

Direct estimation of stock abundance of Pacific saury *Cololabis saira* in the northwestern Pacific Ocean using a mid-water trawl

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Abstract Drifting gill-nets were for a long time the main research gear for investigating the distribution of Pacific saury *Cololabis saira*. However, it has proven to be difficult to estimate the absolute abundance of saury using drifting gill-nets due to a lack of knowledge on the survey areas swept by these gill-nets. A mid-water trawl stock abundance estimation has the advantage of being able to estimate the absolute stock abundance before the commercial fishing season begins, whereas the conventional stock abundance estimation based on catch per unit efforts of commercial fisheries must be done after the commercial fishing season has ended. To confirm the practicality of a mid-water trawl to estimate the stock abundance of saury, we conducted a comparative survey in the northwestern Pacific Ocean using both a mid-water trawl and drifting gill-nets. We found that the geographic distribution pattern of catch per unit effort for both the mid-water

trawl and driftnets was similar. Using the area-swept method and data on the fishing efficiency of the mid-water trawl obtained in a previous study, we were able to estimate the stock abundance plus confidence limits within the research areas. Our results suggest that the size composition of saury sampled by the mid-water trawl can be considered to approximate the actual size composition of saury.

Keywords Area-swept method · *Cololabis saira* · Mid-water trawl · Pacific saury · Stock assessment · Stock abundance estimation

Introduction

Pacific saury *Cololabis saira* is one of the more economically important pelagic commercial fisheries species in countries of the Far East and a key species in offshore surface-water ecosystems [1]. A precise estimation of stock abundance of saury will contribute to the sustainable development of its commercial fishery, resource management, and ocean ecosystem studies.

Matsumiya and Tanaka [2] devised a method to estimate the abundance of saury in commercial fishing grounds employing the specific saury-catching stick-held dip-net fishing method. This method, known as Matsumiya's method, calculates the stock abundance based on catch per unit effort (CPUE) data from the commercial fishery (the stick-held dip-net fisheries). Oozeki et al. [3] improvised this technique and devised a new method for estimating immigrated stock size on the outskirts of commercial fishing grounds using CPUE data from drifting gill nets operated by fisheries research vessels (FRVs). Because both methods use data derived from commercial

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fisheries and/or sampling by FRVs carried out during the commercial fishing season, abundance can only be estimated after the end of the season. In our opinion, abundance should be estimated prior to the fishing season by a fishery-independent method for effective fishery and stock management.

Watanabe et al. [4] proposed a new strategy for estimating stock abundance based on larval survival parameters that determine the production of pre-schooling juveniles and conducted trials using these larval parameters estimated from a seasonal cohort to forecast stock abundance [5]. However, seasonal juvenile production estimated by this procedure did not correspond with actual commercial catches of the seasonal cohort. One possible explanation for this discrepancy is that the spawning area is too large and the spawning season is too long to be surveyed accurately by few FRVs.

Multi-mesh drifting gill-nets (M-driftnets) have been traditionally used to investigate the distribution of saury, but Ueno et al. [6] conducted a trial using a mid-water trawl (Nichimo NST-99; Nichimo Co., Tokyo, Japan) to obtain a quantitative estimate. The use of drifting gill-nets in this context is associated with a great difficulty in estimating the effective survey area swept by these gill-nets because they are passively floating on the surface without any active movement. Basically, it is assumed that their efficiency actually depends on the movement of the target species. In contrast, the mid-water trawl has an advantage over M-driftnets in terms of sampling saury because the area swept by the mid-water trawl is clearly calculable. Naya et al. [7] estimated the fishing efficiency of the mid-water trawl from a series of experiments using a mid-water trawl combined with side-scan sonar. Their results indicate that it is possible to convert catch (in number/weight) per area estimated from mid-water trawl data into the actual saury population size based on fishing efficiency.

To examine the practicality of abundance estimation of Pacific saury by the mid-water trawl, we conducted a comparative experiment with the mid-water trawl versus the research drifting gill-nets in the 2001 pre-fishing season in the Kuroshio–Oyashio transitional zones of the northwestern Pacific Ocean. The aim of this study was to confirm that the catch distribution pattern determined using the mid-water trawl is the same as that determined using drifting gill-nets. A secondary aim was to show that absolute values of the stock abundance can be estimated by an area-swept method utilizing the saury distribution pattern in relation to sea surface temperature. Our expectation was

that this method will be more suitable and applied in practical stock assessment for the saury stock.

Materials and methods

Survey area, sampling, and data acquisition

The fishery research vessel *Hokuho-maru* (664 gross tonnage) was used for sampling operations. The mid-water trawl (NST-99) was manufactured by Nichimo Co., Ltd. in 1996 and operated in daytime only with a warp length of about 200 m at 257 cm/s (5 knots) and a towing duration of about 60 min. The trawl mouth had a horizontal opening of 24 m and a vertical opening of 20 m. The whole head rope, including both wingtips, floated close to the surface. The total length of the trawl was 90 m, and the maximum and minimum mesh size was 1512 and 6 cm, respectively.

The multi-mesh, drifting gill-nets (M-driftnets) were composed of eight different mesh sizes (18, 20, 22, 26, 30, 33, 37, and 43 mm, with a unit length of 37 m and height of 5 m) [8]. For comparison purposes, the M-driftnets and mid-water trawl were operated at the same location within 6 h of each other, with the drift-netting carried out at dusk or dawn at a setting time of about 120 min.

