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DISCOVERY OF FISH WAY USING REMOTE SENSING AND OTHER AIDS

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Abstract

The authors have studied the migration routes of Japanese sardines which few research work has been undertaken, and reported that warm streamer play an important role in the migration of japanese sardnes. This study develops the past study through an oceanographic survey by a research vessel, fish school and SV measurements using acoustic aids, analyses of staellite in agen and fishing information. From these integrated investigations the migratory movements and distribution of Japanese sardines and their relationship with the bait environment were releated as follows:

(l) Japanese sardine schools migrate for feeding from offshore waters to the Sanriku coast and northward therefrom utilizing warm streamers.

(2) Most Japanese sardines are distributed in warm streamers and their peripheral waters. Vertically, they are diistributed in the 10°C layer between 30 and 80 m depth where there is plentiful zooplankton.

(3) Chrolophill-a in the surface layer increases towards the head of the warm stroamer associated with frequent occurrence of Japenese sardine schools.

Key Words: warm streamer, feeding migration, acoustic detection, aerial observation, satellite image, fish way

Introduction

It has been shown that when northward migrating skipjack, *Katsuwonus pelamis*, enter a mixed area from the Kuroshio Extension, they do so via warm tongues in the surface layer (Kawai and Sasaki, 1962). It has also been shown that cold streamers form the southward migration routes of saury, *Colobis saira*, and mackerel, *Scomber japonicus*, (Saitoh, 1983; Hirai, 1985). Japanese sardines, *Sardinaps melanostictus*, also migrate along the Japanese archipelago, but research into their migration routes is far insufficient to provide detailed data and much is still unknown. Warm streamers (WSs) play a major role in defining the northward migration routes of Japanese sardines, as was shown by the authors (Tameishi and Shinomiya, 1994a, 1994b; Tameishi and Sugimoto 1994). This paper discusses the distribution, movement and bait plankton of Japenese sardine schools using acoustic aids in conjunction with analyses of satellite images and aerial observations.

Materials and methods

The following data were obtained and analyzed.

(1) Fishery data: Japanese sardine fishing grounds data (dates, locations, catch volumes, fish species, and school moving directions by sonar detection) compited by the Japan Fisheries Information Service Center (JAFIC).

(2) Satellite data: NOAA satellite images and water temperature distribution charts referring satellite information processed by JAFIC.

(3) Aerial observation data: 23 flights by JAFIC during May - July of 1992 - 1991; 13 flights by Marine Fisheries Resources Development Center for May - July of 1983 -1991; 2 flights by Confederation of North Pacific Purse Seine Netters' Associations, for May 1983 and June 1985.

(4) Oceanographic research data: The surveys were carried out from 5 -18 May 1992 using the RV "Tansei Maru" of Ocean Research Institute, University of Tokyo. Equipment used to inspect oceanographic structural features was CTDO (Neil Brown; 17 observations), XBT (73 observations), and Acoustic Doppler Current Profiller (Furuno Electric). Also, a fluorophotometer (Alex Chlorotec, model ACL-100) was used to observe the horizontal and vertical distribution of chlorophyll-a. Sampling was carried out to calibrate this device. A fish finder and integrator (Furuno Electric FQ50) was used at a frequency of 200 kHz to obtain back scattering strength (SV). Since there is a correlation between zooplankton density and back scattering strength (Johnson and Griffiths, 1990), SV values provide relative abundance. To confirm the

presence of Japanese sardines in warm streamers (WSs), a gill net was used. Observation of Wss, which are characterized by significant short-term fluctuations, were made using satellite images (for 29 April, 7 - 13 May) and aerial observations (on 6, 7 and 12 May) in advance of shipborne research.

Results

1. Fishing ground formation of the northward migration sardine

Fig. 1 shows the approach ot two WSs to Hachinohe and Ryorizaki from 12 - 14 June 1989. From about 13 June, northern WS extended from the warm water mass off Kinkazan, taking on a clearly defined shape on 14 June at approximately 11°C, and a good fishing ground formed off Hachinohe. On the other hand, southern WS of 12°C approached Ryorizaki from 12 -14 June, and a good fishing ground was also formed in Ryorizaki coastal waters.

