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Basin-scale distribution pattern and biomass estimation of Japanese anchovy *Engraulis japonicus* in the western North Pacific

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Abstract The distribution pattern and biomass of the Japanese anchovy *Engraulis japonicus* in the offshore region of the western North Pacific (north of 35°N and west of 170°E) were studied using a quantitative echosounder. This is the first attempt at such a study in this region. Data were collected in summer from 2004 to 2007. The biomass was estimated using data collected at 38 kHz. Species compositions in the backscatterings from pelagic fish were assigned based on the results of trawl hauls taking account of sea surface temperature (SST). Japanese anchovy tended to be high density to the west of 153°E and were distributed in an SST range of 9–24 °C. Although the temporal and spatial coverage of the survey differed each year, at least 1.5–3.4 million tons of Japanese anchovy were present in the survey area between 2004 and 2007. To take account of the spatial coverage of the survey each year, the most reliable biomass estimate for this region in the time period was 3.4 million tons (coefficient of variation 0.22).

Keywords Abundance · Acoustic · Distribution · Hydroacoustic · Kuroshio · Oyashio · Pelagic fish · Stock assessment

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Introduction

Old World anchovies, *Engraulis* spp., are distributed worldwide, mainly in coastal waters [1]. Among these, the Japanese anchovy *E. japonicus* is distributed around Japan and adjacent waters. The Pacific stock of the Japanese anchovy is distributed on the Pacific coast side of Japan [2]. Although this stock tends to inhabit the coastal region, like other *Engraulis* spp., it is well documented that the distribution range expands offshore to as far as 180° longitude when the stock is abundant [3–9].

Japanese anchovy in the offshore region is considered to be transported from the spawning ground on the coastal side of the Kuroshio by the Kuroshio Extension [10, 11]. However, it has been reported that Japanese anchovy also spawn offshore [12–14]. Therefore, offshore Japanese anchovy are considered to be a mixture of the offspring of inshore and offshore spawners [9, 15]. The results of several studies indicate that the biological characteristics of Japanese anchovy distributed in inshore and offshore waters are different. Funamoto and Aoki [12] demonstrated that Japanese anchovy located offshore spawn at a colder water temperature than inshore anchovy. Takasuka et al. [16] further demonstrated that batch fecundities and spawning frequencies in relation to sea surface temperature (SST) are different for inshore and offshore. Yukami et al. [17] suggested that Japanese anchovy grow faster offshore than individuals located inshore based on otolith microstructure analysis. Tanaka et al. [15] found higher stable carbon and nitrogen isotope ratios in Japanese anchovy inshore than offshore. The difference in the isotope ratio may reflect differences in feeding habits as well as differences in the baseline levels of food webs inshore and offshore.

The Pacific stock of Japanese anchovy is an important target species for coastal commercial fisheries. The abundance (number of individuals) and the biomass (total weight) have been estimated by the Fisheries Agency of Japan for the purpose of stock management based on a cohort analysis using commercial catch data and an egg production method using a systematic net sampling data set. Since the cohort analysis and egg production data are restricted to those obtained near coastal waters, the estimates of abundance and biomass are only available in the coastal waters. Although it is generally believed that millions of tons of the Pacific stock of Japanese anchovy are distributed offshore during periods of high abundance, the exact biomass has not been reported.

Echosounders have been commonly used to obtain biomass estimations as well as in distributional studies of, for example, the European anchovy *E. encrasicolus* in the Bay of Biscay [18–21] and Mediterranean Sea [22–24], the Southern African anchovy *E. capensis* on the South African continental shelf [25–28], the northern anchovy *E. mordax* off the west coast of Baja California [29], the Peruvian anchovy *E. ringens* in Peruvian waters [30, 31], and the Argentine anchovy *E. anchoita* in Argentine waters [32]. Large-scale acoustic surveys have been conducted in the East China Sea and the Yellow Sea to estimate the biomass of the Japanese anchovy [33–35]. Regional studies of the Japanese anchovy using echosounders have been conducted in Japanese coastal waters [36–39]. However, to date, no attempt has been made to estimate the biomass of the Pacific stock of Japanese anchovy in the offshore region of the western North Pacific using a quantitative echosounder.

Although there is little commercial fishing of the Japanese anchovy in the offshore region of the western North Pacific, it plays a key role in the marine ecosystem as a prey of predators, including commercially important species such as neon flying squid *Ommastrephes bartramii* [40], salmonids [6], skipjack tuna *Katsuwonus pelamis* [41], and baleen whales [42, 43].

In this paper, the results of the study on the distribution pattern and biomass of Japanese anchovy in the offshore region of the Kuroshio–Oyashio transition zone of the western North Pacific are presented. Data obtained by trawl and echosounder surveys conducted from 2004 to 2007 are used in this study. This is the first attempt at a basin scale study designed to determine the distribution and to estimate the biomass of the stock of Japanese anchovy in the western North Pacific.

Materials and methods

Survey area, period and vessels

The survey area was in the western North Pacific (Fig. 1). The southern, northern, eastern, and western boundaries of the survey area were 35°N, the economic exclusive zone (EEZ) boundaries claimed by foreign countries (except to the west of 147°E), 170°E, and the eastern coastline of Japan, respectively. The continental shelf region of Japan (shallower than 200 m) was not included except in the 2006 survey when a small survey effort was undertaken on the shelf. Eight small blocks were established to take account of the general oceanographic conditions, as suggested in Yasuda [44], in the survey area and to estimate the biomass using a stratified random sampling method [45]. The echosounder survey was conducted in summer (May–August) (Table 1). A cetacean sighting survey vessel, Kyoshin-Maru No. 2 (KS2: 368GT), engaged in an acoustic survey as a part of the Japanese Whale Research Program under Special Permit in the western North Pacific-Phase II (JARPN II). Two trawler fisheries research vessels, Ohmi-Maru (OHM; 403 GT) and Hokuho-Maru (HOK: 664 GT), towed midwater trawls as part of the annual survey of Pacific saury *Cololabis saira* abundance conducted by Tohoku National Fisheries Research Institute. The trawl data were collected in June and July. Because the echosounder and trawl surveys were undertaken independently, the tracklines and timing of these surveys were not exactly the same.