A suitable research area to catch saury was determined from the saury catch distribution/sea surface temperature (SST) database stored at the Tohoku National Fisheries Research Institute. A total of 60 sampling operations were carried out in June and July 2001 in the northwestern Pacific Ocean (from the Japanese coast to 162°E in the SST range of 8.4–20.8 °C; Table 1).

A research transect was roughly set out in a north–south direction. Along this research transect, we first carried out the operation in the higher (or lower) SST areas where saury were very few. Next, we moved northward (or southward) along the research transect line and carried out the operations in areas where saury were plentiful. Lastly, we ended the operation in lower (higher) SST areas where saury were very few. In the northern limit areas for saury, we could not often carry out the sampling because these areas were in the Russian-imposed exclusive economic zone (EEZ). In this case, we carried out the northern-most operation on the research transect just slightly south of the edge of this EEZ.

Forty-four simultaneous operations of the M-driftnets and mid-water trawl were performed for comparative purposes, and an addition 16 trials employed either mid-water trawl or M-driftnets.

Table 1 A list of all operations carried out with the mid-water trawl and M-driftnets

No.	Sampling station	Date (year/ month/day)	Latitude (°N)	Longitude (°E)	SST (°C)	Mid-water trawl		M-driftnets	
						Beginning time of towing, 24-hour notation	Number of saury caught per 60-min tow	Time when setting up M-driftnets was finished, 24-hour notation	Number of saury caught per 120-min setting
1	St1-2	2001/06/16	41.02	143.28	8.4	6:28	0	3:04	0
2	St1-3	2001/06/16	40.32	143.32	14.2	15:37	0	18:21	15
3	St1-4	2001/06/17	40.06	143.32	13.1	7:25	0	2:58	3
4	St1-5	2001/06/17	39.32	143.31	18.5	15:37	0	18:26	3
5	St1-6	2001/06/18	38.59	143.29	16.3	6:21	0	2:58	1
6	St1-7	2001/06/18	38.41	144.33	20.8	15:22	0	18:26	0
7	St4-6-A	2001/06/21	41.36	151.12	13.4	3:26	486	2:54	492
8	St4-7	2001/06/21	41.08	151.30	14.2	18:30	0	17:58	128
9	St4-8	2001/06/22	40.39	151.58	14.8	3:21	44	2:50	7
10	St5-8	2001/06/22	40.20	154.56	13.3	18:50	1650	17:54	871
11	St5-7	2001/06/23	41.01	154.21	13.3	3:21	1	2:56	92
12	St5-6	2001/06/23	41.46	153.52	14.5	18:45	0	17:54	109
13	St5-5	2001/06/24	42.29	153.17	13.8	3:42	363	2:56	4
14	St6-5	2001/06/24	42.52	155.27	13.4	18:45	0	17:52	44
15	St6-6	2001/06/25	42.12	155.60	12.7	3:44	0	2:52	0
16	St6-7	2001/06/25	41.28	156.34	13.7	18:48	390	17:52	1
17	St24-1	2001/06/26	41.46	155.58	14.1	3:39	1214	2:53	16
18	St24-2	2001/06/26	41.47	156.01	14.2	8:18	383	–	–
19	St24-3	2001/06/26	41.50	156.00	14.6	12:30	40	–	–
20	St24-4	2001/06/26	41.47	155.57	14.4	16:50	110	–	–
21	St24-5	2001/06/26	41.47	156.07	14.1	20:17	17	–	–
22	St24-6	2001/06/27	41.47	155.58	14.2	0:14	1	–	–
23	St6-8	2001/06/27	40.46	157.07	12.9	19:03	0	17:52	0
24	St6-9	2001/06/28	40.01	157.40	15.8	3:31	0	2:50	0
25	St6-10	2001/06/28	39.18	158.15	16.9	18:42	0	17:54	0
26	St5-10	2001/06/29	38.60	157.00	16.6	3:51	0	2:56	1
27	St5-11	2001/06/29	39.30	154.17	16.6	18:40	0	17:53	4
28	St4-9	2001/06/30	39.58	153.01	18.0	4:05	0	3:15	1
29	St3-9	2001/06/30	39.30	150.28	16.8	18:41	0	17:54	0
30	St3-8	2001/07/01	40.20	149.37	20.8	4:01	0	3:12	0
31	St3-7	2001/07/01	40.37	149.27	19.8	13:52	0	13:09	0
32	St2-7	2001/07/02	39.30	146.26	18.4	17:33	0	16:46	0
33	St2-6	2001/07/03	40.00	146.16	13.8	3:47	0	2:54	0
34	St2-5	2001/07/07	40.31	146.08	16.5	4:10	0	3:14	8
35	St2-4	2001/07/07	41.01	145.56	15.2	17:27	2	16:44	3
36	St2-3	2001/07/08	41.29	145.45	17.5	3:43	0	2:55	6
37	St2-3-2	2001/07/08	41.31	145.47	17.6	9:51	168	–	–
38	St2-3-3	2001/07/08	41.36	145.50	17.5	13:25	0	–	–
39	St2-2	2001/07/09	41.54	145.26	12.0	7:57	11	9:59	4
40	St2-1	2001/07/09	42.31	145.24	8.9	15:17	0	16:55	0
41	StN-1	2001/07/11	41.35	151.21	17.5	14:23	0	16:28	0
42	StN-3-2	2001/07/12	42.40	153.10	12.5	5:19	1354	2:55	132
43	StN-3-3	2001/07/12	42.39	153.10	12.4	10:55	299	–	–
44	StN-3-4	2001/07/13	42.40	153.10	12.8	15:36	34	–	–

