

In situ Target Strength versus Fork Length Relationships of *Scomber japonicus* and *Scomber australasicus* in Waters off Northeastern Taiwan

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ABSTRACT

Determination of the *in situ* target strength (TS) versus fork length (FL) relationship is essential in order to apply hydroacoustic measurements to assess the abundance of fishery resources. Collections of *in situ* TS signals (using an EK500 sounder on board the R/V *Ocean Research I*) and corresponding fish size measurements for *Scomber japonicus* and *S. australasicus* (surveyed at the Nanfangao fishing port) were carried out concurrently in 1995. An optimal search algorithm using an Excel spreadsheet format was adopted to determine the *in situ* TS versus FL relationship. Results of the *in situ* TS-FL relationship obtained by the search algorithm, with a standard deviation of TS of 4 dB throughout all the size ranges, are as follows: $TS\ (dB) = 29.5 \times \log(FL(cm)) - 90.0$, and $TS\ (dB) = 31.0 \times \log(FL(cm)) - 94.5$ for *S. japonicus* and *S. australasicus*, respectively.

Key words: *in situ* target strength distribution, fork length distribution, *Scomber japonicus*, *Scomber australasicus*

INTRODUCTION

Mackerel and scad are important pelagic fishery resources for the near-shore fishery in Taiwan. According to monthly catch distributions of the Taiwanese mackerel purse seiner fishery, there are two well-known traditional fishing grounds (Tzeng, 1986, 1988). From June to January, purse seine fishing operations are concentrated in the region between Pengchia Yu (25°40'N, 122°05'E) and Fishing Islets (25°45'N, 122°50'E). From February to May, fishing operations occur in areas near the Pratas Islands (15°32'N, 114°52'E).

Although there is over a 30-year history of applying

hydroacoustic techniques to assess fishery abundances, only recently has this technique been intensively applied to mackerel and scad resources inhabiting the waters off Taiwan. Chu (1994) studied the abundance distribution of mackerel and scad by echo integration with scaling factors obtained by measuring the *ex situ* target strength (TS) of dead fish in a designated cage. Wu (1996) studied the *ex situ* TS versus fork length (FL) relationship obtained by measuring the *ex situ* TS of hooked live fish attached to a designated main thread. Foote (1991) indicated that the observed TS signals can be classified mainly based on the environmental situation of the target as either *ex situ* or *in situ*. MacLennan and Simmonds (1992) further indicated that the *in situ* TS signal itself already includes information on environmental, biological, and behavioral elements. As a result, it is more

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appropriate to use *in situ* TS information for echo integration purposes. It was not until the early 1990s, however, that collection of *in situ* TS information became possible after improvements in split-beam technology and the availability of the Simrad EK500 echo sounder.

Although the technology of applying such a scientific echo sounder, i.e., the echo sounder provides quantitative precision which has been accepted and used in fisheries resources assessment, matured in the early 1990s, the essential task remaining for the successful application of *in situ* TS information in fisheries resources assessment is to obtain the most-appropriate relationship of the *in situ* TS versus FL (Burczynski, 1979; Johannesson and Mitson, 1983; Johannesson *et al.*, 1983; MacLennan, 1990; Foote, 1991; MacLennan and Simmonds, 1992; Cordue *et al.*, 2001).

Chang and Yeh (2003) provided a search algorithm with an Excel spreadsheet format to obtain the most-appropriate relationship between the *in situ* TS and FL for scad (*Trachurus japonicus*). The same algorithm was adopted in this paper to obtain the best functional relationship between the *in situ* TS obtained from the R/V *Ocean Research I* versus the FL distribution of *S. japonicus* and *S. australasicus* measured in the Nanfangao fishing port. The main purpose of this study was thus to identify the *in situ* TS data obtained from acoustic surveys which happened to pass over a single school of either *S. japonicus* or *S. australasicus* in the purse seine fishing ground. Information on this pair of concurrent incidents was then used to extract the best functional relationship between the *in situ* TS versus its corresponding FL.