Acoustic data collection

Acoustic data were collected by KS2 while she conducted cetacean sighting surveys on the survey tracklines. Zigzag tracklines were set systematically within the survey area. A calibrated quantitative echosounder (Simrad EK500, Norway) was operated during the daytime on KS2 to acquire acoustic data with the operating frequency at 38 kHz. The transducer was hull-mounted at a depth of 4.3 m below the sea surface. The data were recorded with the aid of Echoview software (Myriax, Australia).

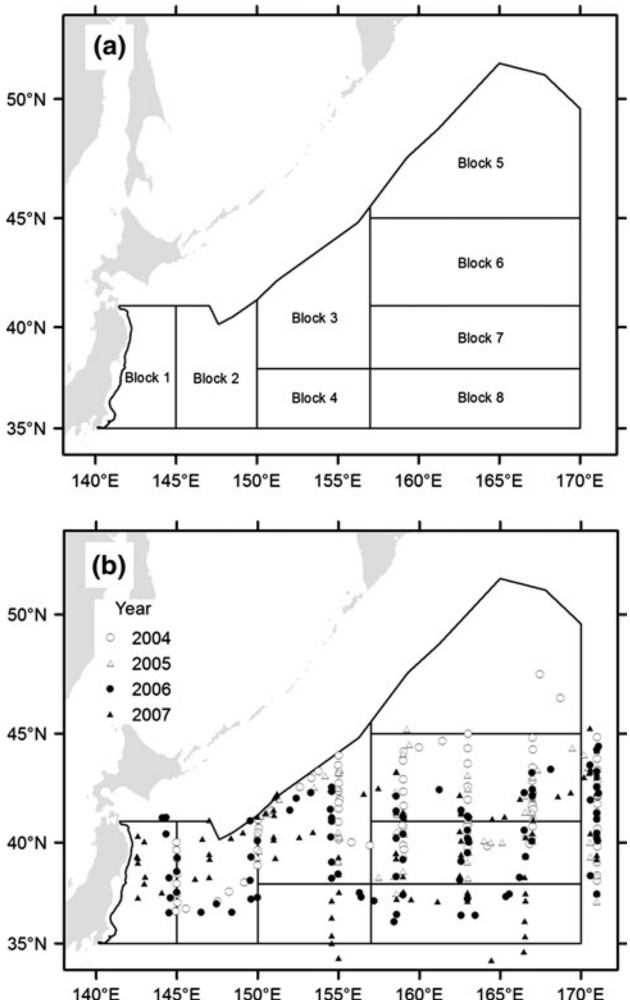

Fig. 1 Survey area (**a**) and locations of midwater trawl sampling stations (**b**). Eight survey blocks were established in the area

Trawling

OHM and HOK performed midwater trawls at predetermined stations to collect biological samples, with the primary purpose of estimating the abundance of Pacific saury. Meridional tracklines were set approximately 4° apart in the longitudinal direction, and sampling was conducted at three stations per day along the tracklines as well as while moving between the tracklines. The midwater trawls (NST-99, Nichiomo, Japan) were 86.3 m long with a mouth opening of 900 m^2 and a 6.0 m cod end with a 17.5 × 17.5 mm mesh inner. The specifications of the midwater trawl are given in detail in Ueno et al. [46]. The towing speed of the trawl net was 4–5 knots, and the water depth layer sampled by the midwater trawl was 0–20 m. Floats were attached to the bridle of the trawl so that the trawl could be towed at the surface where the Pacific saury is mainly distributed [46]. The towing continued for 1 h at each station.

Sea surface temperature

The SST was recorded every hour by using a temperature sensor positioned at the bottom of KS2 ,while acoustic data were collected along the tracklines. The SST at each trawling station was also recorded by using sampled water with a thermometer. Level 3 seasonal composite SST data in the summer (21 June to 20 September of each year) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the satellite Aqua were used to observe the qualitative relationship between the SST and the distribution patterns of Japanese anchovy. The Aqua MODIS data were downloaded from Ocean Color Web (http://oceancolor.gsfc.nasa.gov/).

Table 1 Timing of the echosounder survey for each block in each year

Block	Year			
	2004	2005	2006	2007
1	14–29 May	–	29 June–6 July	22–24 June
				28–30 July
2	30 May–8 June	–	17–19 May	24–27 June
			25–29 June	25–28 July
3	10–16 June	17–26 May	18–24 June	10–16 June
	22–29 June	12–17 July	11–17 July	27 June–2 July
4	–	27 June–5 July	19–25 May	20–24 July
5	–	22 August	5–26 August	15–28 May
6	2–18 August	18 July–21 August	17 July–4 August	29 May–10 June
	22–23 August			
7	30 June–2 July	27 May–11 June	7–18 June	2–10 July
	7–8 July			
	19–31 July			
8	–	12–26 June	25 May–5 June	10–20 July