Table 1 continued

No.	Sampling station	Date (year/month/day)	Latitude (°N)	Longitude (°E)	SST (°C)	Mid-water trawl		M-driftnets	
						Beginning time of towing, 24-hour notation	Number of saury caught per 60-min tow	Time when setting up M-driftnets was finished, 24-hour notation	Number of saury caught per 120-min setting
45	StN-3-5	2001/07/12	42.49	153.17	12.4	–	–	18:59	0
46	StN-3-6	2001/07/12	42.42	153.22	12.6	–	–	22:59	7
47	StN-4-2	2001/07/13	43.57	155.43	12.9	–	–	18:57	9
48	StN-4-1	2001/07/13	43.57	155.36	12.5	14:50	315	–	–
49	StN-5	2001/07/14	44.29	156.12	11.2	11:13	39	–	–
50	St7-0	2001/07/14	44.44	156.46	11.4	15:22	18	16:50	24
51	St7-1	2001/07/15	44.03	157.54	12.8	6:20	1	–	–
52	St7-2	2001/07/15	43.06	158.42	15.3	14:46	839	19:58	231
53	St7-3	2001/07/16	42.17	159.22	14.3	4:57	4386	3:00	35
54	St7-4	2001/07/16	41.28	160.01	15.5	14:49	27332	16:55	1391
55	St7-5	2001/07/17	40.37	160.43	15.5	5:19	0	2:54	3
56	St7-6	2001/07/17	39.42	161.21	17.1	14:48	0	16:57	3
57	StD6-6	2001/07/18	42.10	156.04	15.9	16:48	284	–	–
58	StD5-6	2001/07/19	41.50	154.24	17.5	5:10	6672	3:02	125
59	StD4-7	2001/07/19	41.17	152.00	19.8	14:52	0	16:59	0
60	StD3-8	2001/07/20	40.28	149.57	19.7	5:09	0	2:59	0

SST Sea surface temperature

Area (stratum) for CPUE analysis and abundance estimation

The area-swept method was used to calculate stock abundance, as described previously for demersal fish species [9], because Pacific saury is known to be distributed in very shallow waters (<15 m deep) [10] and the vertical opening of the mid-water trawl could cover an area extending from the surface to a depth of 20 m. Pacific saury is widely distributed in the Kuroshio–Oyashio transitional zone of the North Pacific Ocean [1]. The size composition and maturation stage of Pacific saury are believed to be much different in the southern and northern habitats [11, 12].

In the early summer when this survey was carried out, the proportion of small-sized Pacific saury is comparatively dominant in the southern waters while the proportion of large-sized fish gradually increases towards the north [11, 12]. Moreover, warm water in the southern habitat is considered to accelerate the maturation of Pacific saury [13]. In such conditions, mature Pacific saury looking for drifting seaweed to spawn would concentrate just near the sea surface. On the other hand, Pacific saury in the northern habitat is known to migrate into deeper waters (10–15 m deep) [10]. The consequent differences in the size composition and the distribution pattern of saury between the northern

and southern habitats indicate that it is not appropriate to calculate stock abundance without area stratification.

To decide strata for abundance estimation, we examined differences in the size composition of saury according to SST distribution at sampling sites where >100 saury were caught by the mid-water trawl. Based on these catch data and SSTs, we divided the survey area into a low SST water stratum and high SST water stratum to calculate the stock abundance.

Comparison of catch between mid-water trawl and M-driftnets

The CPUE of the mid-water trawl was calculated by dividing the number of saury caught in an operation by the towing period (in minutes, from the beginning to the end of towing) and then by multiplying the product by 60 (minutes). This value corresponds to the number of saury caught per 60-min tow of the trawl. The CPUE of the M-driftnets was calculated by dividing the total number of saury caught in an operation (all mesh sizes) by the setting duration (in minutes, from the setting of the M-driftnets to their lifting out of the water) and then by multiplying the product by 120 (minutes). This value corresponds to the number of saury caught per 120-min setting of the M-driftnets.

We compared the paired CPUEs from the mid-water trawl and M-driftnets at each sampling station to determine the fishing characteristics and suitability of the mid-water trawl for stock abundance estimation.

Estimation of stock abundance and confidence limits

Using geographic information system analysis (GIS; Marine Explorer, Environment Simulation Laboratory Co, Ltd. <http://www.esl.co.jp/mesupport.htm>), we constructed an SST map based on SSTs observed at research stations. Optimal interpolation at an unmeasured location was done by the Kriging method with the GIS software. The CPUE data from the mid-water trawl operations were averaged according to appropriate SST ranges and compared. Size composition was also compared between the same SST ranges. Confidence limits of stock abundance estimates were estimated by the bootstrap method. The fishing efficiency [catch rate used in individual per swept-area (m^2)] of the mid-water trawl was that from a previous study (0.179) [7].