MATERIALS AND METHODS

In situ TS data were obtained through use of a calibrated SIMRAD EK500 scientific echo sounder with a 38-kHz split-beam transducer on board the R/V *Ocean Research I*, and collected with an IBM-compatible AT computer during cruise OR425 conducted on July 12–17, 1995 and cruise OR431

conducted on September 25–October 3, 1995. Before each cruise, the acoustic system was carefully calibrated following the technique described by Foote (1987) using a 60-mm standard copper sphere with the TS of -33.6 dB at Beesha Fishing Port, Keelung. The value of the TS was obtained with a time-varied gain setting at 40 log (R). The EK500 echo sounder has a built-in echo detector to screen out single fish targets. The acoustic transmission was logged at a rate of 1/s, and the TS values obtained were grouped into 1-dB intervals. TS measurements were made using the split-beam method (Foote *et al.*, 1984; Traynor and Ehrenberg, 1990).

TS data from stations 31 and 32 near Fishing Islets (Fig. 1) with a purse seiner concurrently being operated were chosen to estimate the TS-FL relationship of mackerel. Before establishing the TS-FL relationship, the assumptions made were that (1) the distribution pattern of the TS measurements for each fish was normally distributed with a standard deviation, and (2) each fish in this area had the same probability of being caught by the purse seine, as well as being detected by the echo sounder.

The FL compositions of *S. japonicus* and *S. australasicus* were randomly measured from the catch of purse seiners of the Shun-Tien Fishery Co. caught near stations 31 and 32, where the purse seiners were simultaneously fishing during the acoustic surveys. The purse seine net has a circumference of 300 m, an effective depth from the surface down to 100 m, and a mesh size of 3 cm.

Estimation of the TS-FL relationship of mackerel followed the algorithm presented in the paper by Chang and Yeh (2003). The class intervals of TS and FL distributions were set to 1 dB and 1 cm, respectively. The Premium Solver for Excel V6.0 software was used to calculate the optimal slope (a) and intercept (b) of the TS-FL relationship.

RESULTS

Results of random samples from landings of fish caught concurrently with the acoustic surveys showed that only one species of mackerel was caught

