low in the roll (range, 2.5 to 7 dB), in the lateral direction (4 to 6 dB), and in the pitch plane (from 8 to 12 dB). The effects of the roll and pitch angle were not as great as those in the yaw angle.

Generally, our experimental results showed that all fish targets were highly directional scatterers, and the target strength of fish was correspondingly affected by the fish orientation.

3.2 The dependence of three-dimensional target strength on fish length

**Figure 5** shows the relationship between the fish body length and the target strength. In these figures, each point represents the maximum and average TS of the fish. The maximum TS was defined as the peak value in the TS functions against the horizontal incident angle. The average TS was determined by averaging the TS function with respect to the fish orientation.

The average and maximum TS of the fish varied from −51.2 to −36.2 dB and −47.0 to −31.9 dB, respectively. The maximum and average TS values are plotted on the y-axis with body lengths (TL) on the x-axis for fish pitch angles of 0°, 30°, 60°, and 90°.

Increases in fish body length resulted in a slight upward shift in the maximum and average target strength (Fig. 5). A good relation between the fish body length and the maximum and average TS were obtained (Fig. 5 with pitch angles of 0°, 30°, and 60°). Physically, an increase in the fish body length, would result in an increase in target strength. The variations of TS of smaller fish were smaller than those of larger fish.

Generally speaking, the greater the fish length, the narrower the directivity of the TS, in theory. These influences lead to changes of the target strength (maximum and average TS).

![Figure 5](image)

**Fig. 5** Relationship between the body length of fish (BL) and the target strength of a fish (TS) in pitch angles of 0°, 30°, 60°, and 90°. Black and white circles denote the average and the maximum TS values of fish, respectively. $R^2$ denotes a coefficient of determination of the regression equation.