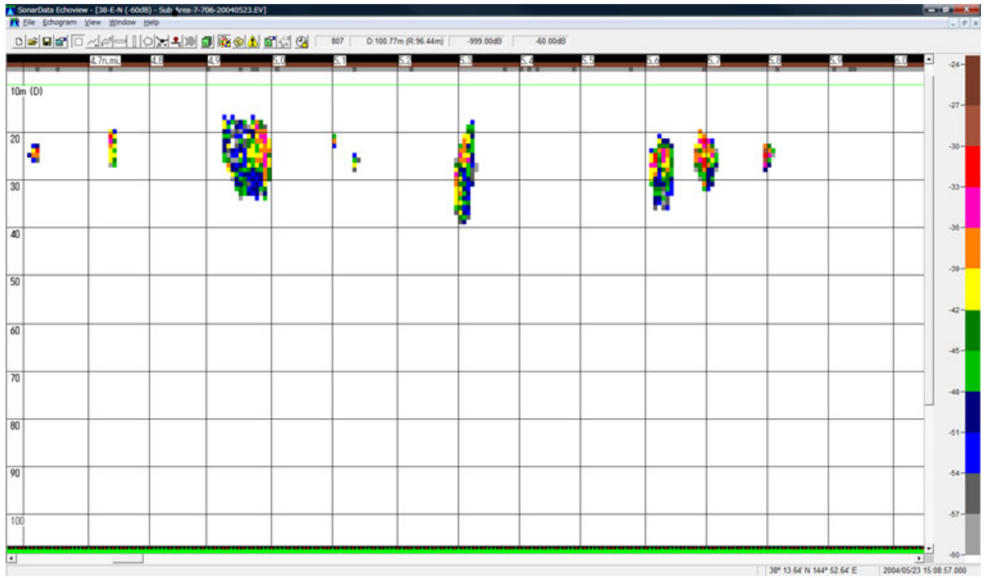

Fig. 2 Typical echosigns of pelagic fish schools recorded with the echosounder. The data were recorded at 38°13′ N and 144°52′ E on 23 May 2004. The grid size is 0.1 n.mile (*horizontal direction*) × 10 m (*vertical direction*)

Data analysis

Japanese anchovy, Japanese sardine *Sardinops melanostictus*, and mackerel (including both chub *Scomber japonicus* and spotted *S. australasicus* mackerel) are the only small pelagic fish species to form dense schools in the survey area. Although Pacific saury also form dense schools, they are distributed near the sea surface [46]. Therefore, they are rarely detected with an echosounder. For this reason, Pacific saury were not considered in this analysis. Species seen in echosigns could not be identified by trawling in the field because the echosounder and trawl survey vessels were operated independently. Accordingly, pelagic fish were distinguished from the other backscatterings based on their shapes and auxiliary acoustic characteristics (e.g., backscattering intensity) [47, 48], although the species compositions of pelagic fish schools could not be identified. Typical echosigns of pelagic fish observed during the survey are shown in Fig. 2. To add the species composition information to the acoustic data, the proportion of the species composition by number of individuals was obtained using trawl data. The proportion was calculated for each 1 °C SST increment, as were the arithmetic mean lengths. Because anchovy larvae have a different acoustic property from that of juveniles and adults [49], these were not considered in the analysis. The target strengths (TS) of anchovy and mackerel corresponding to their mean lengths were calculated using formulas (1) [50] and (2) [51], respectively:

$$\mathrm{TS} = 20\log L_{\mathrm{t}} - \frac{20}{3}\log\left(1 + \frac{z}{10}\right) - 67.6 \tag{1}$$

$$\mathrm{TS} = 20\log L_{\mathrm{t}} - 70.9 \tag{2}$$

where TS is in decibels (dB), L_{t} is the total length (cm), and z is the water depth (m) corresponding to the Japanese anchovy distribution. Formula (1) was used as a substitution for sardine. The mean distribution depths ($\bar{z}$) of Japanese anchovy were used in the formula as suggested by Murase et al. [52] and were calculated as:

$$\bar{z} = \frac{\sum z_i s_{\mathrm{A}i}}{\sum s_{\mathrm{A}i}} \tag{3}$$

where z_i is the ith 1 m depth bin and $s_{\mathrm{A}i}$ is the nautical area scattering coefficient (m^2/n.mile^2) of pelagic fish in the ith depth bin. For this purpose, the s_{A} of pelagic fish was calculated every 1 n.mile of the survey transect in each 1 m depth bin for a water depth of 10–150 m. Because the scale length [L_{s}; from the most anterior part of the fish to the most posterior part covered by scales (cm)] of Japanese anchovy was measured in the field, it was converted to L_{t} (cm) using the following formula:

$$L_{\mathrm{t}} = 1.092L_{\mathrm{s}} + 0.848. \tag{4}$$

This formula was estimated by using data collected by the authors in other locations ($n = 591$, $R^2 = 0.98$). The L_{s} of the Japanese sardine and the fork length of the mackerel were used as substitutes for L_{t} because no conversion formula was available. The arithmetic mean lengths of the Japanese sardine and the mackerel were calculated for each 1 °C SST increment.

Acoustic data were analyzed with the aid of Echoview, with the noise threshold set at −60 dB. The s_{A} was calculated every 1 n.mile of the survey tracklines over a defined depth interval (10–150 m) for the purpose of biomass estimation. SST data recorded along the tracklines every hour, corresponding to the midpoints of the 1 n.mile intervals, were assigned to acoustic data. Time at the midpoints of the intervals was rounded to the nearest hour. A s_{A} was allocated to Japanese anchovy, Japanese sardine, and mackerel, respectively, based on their proportions in the 1 °C SST increments. These proportions were applied to the 1 n.mile intervals corresponding to the SST. Although most Japanese anchovy are distributed in shallow water (e.g., <50 m), they are also distributed in deeper water (>50 m) according to our unpublished data as well as results from other studies [53, 54], with the maximum recorded water depth reported being 150 m [53]. Based on information regarding the vertical distribution pattern of Japanese anchovy, acoustic data obtained at depths from 10 to 150 m were used in the analysis. The biomass density (ρ; t/n.mile^2) was calculated as:

$$\rho = \left(\frac{s_{\mathrm{A}}}{\sigma_{\mathrm{sp}}}\right) w \tag{5}$$

where σ_{sp} is a spherical scattering cross-section and w is the wet weight of anchovy corresponding to the mean length calculated by using the SST in 1 °C increments. A weight–length relationship formula reported by Kubota et al. [2] was used:

$$w = 0.010 L_{\mathrm{s}}^{3.00}$$

where w is the wet weight (g) of an individual. The parameters in the formula are mean values between 1998 and 2007, with mean of $n = 13{,}470$ and mean of $R^2 = 0.944$. The σ_{sp} is derived as:

$$\sigma_{\mathrm{sp}} = 4\pi 10^{0.1\mathrm{TS}} \tag{6}$$

The biomass and its variance in the survey area were estimated based on the stratified random sampling method [45] as follows. The weighted mean of ρ for each block was:

$$\overline{\rho_k} = \frac{\sum_{i=1}^{N_k} \overline{\rho_{ki}} n_{ki}}{\sum_{i=1}^{N_k} n_{ki}} \tag{7}$$

where, $\overline{\rho_k}$ = mean ρ in the kth block, N_k = number of transects in the kth block, $\overline{\rho_{ki}}$ = mean ρ on the Ith transect in the kth block, and n_{ki} = number of 1 n.mile intervals on the ith transect in the kth block. In this formula, each transect is regarded as a single biomass density sample. The variance of $\overline{\rho_k}$ was then calculated as:

$$\mathrm{var}(\overline{\rho_k}) = \frac{N_k}{N_k - 1} \frac{\sum_{i=1}^{N_k} \left(\overline{\rho_{ki}} - \overline{\rho_k}\right)^2 n_{ki}^2}{\left(\sum_{i=1}^{N_k} n_{ki}\right)^2}. \tag{8}$$

The biomass (B_k) in the kth block was estimated as:

$$B_k = A_k \overline{\rho_k} \tag{9}$$

where, A_k is the area of the kth block (n.mile^2). The variance of B_k was calculated with the following formula:

$$\mathrm{var}(B_k) = A_k^2 \mathrm{var}(\overline{\rho_k}) \tag{10}$$

The coefficient of variation (CV) of B_k was calculated as:

$$\mathrm{CV}(B_k) = \frac{\sqrt{\mathrm{var}(B_k)}}{B_k} \tag{11}$$

The biomass (B_0) in the survey area was calculated as:

$$B_0 = \sum_{k=1}^{N} B_k \tag{12}$$

The variance of B_0 was:

$$\mathrm{var}(B_0) = \sum_{k=1}^{N} \mathrm{var}(B_k) \tag{13}$$

The CV of B_0 was calculated as:

$$\mathrm{CV}(B_0) = \frac{\sqrt{\mathrm{var}(B_0)}}{B_0} \tag{14}$$

The degree of coverage (d) defined by Aglen [55] was used to measure the sampling intensity of the echosounder survey. The degree of coverage is written as:

$$\mathrm{d} = \frac{D}{\sqrt{A}} \tag{15}$$

where D is the total length of the trackline (n.mile) and A is the size of the survey area (n.mile^2).

Results

Biological samples of pelagic fish were obtained at a total of 347 trawl stations from 2004 to 2007 (Fig. 1). Among these, both Japanese anchovy and mackerel were sampled simultaneously at 68 stations, with Japanese anchovy being dominant (>90 % of the total catch in numbers) at 38 stations and mackerel being dominant at seven stations. Japanese anchovy and mackerel were moderately mixed (up to 50%) at the remaining 23 stations. The species composition of the pelagic fish in 1 °C increments is given in Table 2. Japanese anchovy was the dominant catch in most cases, but the proportion of mackerel increased when the SST exceeded 14 °C, especially in 2004 and 2007. The relatively large CV suggested that the number of sampled individuals in each haul varied greatly.

The length frequency of Japanese anchovy in each 1 °C SST increment indicated that small individuals tended to occur when the SST was high, while large individuals tended to occur when the SST was low, although no consistent change in length frequency was observed along the SST gradient. The mean L_{t} (range 4.8–15.3 cm) and corresponding w (range 0.5–23.2 g) for anchovy are summarized in Table 3.

Table 2 Species composition in 1 °C increments for each year. Number of hauls and coefficient of variation are also shown

SST (°C)	Year																				
	2004										2005										
	Number of hauls	Japanese anchovy			Japanese sardine			Mackerels			Number of hauls	Japanese anchovy			Japanese sardine			Mackerels			
		Number of individuals	%	CV	Number of individuals	%	CV	Number of individuals	%	CV		Number of individuals	%	CV	Number of individuals	%	CV	Number of individuals	%	CV	
8	6	0	0	0.00	0	0	0.00	0	0	0.00	7	0	0	0.00	0	0	0.00	0	0	0.00	
9	5	1	100	2.00	0	0	0.00	0	0	0.00	4	0	0	0.00	0	0	0.00	0	0	0.00	
10	13	140	97	2.13	0	0	0.00	4	3	2.67	10	0	0	0.00	0	0	0.00	0	0	0.00	
11	11	673	100	2.63	0	0	0.00	0	0	0.00	7	3	100	2.45	0	0	0.00	0	0	0.00	
12	9	12,954	100	2.81	5	0	2.83	31	0	2.83	9	7,825	100	2.81	0	0	0.00	0	0	0.00	
13	13	20,820	99	3.46	3	0	3.46	135	1	3.44	8	12	52	1.33	0	0	0.00	11	48	2.15	
14	6	3,485	80	2.20	0	0	0.00	878	20	2.13	2	192	99	0.99	0	0	0.00	1	1	1.00	
15	7	58,261	59	2.44	64	0	2.41	39,959	41	1.63	8	13,243	96	1.94	13	0	2.65	580	4	2.59	
16	4	12,041	100	1.70	2	0	1.73	37	0	1.55	5	8,385	99	2.00	31	0	2.00	19	0	2.00	
17	7	4,989	28	2.26	0	0	0.00	12,808	72	2.39	9	50,645	99	2.35	64	0	2.26	204	0	1.73	
18	7	36,547	99	1.43	2	0	2.45	532	1	2.00	–	–	–	–	–	–	–	–	–	–	
19	1	16,961	85	0.00	13	0	0.00	3,086	15	0.00	–	–	–	–	–	–	–	–	–	–	
20	3	86	71	1.41	0	0	0.00	35	29	1.41	–	–	–	–	–	–	–	–	–	–	
21	1	18,964	100	0.00	0	0	0.00	42	0	0.00	–	–	–	–	–	–	–	–	–	–	