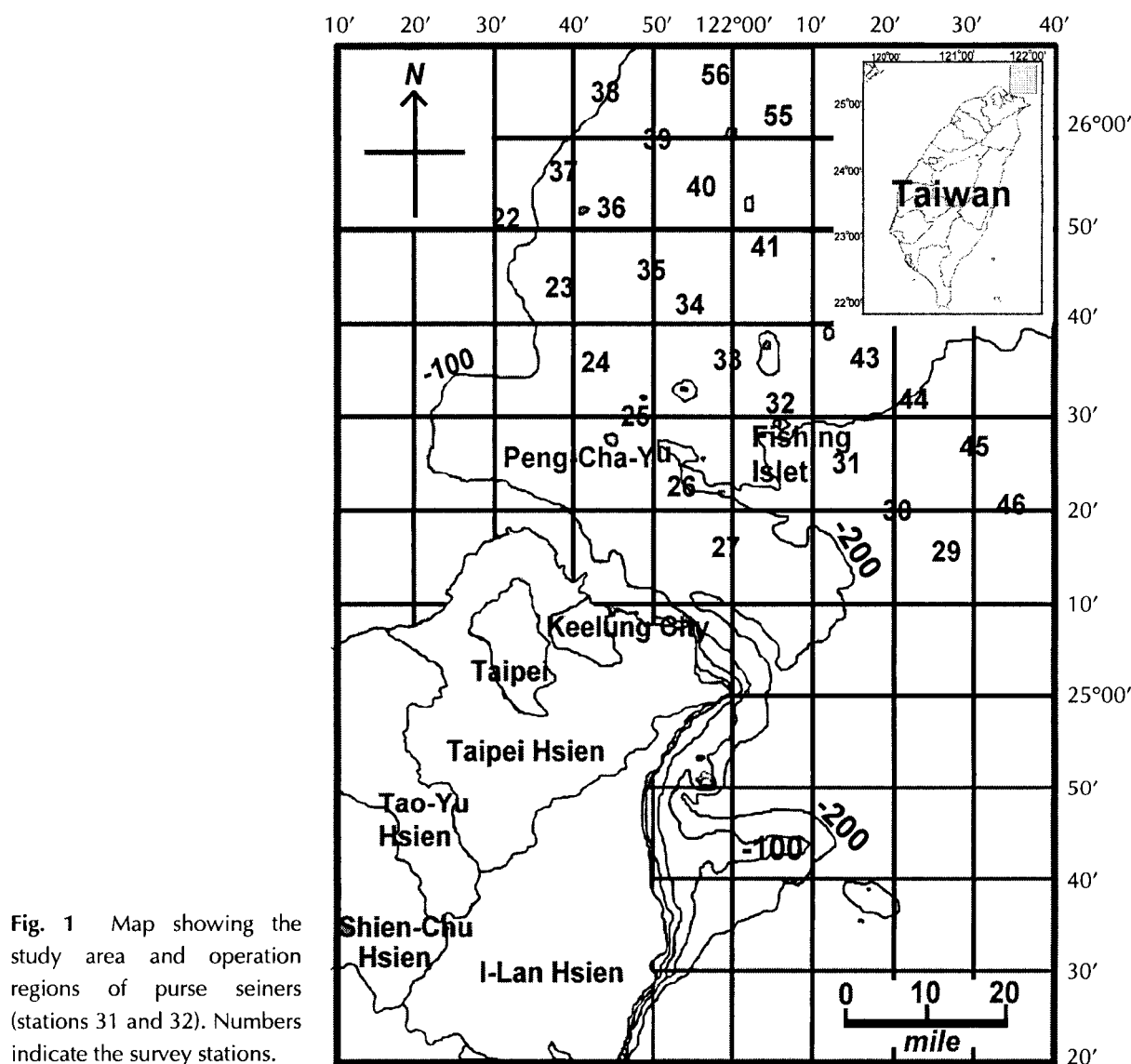


Fig. 1 Map showing the study area and operation regions of purse seiners (stations 31 and 32). Numbers indicate the survey stations.

during each survey, which was *S. australasicus* for OR425 and *S. japonicus* for OR431, each of which accounted for almost 100% of the respective total catch. The range of FL of *S. australasicus* was 22.5~29.2 cm, the mean FL was 25.6 cm, and the standard deviation (σ_{FL}) was 0.4 cm (Fig. 2). The range of FL of *S. japonicus* was 26.8~34.0 cm, the mean FL was 30.6 cm, and the standard deviation (σ_{FL}) was 0.9 cm. The FL distribution of each species was used in determining its TS-FL relationship.

All of the TSs sampled from the acoustic survey of both species were between -54 and -31 dB at depths of 20~100 m. The TS sample size in this region was 1428 for *S. australasicus* and 1323 for *S.*

japonicus. The *in situ* TS appeared to have almost a mono-modal distribution with low values in this study (Fig. 3). Further, there was a tendency towards a superior grade of a normal distribution for the *in situ* TS distribution of these two species, because respective values of their kurtosis and skewness were about 3.4 and 0.5 for *S. australasicus*, and 3.2 and 0.2 for *S. japonicus*.

Through an intensive fitting search, the suitable TS-FL relationship for each σ_{TS} was determined, and the minimal objective function value of both species fell in the σ_{TS} value of 4 dB (Table 1). The following relationships were the optimal model search result for the two species:

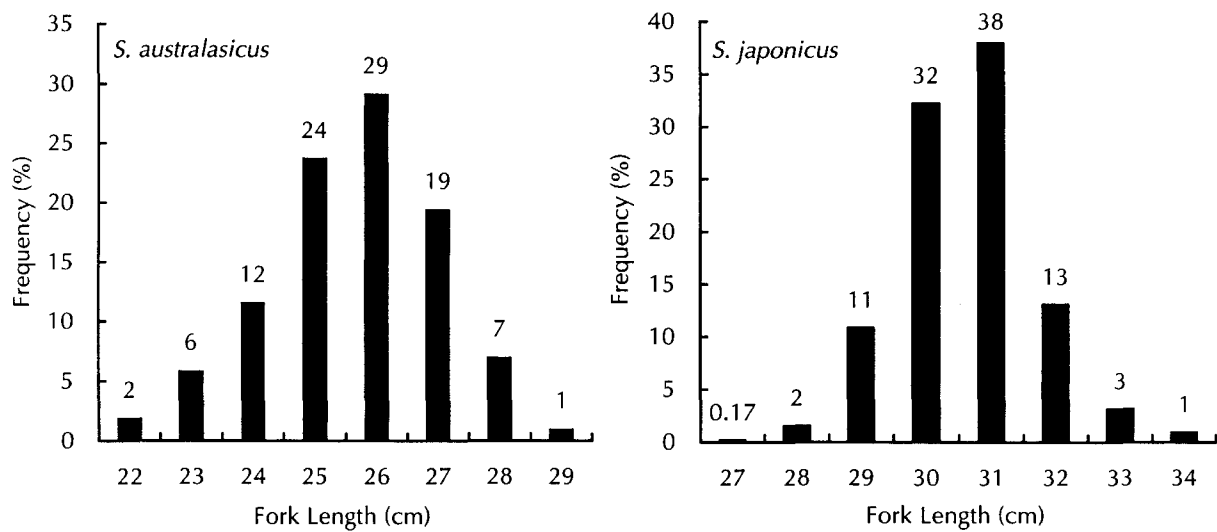


Fig. 2 Fork length distributions of *Scomber australasicus* (left) and *S. japonicus* (right) sampled from purse seiners at Nanfangao fishing port.

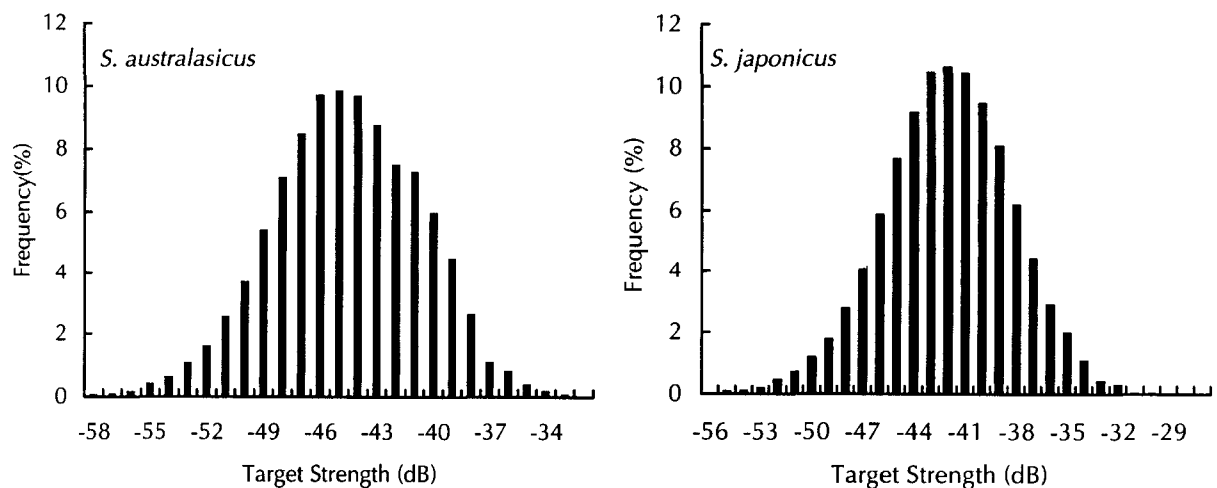


Fig. 3 Target strength distributions of *Scomber australasicus* (left) and *S. japonicus* (right) sampled from purse seiners at Nanfangao fishing port.