Results

Area (stratum) for CPUE analysis and abundance estimation

Comparison of size compositions of Pacific saury and SSTs at the sampling stations (Table 2) indicate that in high SST waters, small-sized (knob length <239 mm) and medium-sized (knob length 240–279 mm) saury were the dominant size groups, whereas in low SST waters, medium-sized and large-sized (knob length >280 mm) were the dominant size groups. The trend in the size composition was consistent with data reported previously [11, 12]. Suyama reported that the abundance of mature saury increased in waters with a SST of ≥ 15 °C [13].

Based on these biological features and SSTs of research stations where the saury were caught, we divided the survey area into low SST water stratum (>11 and <15 °C, A-stratum) and high SST water stratum (<18 and ≥ 15 °C, B-stratum) to calculate the abundance estimation. The upper and lower limits of SST for these strata were decided upon from the upper and lower limits of SST where saury were caught.

Comparison of CPUE data between mid-water trawl and M-driftnets

The CPUE data of the mid-water trawl and M-driftnets are shown in Table 1 and Fig. 1. The locations where saury were caught by the M-driftnets and by the mid-water

trawl were generally consistent. The trend in catch abundance distribution by both fishing gears also appeared to be similar.

To examine the relationship between the CPUE data and both gears more closely, the CPUE data of the mid-water trawl and M-driftnets were log-transformed and plotted on the x - and y -axes, respectively (Fig. 2). We added 1 to all original CPUE data before their logarithmic conversion to compensate for the 0 values. The upper part of Fig. 2 compares the data for all comparative sampling operations and shows a significant correlation in CPUE data for both gears (Spearman's rho 0.673, $P < 0.01$). The lower left part of Fig. 2 compares CPUE data between gears at SST of <15.0 °C, which also shows a significant correlation (Spearman's rho 0.496, $P < 0.05$). The lower right part of Fig. 2 compares CPUE data between gears at SST of ≥ 15.0 °C, and this correlation coefficient is also significant (Spearman's rho = 0.641, $P < 0.01$). It was found that while the M-driftnets caught a few saury, the mid-water trawl often caught none.

Comparison of size composition of catch according to fishing gear

To examine differences in the size composition of saury collected by both gears, we compared the size composition of the catch from the sampling sites where >30 saury were caught by both gear types (Fig. 3). A comparison of the average size composition for both gears is shown in the lowest part of Fig. 3. The proportions of small-/medium-sized fish (knob length 180–279 mm) were comparatively higher in the mid-water trawl, and the proportions of medium-/large-sized fish (knob length 280–340 mm) were higher in the M-driftnets.

Abundance estimation

An SST map and the strata for abundance estimation are shown in the upper and lower parts of Fig. 4, respectively. The areas of both strata were calculated using GIS "Marine Explore" analysis. Stock abundance as numbers/weight for each stratum area was calculated from the average CPUE for mid-water trawl operations within each stratum using the area-swept method (Table 3). For specific biological sampling, we occasionally repeated sampling operation in specific narrow areas within 24 h. In such cases, we adopted the catch data of the first sampling station for the abundance estimation and excluded the data of successive sampling operations. The excluded sampling stations were St2-3-2, St2-3-3, St24-2, St24-3,

Table 2 Fluctuation in size composition of Pacific saury *Cololabis saira* by the mid-water trawl mode according to sea surface temperature

Sampling station	SST	Number of saury caught	Size composition (knob length in mm)																															
			120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350								
StN-3-3	12.4	299	0	0	0	0	0	0	2	0	4	14	20	18	22 ^a	12	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
StN-3-2	12.5	1354	0	0	0	0	0	0	0	0	4	0	6	6	22	26 ^a	26 ^a	8	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	
StN-4-1	12.5	315	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	33 ^a	26	15	7	0		
St5-8	13.3	1650	0	0	0	0	0	0	0	0	4	6	24	22	30 ^a	2	2	0	0	0	4	4	4	2	0	0	0	0	0	0	0	0	0	
St4-6-A	13.4	486	0	0	0	0	0	0	0	0	0	4	17	31	28 ^a	11	2	0	0	4	1	2	0	0	0	0	0	0	0	0	0	0	0	
St6-7	13.7	397	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	8	32	42 ^a	12	0	0	0	0	0	0	0	0	0	0	
St5-5	13.8	363	0	0	0	0	0	0	0	0	2	4	34	36 ^a	8	10	0	2	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	
St24-1	14.1	1214	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	36	46 ^a	14	2	0	0	0	0	0	0	0	0	0	
St24-2	14.2	383	0	0	0	0	0	0	0	0	2	6	4	2	2	0	0	0	2	12	35 ^a	22	10	2	0	0	0	0	0	0	0	0	0	0
St7-3	14.3	4386	0	0	0	0	0	0	0	0	0	2	2	2	2	4	6	0	6	14	16	16	22 ^a	8	0	0	0	0	0	0	0	0	0	0
St24-4	14.4	110	0	0	0	0	0	0	0	0	0	2	0	4	0	0	0	0	6	10	22	41 ^a	16	0	0	0	0	0	0	0	0	0	0	0
St7-2	15.3	853	0	0	0	0	0	0	0	0	2	12	10	20 ^a	18	12	10	2	0	2	4	6	2	0	0	0	0	0	0	0	0	0	0	0
St7-4	15.5	27,332	0	0	0	0	0	0	4	8	31	20 ^a	14	6	8	4	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
StD6-6	15.9	289	0	0	0	0	0	0	0	0	12	12	8	4	12	21 ^a	12	13	4	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
StD5-6	17.5	6672	0	0	0	0	0	14	20 ^a	16	10	18	6	6	4	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
St2-3-2	17.6	168	2	14	37 ^a	31	12	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Values with "Size composition" are given as the percentage