SST (°C)	Year																			
	2006										2007									
	Number of hauls	Japanese anchovy			Japanese sardine			Mackerels			Number of hauls	Japanese anchovy			Japanese sardine			Mackerels		
		Number of individuals	%	CV	Number of individuals	%	CV	Number of individuals	%	CV		Number of individuals	%	CV	Number of individuals	%	CV	Number of individuals	%	CV
8	6	23	100	2.24	0	0	0.00	0	0	0.00	1	0	0	0.00	0	0	0.00	0	0	0.00
9	11	0	0	0.00	0	0	0.00	0	0	0.00	4	0	0	0.00	0	0	0.00	0	0	0.00
10	4	0	0	0.00	1	100	1.73	0	0	0.00	5	3	100	1.33	0	0	0.00	0	0	0.00
11	10	1,817	100	2.48	0	0	0.00	0	0	0.00	11	60	100	1.18	0	0	0.00	0	0	0.00
12	6	5	100	2.24	0	0	0.00	0	0	0.00	8	81	99	1.23	0	0	0.00	1	1	2.65
13	8	5,632	100	1.79	1	0	2.65	0	0	0.00	13	5,217	97	2.37	19	0	2.64	146	3	3.41
14	10	44	100	1.05	0	0	0.00	0	0	0.00	13	14,762	100	1.82	4	0	2.67	2	0	2.35
15	9	11,360	100	2.81	0	0	0.00	11	0	2.83	8	3,332	31	1.95	20	0	2.65	7,327	69	1.46
16	6	343	90	1.49	0	0	0.00	40	10	2.24	12	6,826	20	2.93	2	0	2.24	26,486	80	3.31
17	8	1,005	100	1.75	0	0	0.00	0	0	0.00	8	90,160	85	1.54	50	0	2.35	15,696	15	2.01
18	9	1,211	100	1.41	2	0	2.83	4	0	1.54	5	847	38	1.68	34	2	2.00	1,347	60	1.23
19	1	0	0	0.00	0	0	0.00	0	0	0.00	3	6,437	89	0.95	11	0	0.90	766	11	1.25

Table 2 continued

SST (°C)	Year 2006										2007									
	Number of hauls	Japanese anchovy			Japanese sardine			Mackerels			Number of hauls	Japanese anchovy			Japanese sardine			Mackerels		
		Number of individuals	%	CV	Number of individuals	%	CV	Number of individuals	%	CV		Number of individuals	%	CV	Number of individuals	%	CV	Number of individuals	%	CV
20	–	–	–	–	–	–	–	–	–	–	4	27,931	60	1.43	114	0	0.98	18,786	40	1.51
21	1	0	0	0.00	0	0	0.00	0	0	0.00	1	9	69	0.00	0	0	0.00	4	31	0.00

SST Surface sea temperature, *CV* coefficient of variation

The mean distribution depth of anchovy in each block for each year is summarized in Table 4. The mean distribution depth from 2004 to 2007 was 24 m.

The estimated biomass of anchovy in each block for each year and in the survey area for each year is shown in Tables 5 and 6, respectively. Not all of the blocks were surveyed in 2004 and 2005, and although all the blocks were surveyed in 2006 and 2007, the degree of coverage indicated that the coverage of the 2006 survey ($d = 5.3$) was greater than that of the 2007 survey ($d = 3.2$). The estimated biomass in 2004, 2005, 2006 and 2007 was 2.84 (CV 0.22), 1.52 (CV 0.43), 3.36 (CV 0.22), and 2.76 (CV 0.31) million tons, respectively. The contribution of blocks 1, 2, and 3, which were located relatively closer to Japan, to the estimated biomass over the entire survey area was high in 2004 (93 %), 2006 (86 %), and 2007 (82 %). In general, the biomass in blocks further offshore than block 3 were relatively low, except in block 6 in 2005.

Maps of the Japanese anchovy distribution from 2004 to 2007 are shown in Fig. 3. No anchovy was observed to the north of 47°N in 2006 and 2007 while the water to the north of 47°N was not surveyed in 2004 and 2005. There were no apparent latitudinal density trends in the region to the south of this latitude. Japanese anchovy tended to be concentrated to the west of 153°E in 2004, 2006, and 2007, although the annual distribution patterns were not consistent. No survey was undertaken in the region to the west of 150°E in 2005. The mean density from 2004 to 2007 by longitude in 1° increments indicated that anchovy were mainly distributed to the west of 153°E (Fig. 4). The highest density (1,477 t/n.mile^2) in 1 n.mile interval was observed at 44°33′N and 166°48′E in 2005. The mean densities from 2004 to 2007 by SST in 1 °C increments indicated that the anchovy densities were comparable from 11 to 23 °C except at 21 °C (Fig. 5), with the density declining beyond this temperature range. The horizontal distribution patterns of Japanese anchovy in relation to SST depicted in Fig. 3 also indicate that Japanese anchovy were distributed in an intermediate SST range in the survey area.

