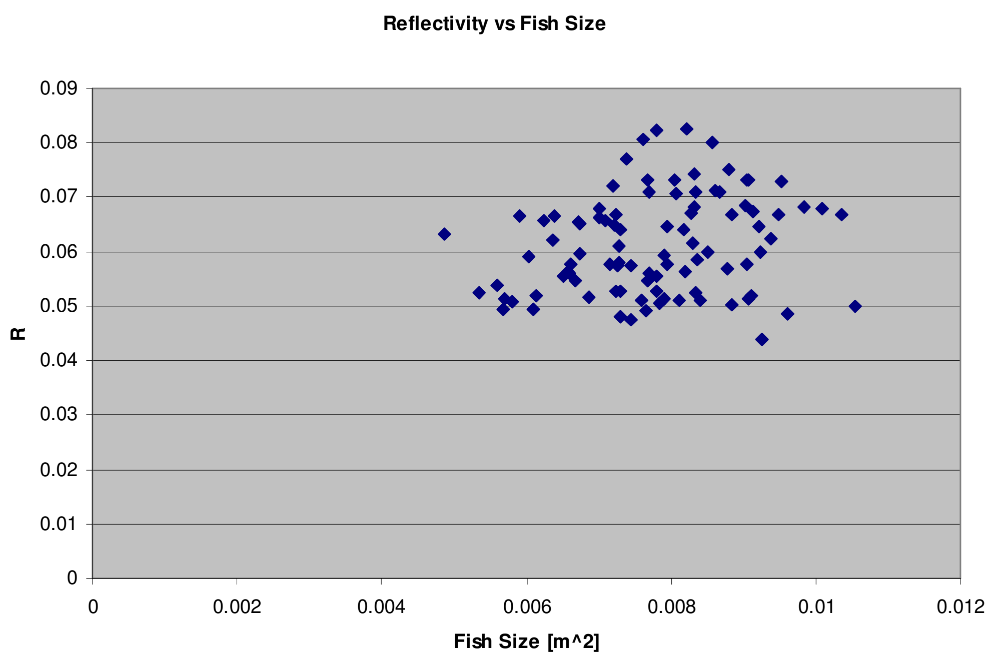

Figure 4.

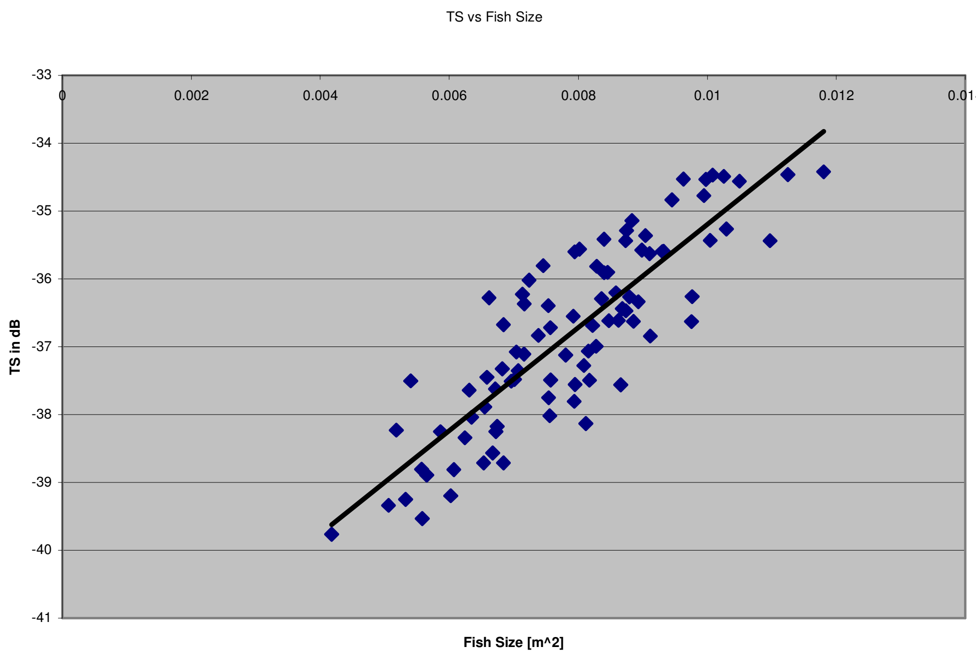

Figure 5.