^a The most frequent value

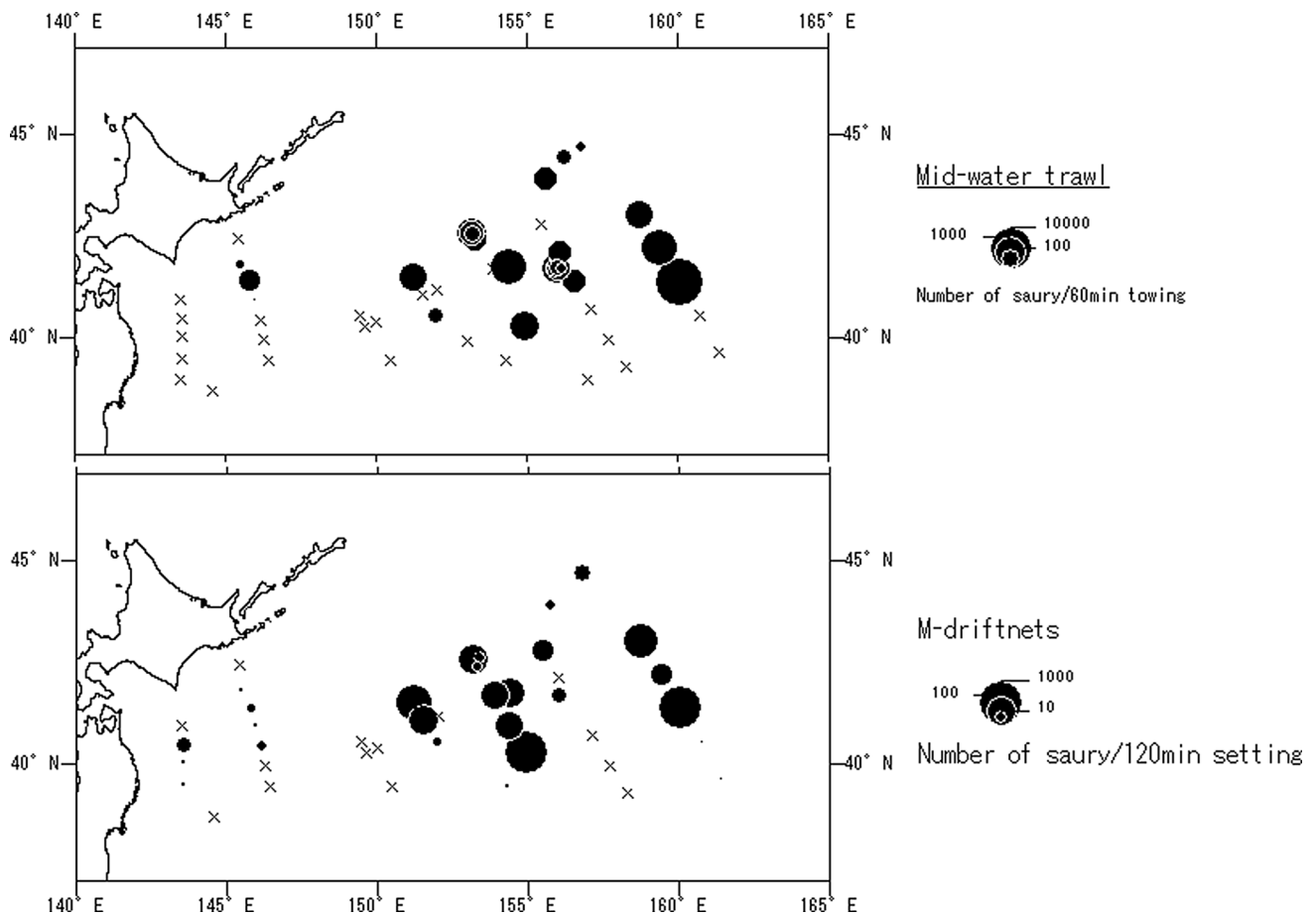


Fig. 1 Map showing catch per unit effort (CPUE) distribution data of Pacific saury *Cololabis saira* using a mid-water trawl and M-driftnets. Cross indicates no catch

St24-4, StN3-3, and StN3-4. This step was performed to avoid the geographical bias of abundance estimation arising from repeated sampling operations conducted in a short time/narrow area. The stock abundance by total weight was calculated as 1,132,000 tons with a 2.5% upper and lower confidence limit of 268,000 and 2,481,000 tons, respectively. The coefficient of variation was estimated as 50.3%.

Discussion

Why is size composition different between equipment types?

Takahashi [8] reported that M-driftnets tend to selectively retain larger saury because of its biased-proportional mesh

composition, which would explain the difference in size composition in our results. To the contrary, Gunderson [14] noted that large fish were able to more readily escape from fishing gear compared to their smaller counterparts, but that this tendency varied with gear type and target species. Thus, the difference in size composition may be interpreted as the active escaping of saury from the mid-water trawl. However, our study results show that the mid-water trawl often retained many large saury [see, for example, Table 2, stations St24-1 and St7-3, at which >1000 saury were collected and the proportions of larger fish (knob length 280–340 mm) were >70%]. This result suggests that the size range of saury caught by the mid-water trawl is sufficiently wide and that this gear actually had a certain degree of efficiency for catching larger fish. Accordingly, we expect that the mid-water trawl is useful for estimating exact stock abundance.