Discussion

The results of this study confirm the general belief that millions of tons of the Pacific stock of Japanese anchovy are distributed in the offshore area in the western North Pacific. At least 1.7–3.4 million tons of Japanese anchovy were present in the survey area between 2004 and 2007. Because the temporal and spatial coverage of the survey differed each year, the trend in terms of the biomass during the period could not be estimated. Surveys were undertaken in all survey blocks in 2006 and 2007. The degree of coverage in 2006 and 2007 was 5.3 and 3.2, respectively,

Table 3 Total length (L_t) and wet weight (w) of Japanese anchovy in 1 °C increments for each year

SST (°C)	Year											
	2004			2005			2006			2007		
	L_t (cm)	CV of L_t	w (g)	L_t (cm)	CV of L_t	w (g)	L_t (cm)	CV of L_t	w (g)	L_t (cm)	CV of L_t	w (g)
8	–	–	–	–	–	–	14.9	0.07	21.3	–	–	–
9	9.6	0.00	5.1	–	–	–	–	–	–	–	–	–
10	11.5	0.13	9.2	–	–	–	–	–	–	8.9	0.12	3.9
11	8.6	0.15	3.6	10.5	0.15	6.9	13.9	0.05	17.2	7.8	0.18	2.6
12	13.2	0.07	14.6	15.3	0.05	23.2	10.3	0.21	6.5	7.6	0.20	2.3
13	13.3	0.05	14.8	7.1	0.32	1.9	13.7	0.07	16.4	10.1	0.07	6.0
14	14.0	0.10	17.6	4.8	0.18	0.5	10.9	0.29	7.8	13.5	0.12	15.6
15	13.6	0.06	16.0	13.2	0.16	14.4	9.7	0.09	5.4	8.9	0.25	4.0
16	13.4	0.07	15.3	10.7	0.07	7.4	8.0	0.26	2.8	14.3	0.05	18.5
17	13.7	0.09	16.2	7.5	0.23	2.3	6.3	0.15	1.2	10.0	0.08	5.8
18	12.8	0.18	13.2	–	–	–	8.8	0.47	3.8	9.7	0.12	5.3
19	14.5	0.05	19.5	–	–	–	–	–	–	7.2	0.28	1.9
20	9.8	0.10	5.5	–	–	–	–	–	–	9.5	0.09	4.9
21	9.7	0.13	5.4	–	–	–	–	–	–	9.9	0.03	5.6

Table 4 Mean distribution depth of Japanese anchovy in each block for each year

Block	Year									
	2004		2005		2006		2007		All years	
	Mean distribution depth (m)	CV	Mean distribution depth (m)	CV	Mean distribution depth (m)	CV	Mean distribution depth (m)	CV	Mean distribution depth (m)	CV
1	26	0.40	–	–	33	0.59	22	0.42	28	0.51
2	19	0.26	–	–	20	0.37	38	0.89	28	0.91
3	19	0.58	13	0.33	20	0.39	30	0.79	22	0.64
4	–	–	15	0.19	–	–	84	0.45	16	0.65
5	–	–	14	0.26	18	0.36	–	–	14	0.31
6	17	0.19	11	0.27	18	0.24	–	–	12	0.30
7	17	0.19	16	0.42	22	0.22	21	0.99	18	0.49
8	–	–	13	0.69	95	0.44	30	0.59	23	1.11
All	22	0.41	12	0.40	25	0.66	35	0.89	24	0.82

with an d value of >6 indicating sufficient coverage [55]. Therefore, the 2006 estimate of 3.4 million tons (CV 0.22) can be considered to be the most reliable biomass estimate obtained in the survey area between 2004 and 2007. The contributions of blocks 1, 2, and 3 to the estimated biomass in the entire survey area were high in 2004, 2006, and 2007. Kubota et al. [2] carried out an assessment of the Pacific stock of Japanese anchovy based on a cohort analysis using commercial catch data for the coastal waters of Japan [2]. According to these authors, the biomass level from 2004 to 2007 was high compared with that of the previous 30 years. However, the trend declined from 2004 to 2007 after reaching its peak in 2003. The estimated biomass reported in this paper can be considered to be at level compared with that over the past 30 years, but to be declining during the past 5 years on the assumption that inshore and offshore biomass estimates are linked.

Some of the larval Japanese anchovy that hatch in the coastal side of the Kuroshio are believed to be transported offshore by the Kuroshio Extension and then to migrate northward into the Kuroshio–Oyashio transition region [56]. Consequently, it can be assumed that small individuals prevail in areas with a high SST, while large individuals prevail in areas with a low SST. The mean lengths