Table 1 Search results of slopes and intercepts for the fork length/target strength relationship of *Scomber australasicus* and *S. japonicus*. The optimal result is marked by a pound sign (#)

Species	a	b	$\sigma_{TS}(\text{dB})$	$\int_j [\hat{f}(TS_j) - f(TS_j)]^2$
<i>Scomber australasicus</i>	# 31.0	# 94.5	# 4	# 0.83
<i>Scomber japonicus</i>	# 29.5	# 90.0	# 4	# 0.60

#: Optimal result.

S. australasicus:

$$TS = 31.0 \times \log(FL) - 94.5$$

(FL: 22.5~29.2 cm; $\sigma_{TS} = 4$ dB), and

S. japonicus:

$$TS = 29.5 \times \log(FL) - 90$$

(FL: 26.8~34.0 cm; $\sigma_{TS} = 4$ dB).

The theoretical TS distribution provided by the optimal model search and the observed TS distributions of *S. australasicus* and *S. japonicus* were compared (Fig. 4). The least-squared values of the fitting results were 0.83 and 0.60, respectively. This suggests that the best-predicted mean *in situ* TS

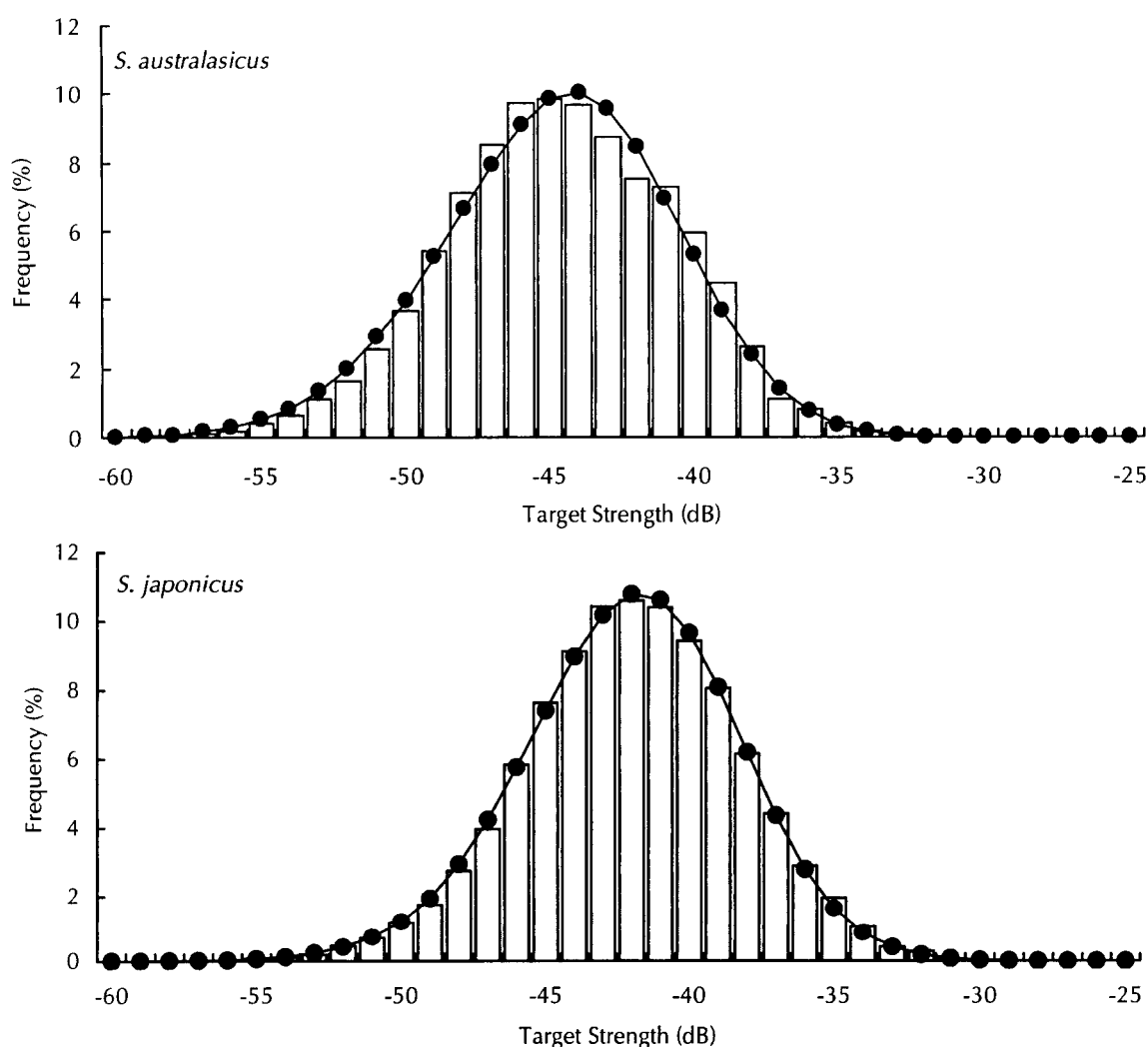


Fig. 4 Comparison between the observed target strength (TS) distribution (bar chart) and the theoretical TS distribution (curve) of *Scomber australasicus* (upper) and *S. japonicus* (lower).

distributions of mackerel in the present study were -44.6 dB for *S. australasicus* and -42.5 dB for *S. japonicus* in the given temporal and spatial situation.

DISCUSSION

As compared with the *in situ* TS of *T. japonicus* presented by Chang and Yeh (2003), there was a little larger kurtosis for *S. japonicus* than *T. japonicus* (coefficient of kurtosis = 1.2). This implies that the range of the length distribution of mackerel, either *S. japonicus* or *S. australasicus*, was much more concentrated than that of scad. The different characteristics of the present *in situ* TS distribution

may be helpful as a basis for judging the *in situ* TS distribution of a single species.