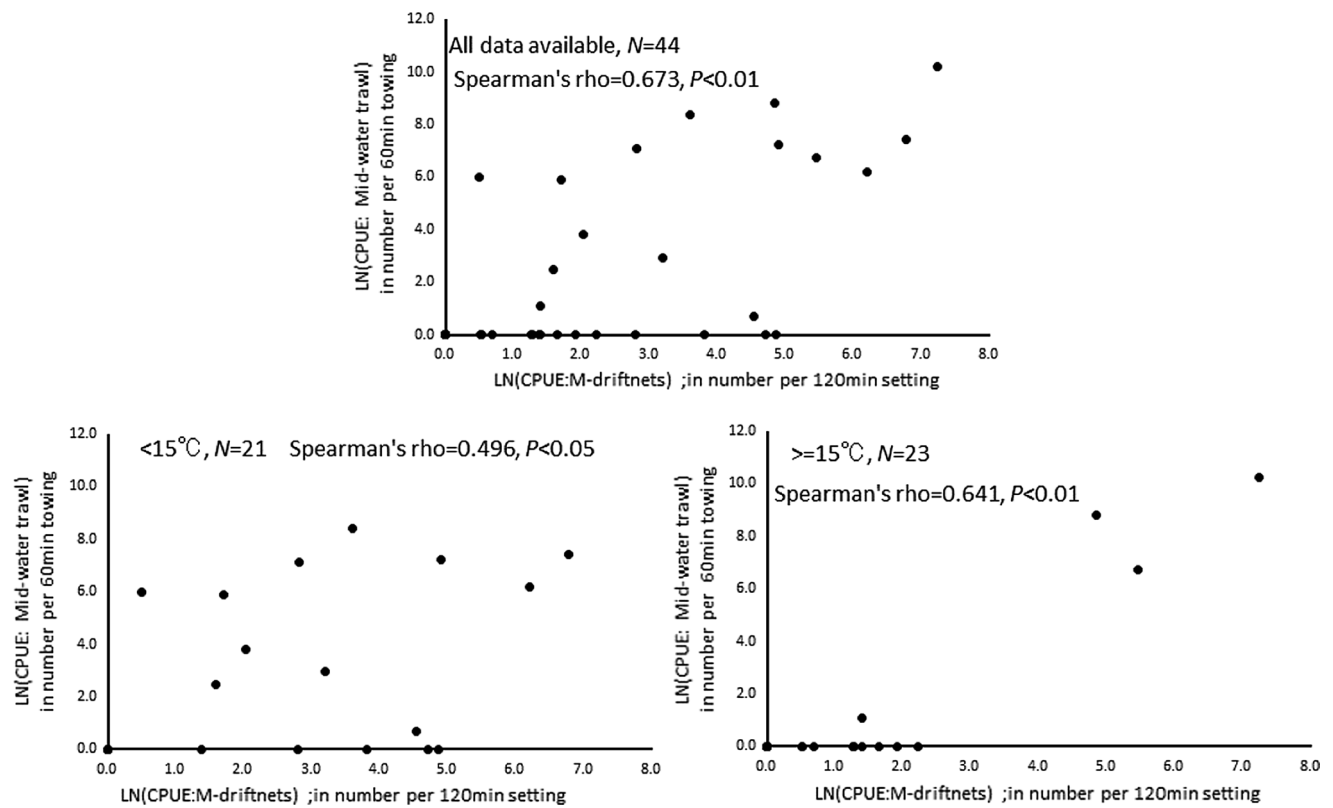


Fig. 2 Relationship between log (CPUE + 1.0) for the mid-water trawl and M-driftnets in all data sets and at different sea surface temperature (SST) ranges

Practicality of stock abundance estimation using the mid-water trawl and area-swept method