Table 5 Estimated biomass of Japanese anchovy in each block for each year

Year	Block							
	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8
2004								
N_k	8	6	6	No survey	No survey	7	7	No survey
Σn_i	424	1,055	1,259			822	1,201	
ρ	35.14	9.43	1.30			0.69	0.87	
A_k	50	81	101			137	108	
B_k	1.77	0.76	0.13			0.09	0.09	
CV (B_k)	0.33	0.23	0.28			0.52	0.66	
d	1.89	3.72	3.95			2.22	3.65	
2005								
N_k	No survey	No survey	6	2	Excluded due to low coverage	8	7	5
Σn_i			878	142		1,097	924	399
ρ			0.17	2.75		5.16	1.57	4.03
A_k			101	61		137	108	113
B_k			0.02	0.17		0.70	0.17	0.46
CV (B_k)			0.95	0.58		0.86	0.95	0.25
d			2.76	0.58		2.97	2.81	1.19
2006								
N_k	6	5	5	3	6	5	6	2
Σn_i	538	634	637	251	836	774	598	411
ρ	16.86	8.30	13.85	0.00	0.42	0.73	1.51	1.06
A_k	50	81	101	61	141	137	108	113
B_k	0.85	0.67	1.40	0.00	0.06	0.10	0.16	0.12
CV (B_k)	0.44	0.60	0.35	0.00	0.89	0.19	0.79	0.63
d	2.39	2.23	2.00	1.02	2.23	2.09	1.82	1.22
2007								
N_k	4	5	3	3	4	5	3	5
Σn_i	425	732	344	81	232	501	307	208
ρ	2.13	19.50	5.69	0.16	0.00	0.00	0.67	3.69
A_k	50	81	101	61	141	137	108	113
B_k	0.11	1.57	0.58	0.01	0.00	0.00	0.07	0.42
CV (B_k)	0.46	0.39	0.94	0.47	–	–	1.23	0.40
d	1.89	2.58	1.08	0.33	0.62	0.93	0.93	0.62

N_k Number of transects in the kth block, n_i number of 1 n.mile intervals, ρ biomass density (t/n.mile^2), A_k area of the kth block (10^3 n.mile^2), B_k biomass in the kth block (10^6 t), d degree of coverage

of the Japanese anchovy were calculated in 1 °C SST increments in our study based on this assumption. However, no consistent change in length frequency was observed along the SST gradient although small individuals did tend to occur when at high SST while large individuals tended to occur at low SST. Small individuals (e.g., juveniles) may have been underrepresented in the trawl samples because of gear selection. The use of sampling gears, such as a multiple layer opening/closing Matsuda-Oozeki-Hu-Trawl (MOC-MOHT) [57], specifically designed to sample larval and juvenile pelagic fish, is necessary to have more realistic length frequency of the Japanese anchovy. Although the sampling locations are also an important factor when determining mean length, they were not considered in this study because the echosounder and trawl survey vessels operated independently in terms of time and location. It has been reported that offshore Japanese anchovy spawn at an SST as low as 5 °C [12]. Individuals hatched offshore at a low SST might therefore be reflected in the length frequency at a low SST, as seen at 11 °C in this study. There were several differences between the biological characteristics of inshore and offshore adult Japanese anchovy [12, 15–17]. The distribution patterns of eggs and larvae of Japanese anchovy

Table 6 Estimated biomass of Japanese anchovy in the survey area for each year

	Year			
	2004	2005	2006	2007
Surveyed blocks	1, 2, 3, 6, 7	3, 4, 6, 7, 8	1–8	1–8
Σn_i	4,761	3,440	4,679	2,830
A_0	477	520	792	792
B_0	2.84	1.52	3.36	2.76
CV (B_0)	0.22	0.43	0.22	0.31
d	6.89	4.77	5.26	3.18

n_i number of 1 n.mile intervals, A_0 surveyed area (10^3 n.mile^2), B_0 biomass (10^6t), d degree of coverage

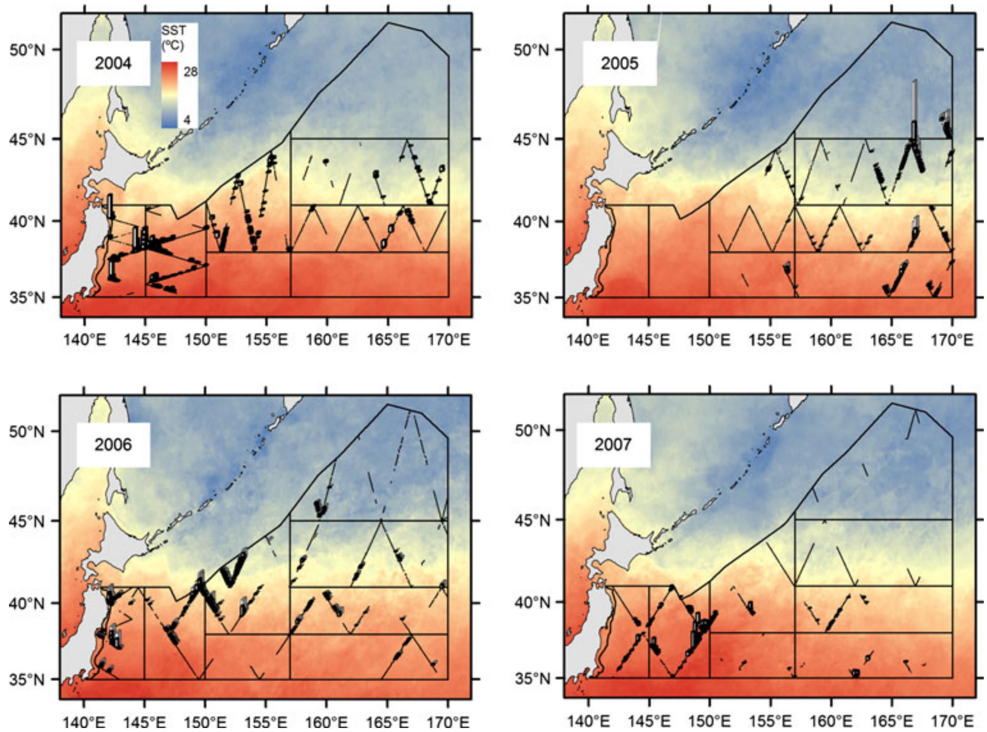

Fig. 3 Distribution patterns of Japanese anchovy from 2004 to 2007. *Bars* Relative densities of anchovy. The highest density (1,477 t/n.mile^2) in 1 n.mile intervals was observed at 44°33′N and 166°48′E in 2005. *Thin black lines* Surveyed tracklines. Seasonal composite surface seawater temperture (SST) data in the summer, derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the satellite, Aqua, are also shown

were estimated by performing a numerical particle-tracking experiment [11] because anchovy can be transported passively by currents. However, the factors that determine the distribution patterns of juvenile and adult Japanese anchovy, which can move actively, have yet to be examined. It is expected that their distribution patterns are also related to their life history as well as environmental factors other than the SST and currents. The spawning season of the Japanese anchovy is from spring to autumn [2]. The timing and location of the hatching could also affect the distribution patterns.