Although the TS-FL relationship can easily be measured using dead or suspended fish, behavioral and physiological conditions still have marked impacts on TS values (Foote, 1980b; Ona, 1990; Orłowski, 2001). MacLennan and Simmonds (1992) indicated that the dorsal fixed TS measurements are of limited practical use, because wild free-swimming fish adopt a range of tilt angles. Values of the TS would vary among individual wild fish, and the mean TS value would be smaller than the value recorded from the dorsal aspect. Love (1971) suggested that the TS averaged over the tilt angle distribution range

Table 2 Results of target strength measurements of mackerel

Species	Instrument	Method	Length(cm)	TS(dB)	Reference
Mackerel (live fish)	SIMRAD EK38A	Sheltered inlet	29.0~34.0	-37.6~-43.0	Nakken and Olsen(1977)
Mackerel (live fish)	SIMRAD EK120A	Sheltered inlet	35.0~41.0	-37.9~-41.9	Nakken and Olsen(1977)
<i>Scomber japonicus</i> (dead fish)	25kHz, 100kHz	Water tank	23.0~26.8	-32~-43.0	Mukai <i>et al.</i> (1994)
<i>Scomber japonicus</i> (dead fish)	SIMRAD EK500	Vessel suspending	14.0~28.0	-32.0~-42.0	Chu, Ph.D. thesis (1994)
<i>Scomber japonicus</i> (<i>ex situ</i> , live fish)	SIMRAD EK500	Vessel suspending	24.5~38.1	-35.5~-42.6	Wu, Master thesis (1994)
<i>Scomber japonicus</i> (<i>in situ</i> , live fish)	SIMRAD EK500	<i>In situ</i> (split beam)	28.0~34.0	-44.8~-47.3	This study (2005)
<i>Scomber australasicus</i> (<i>in situ</i> , live fish)	SIMRAD EK500	<i>In situ</i> (split beam)	22.5~29.2	-49.0~-52.5	This study (2005)

of $\pm 45^\circ$ would be representative of wild fish. Further, according to the results of Nakken and Olsen's experiments conducted in a sheltered inlet, the mean TS appropriate for wild fish would be 6 dB less than the maximum dorsal-aspect value (MacLennan and Simmonds, 1992). Foote (1980a) suggested that TS measurements be directly sampled by *in situ* methods (Foote, 1980a), so that measurements are made under conditions similar to those likely to be encountered in the real acoustic abundance survey.