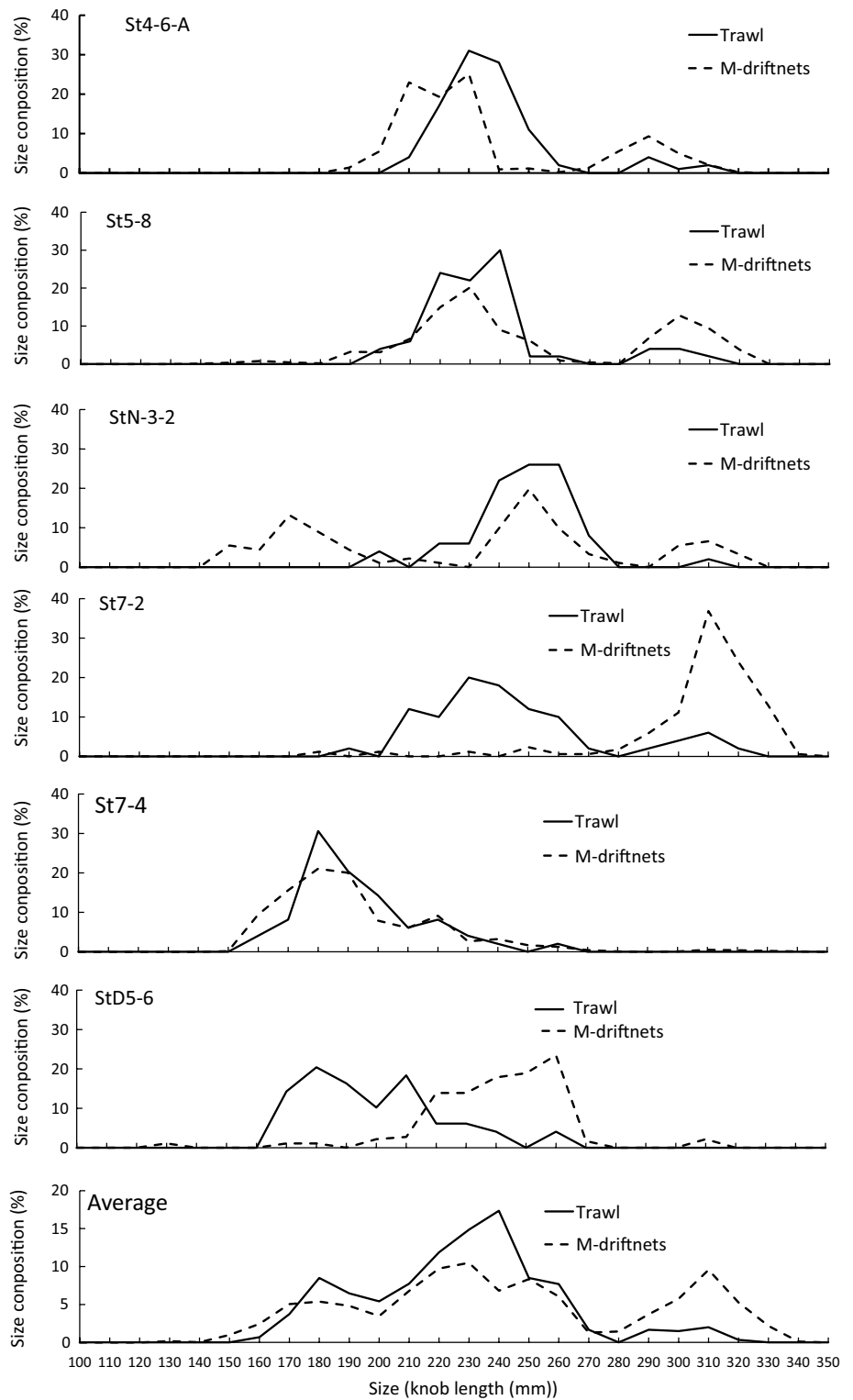
The results of our study show that data obtained using the mid-water trawl, similar to data obtained using M-driftnets, could be used to detect the trend of abundance and distribution of Pacific saury. Compared to two previously reported sampling techniques [2, 3], the use of a mid-water trawl has two additional advantages for estimating stock abundance: (1) catch data can be used to estimate stock abundance prior to the start of the commercial fishing season; (2) catch data can be used to calculate absolute abundance and the confidence limits of abundance. These aspects clearly demonstrate that the mid-water trawl is practical for abundance estimation. In our opinion, these advantages will contribute to the more effective management of the saury fishery.

In areas where very few of saury were caught by M-driftnets (Fig. 2), often none were taken by the mid-water

trawl. These cases were only found in waters with a SST of $\geq 15^{\circ}\text{C}$, and the few saury caught were often entangled in the extreme upper edges of the M-driftnets, which may suggest that these fish inhabited the surface layers ($<1\text{ m}$). In contrast, because the head rope of the mid-water trawl passed through the surface layer at high speed (257 cm/s), it may have scattered Pacific saury and the fishing efficiency of the trawl may have been lower in these layers. As a result, in such cases, saury were captured only by M-driftnets but not by mid-water trawl. This result suggests that saury density estimated by the mid-water trawl may be a slight underestimate, but a conservative way to assess stock abundance.

In most of the sampling stations where many Pacific saury were caught by the mid-water trawl, fewer fish were caught by the M-driftnet. The effective height of the mid-water trawl (about 20 m) was much higher than that of the M-driftnets (5 m). This difference in height may affect the difference in catch between the both sampling gears.

Fig. 3 Size composition (knob length) of Pacific saury taken with the mid-water trawl and M-driftnets. Catch data are for six sampling sites where >30 individuals of saury were caught by both equipment types. The average size composition for the six stations is also shown



Improvement in the accuracy of the abundance estimation

The point estimates of stock abundance (in individual and weight), the 2.5% upper and lower confidence limits,

and coefficients of variation are shown by stratum and for the entire catch in Table 3. The confidence limits of the whole area ranged from 24 to 219% of the point estimate in weight. The coefficient of variation was also comparatively large at 50.3%. To reduce the range within the