The mean distribution depth of pelagic fish, including the Japanese anchovy, was around 20 m in this study. Although the Japanese anchovy has been observed at depths of up to 150 m [53], it is mainly confined to shallow water. The mean distribution depth in block 8 in 2006 (95 m) and in block 4 in 2007 (84 m) was deeper than that in other blocks. However, as only a few schools observed in these two blocks contributed to the mean depths, they can be considered to be exceptions. We assumed that the species composition in water deeper than 20 m is the same as that in water less than 20 m deep. The assumption is not far from the true species composition given the mean distribution depth of pelagic fish. However, the vertical distribution patterns of pelagic fish in the survey area should be studied to validate this assumption.

Both Japanese anchovy and mackerel were sampled simultaneously at 68 stations, with mackerel being the dominant pelagic fish in terms of number at seven of these sampling stations and Japanese anchovy and mackerel being moderately mixed at 23 stations. Although the echosigns of mackerel near the coast of Japan are distinctive, they have rarely been reported offshore [47]. Japanese anchovy and mackerel found offshore would be in the same

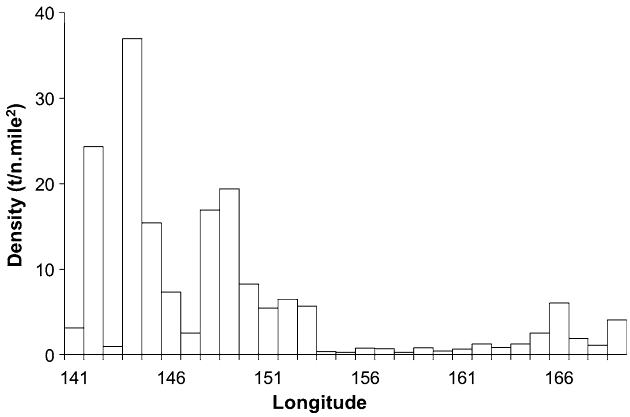

Fig. 4 Mean density of Japanese anchovy by longitude from 2004 to 2007

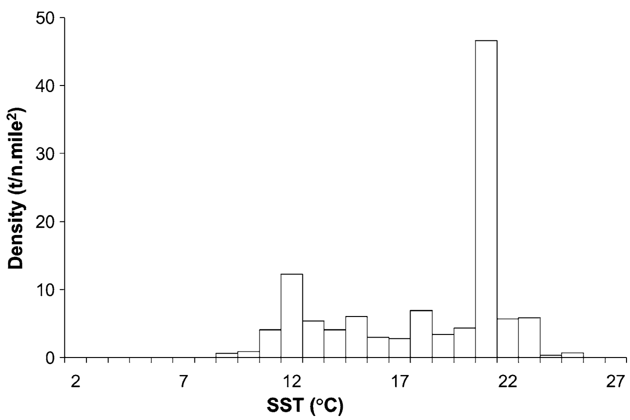

Fig. 5 Mean density of Japanese anchovy by SST from 2004 to 2007

schools in some cases, as indicated by the trawl sampling results. It is difficult to distinguish between these two species based solely on echosign characteristics. Chub and spotted mackerel hatched inshore are considered to be transported offshore by currents in a manner similar to the Japanese anchovy [58, 59]. Japanese anchovy and mackerel hatched inshore at almost the same location and time would end up in almost the same offshore environment. Based on the above assumption, species composition was assigned according to acoustic data in relation to the SST. As with mean length, the sampling locations were not considered in this study because the echosounder and trawl survey vessels were operated independently with respect to time and location. However, the species composition in schools of pelagic fish could be related to factors other than SST. Such factors should be investigated in a future study.

Several factors could contribute to either over- or underestimation. There are three potential factors that could contribute to underestimation. First, the continental shelf area of Japan where Japanese anchovy fishing is mainly conducted has not been well surveyed. Any biomass estimation undertaken on the continental shelf region will increase the biomass reported in this study. Second, Japanese anchovy distributed at depths above 10 m were not considered because the echosounder could not detect echoes in water shallower than 10 m. Third, the biomass of Japanese anchovy larvae was not included in the data because it has a different acoustic property from juvenile and adult anchovy [49].

A change in the assumptions associated with TS will either increase or decrease the estimated biomass reported here. Murase et al. [52] pointed out that the effect of pitch angle on biomass estimation is not negligible even if the depth-dependent TS is taken into account. A change in pitch angle will result in either the over- or underestimation of the biomass depending on the angle. Uncertainties related to the species identification methods, as described above, could affect the estimated biomass. Other sources of uncertainties stemming from the calibration, length-to-weight model, bubble attenuation, and signal thresholding could also affect the accuracy of the biomass estimation [60].

It has been well documented that an abundance of small shoaling pelagic fish (Japanese anchovy, Japanese sardine, Pacific saury and mackerel) show decadal fluctuations in response to climatic regime shifts [61–63]. However, the effect of such shifts on the distribution pattern and biomass of the Japanese anchovy in the offshore region of the western North Pacific has not been well documented. The continuation of a systematic acoustic survey independent of fishing activity is critically important for monitoring the changes in the distribution pattern and biomass of the Japanese anchovy in the western North Pacific.

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