There are only five published reports (Nakken and Olsen 1977; Ona, 1990; Chu, 1994; Mukai *et al.*, 1994; Wu, 1996) on mackerel with *ex situ* TS measurements using a dual-beam echo sounder, but no report on *in situ* measurements except this study. According to results shown in Table 2, values for *S. japonicus* and *S. australasicus* were 4.3~7.2 and 4.0~11.6 dB lower, respectively, than the results of Nakken and Olsen (1977) for a length range of 29~34 cm using a 38-kHz echo sounder, and 0.8~6.5 and 2.6~8.7 dB lower, respectively, than results of Nakken and Olsen (1977) for a length range of 35~41 cm using a 120-kHz echo sounder in this paper. Further, when compared with *ex situ* measurements of either live or dead fish fixed under the vessel (Chu, 1994; Wu, 1996), there was a maximum distance for

S. japonicus of 11.25~11.3 dB (with FLs of 26~28 cm) compared with Chu's measurement, and 6.86~7.56 dB (with FLs of 26~34 cm) compared with Wu's measurement, respectively, from *in situ* measurements in this study (Table 2).

Regardless of whether the method involved a water tank or a vessel with suspended dead or live fish, there was an average of 6.2 (0.8~11.6) dB larger values than the results of this study. This indicates that TS values of both live and dead fish measured *ex situ* are quite larger than those of live fish measured *in situ*. This suggests that there is good agreement between the conclusions of Nakken and Olsen's (1977) and this study.

One assumption we made in this study was that TS measurements of the fish were normally distributed with a standard deviation of σ_{TS} . As mentioned earlier, σ_{TS} might be an important parameter in the TS-FL relationship; results showed that the optimal slope and intercept for the TS-FL logarithmic-linear formula at σ_{TS} was 4 dB. The value of the standard deviation in this study was only a small factor interfering with the estimation of the TS-FL relationship of *S. australasicus* and *S. japonicus*, similar to that reported by Chang and Yeh (2003).

According to the results described above, we found that there are two important limitations of the *in situ* technique which should be considered when applied to individuals. The first is that it is essential for recording and analysis to carefully select only those echoes that come from isolated fish especially with single species, because the superimposed echoes from two species which are close to each other will have a combined energy different from that coming from a single species. The second is that it is necessary with the *in situ* technique to obtain a representative sample of the fish which have been observed acoustically to determine the FL and species composition. The method adopted in the present study was to follow a group of purse seiners, conduct the *in situ* TS sampling before the fishing operation began, and then obtain FL data from the landing place at the fishing port for fish caught concurrently with the acoustic survey.

In summary, our results of mean TS values for *S. australasicus* and *S. japonicus* measured *in situ* were much lower than those published by Chu (1994) and Wu (1996). This implies that *ex situ* TS values have a great impact on assessments of the abundance of stocks. Careful studies on the relationship between TS and systematic day/night changes are needed in the future.

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台灣東北部白腹鯖與花腹鯖現場標物反射強度與尾叉長 關係式之研究

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摘 要

應用水中聲學法評估魚類資源時，一項不可或缺的步驟就是求算魚種現場標物反射強度 (*in situ* target strength, TS) 與尾叉長 (fork length, FL) 之關係式。本研究係根據海研壹號的 EK500 科學魚探收錄的白腹鯖及花腹鯖的現場標物反射強度，以及實地採樣測量於相同時空下捕獲之該兩種魚類的尾叉長等兩組資料，求算其 TS-FL 關係式，以作為日後評估其資源動態之依據。結果顯示，白腹鯖的尾叉長頻度分布為 26.8 ~ 34.0 cm，TS-FL 關係式為： $TS (dB) = 29.5 \times \log (FL(cm)) - 90.0$ ；花腹鯖為 22.5 ~ 29.2 cm，關係式為 $TS (dB) = 31.0 \times \log (FL(cm)) - 94.5$ 。

關鍵詞：現場標物反射強度分布，尾叉長頻度分布，白腹鯖，花腹鯖

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