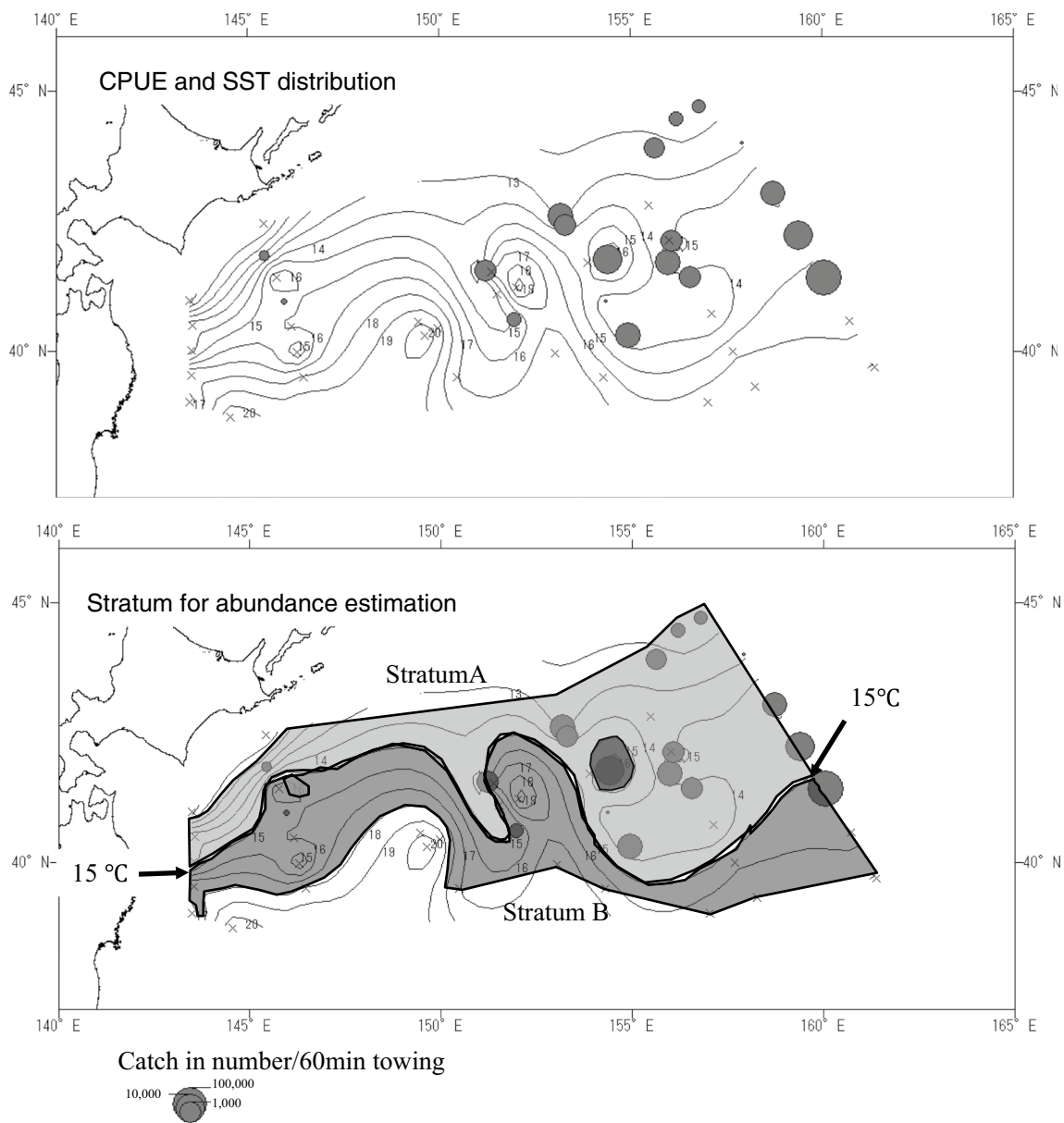


Fig. 4 Distribution of mid-water trawls CPUE/sea surface temperature (SST) contour lines and area (*Stratum*) for estimation of stock abundance using the area-swept method. *Stratum A* includes low SST

water stratum areas (>11 and <15 °C SST), *Stratum B* includes high SST water stratum areas (≥ 15 and <18 °C SST)

confidence limits, sampling activity must be increased in the strata. For medium- and large-sized saury (knob length 210–350 mm), sampling needs to be increased in the low SST waters (for example, A-stratum >11 and <15 °C) that contain the majority of the stock. For smaller saury, sampling activity should be increased in the high SST waters (for example, B-stratum, ≥ 15 and <18 °C); however, this is difficult to achieve in all research areas because of

limitations in time and cost. The layers where a focused research effort should be conducted differ depending on the purpose of the investigation. In order to manage the commercial catch in a given year when the survey is to be carried out, northern strata in which large- and medium-sized saury are dominant should be important focus of the research survey because these sizes of saury are main targets of commercial fisheries.

Table 3 Stock abundance estimated in numbers and weight

Strata information	SST range (°C)	Area (10 ³ km ²)	Stock abundance in number			Stock abundance in weight		
			Stock abundance (point estimate) (individuals 10 ⁶)	Confidence limit Upper 2.5% Lower 2.5%	Coefficient of variation (%)	Stock abundance (point estimate) (10 ³ ton)	Confidence limit Upper 2.5% Lower 2.5%	Coefficient of variation (%)
A (low SST water stratum areas)	>11.0 to <15.0	312	4089	8199 1106	46.2	509	1,113 111	54.6
B (high SST water stratum areas)	≥15.0 to <18.0	253	15,063	41,589 315	73.4	622	1,820 9	78.7
Total	–	565	19,152	46,376 3452	58.9	1132	2481 268	50.3

We suggest that another method by which to reduce the range of the confidence limits is to improve the method of area stratification based on the trend of various factors, such as the SST, the length composition of saury, and the saury catch distribution by the mid-water trawl.

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