This type of phenomena are commonly observed and indicate that the approach of WS from offshore waters greatly influence the migration of Japanese sardines towards the coast.

2. Detection of sardine schools with acoustic devices, aircraft, and satellite images

Fig. 2 shows Isotherms at 5°C intervals from sea surface temperature (SST) charts, produced using data obtained by the oceanographic survey using the RV "Tansei Maru" from 5 - 18 May 1992 and SST data collected by JAFIC and through satellite image. On this charts, the locations of Japanese sardine sohools detected by fish finder were plotted. Almost all the schools were within or close to a WS.

Table 1, based on the results of aerial observations for 10 years, shows the numbers of fish schools and segments where schools were found in the water masses. Schools were found in warm-core rings and WSs in a total of 140 segrnents - much more than in any other water mass. This illustrates the strong link between northward migrating Japanese sardine and warm-core rings and Wss.

Aerial observations made on 12 May 1992 revealed 9 Japanese sardine schools in WSs of approximately 10°C and 9 schools around their frontal regions. Extending a observation line from the head of a WS to the coast revealed 5 further schools in coastal waters. These were assumed to have migrated from offshore waters.

Fig. 3 is a NOAA satellite image of waters off the Sanriku region on 21 May 1991, on which Japanese sardine fishing grounds were superimposed. In this image, a WS of approximately 10°C extended from the coast towards the northeast. From 2:00 to 20:35 on 21 May 1991, fishing grounds moved progressively along this WS. The inset shows relative frequencies (1987 - 1990) of moving directions of Japanese sardine schools during the northward migration season, as observed by scanning sonar. This illustrates most of schools migrating in a N-NE direction.

In conclusion, northward migrating Japanese sardine use WSs to migrate from offshore waters to the Sanriku coastal waters, and after feeding, these schools migrate further north again.

3. Temperature profiles, the distributions of plankton and Japanese sardine schools in warm streamers.

Observations were made along line-A (St. Tx8 - Tx13, the root part of WS, Fig. 2.) using the RV "Tansei Maru" on 8 May 1992. Fig. 4 shows (a) the values of SV, which index relative abundance of zooplankton in the 50 - 90m depth range, (b) relative levels of chlorophyll-a and water temperature in the surface layer and (c) vertical water temperature profile.

The Japanese sardine schools were distributed at a depth of 50 - 80 metres in water of around 10°C (the bottom part of WS (Fig. 4(c)). The value of SV was high in the WS area of approximately 10°C between St. Tx9 and Tx11. In the cold water on either side (Tx8 - Tx9 and Tx12 - Tx13), the value was low. In places where fish schools were detected, there was 2.5 times zooplankton volume seen in the cold water areas (Fig. 4 (a) (c)).

The level of chlorophyll-a in the surface layers of WS was relatively low, partly due to the distribution down to great depths of Kuroshio water at approximately 10°C (Fig. 4 (b) (c)). The region with tho most abundant zooplankton was St. Tx11 - Tx12, which corresponded to the frontal region. The absence of fish schools in this region can be attributed to the inability of Japanese sardines to exist in cold water (Fig. 4 (a, c)).

The same observations were made along line-D (St. 1x - 6x, the head part of WS, Fig. 1) on 12, 13 May (Fig. 5). Vertical water temperature profile (Fig. 5 (c)) gives a feature of the oceanographic condition in the head part of the WS. In the head part, the depth of the WS at approximately 10°C is shallow down to about 30 rnetres. Japanese sardine schools were detected and caught by a gill net in this bottom part of the WS (Fig. 5 (c)).

The SV values in the 20 - 50 metre layer were highest inside the WS where fish schools were observed (Fig. 5 (a) (c)). Chlorophyll-a in the surface layer was distributed widely in all 10°C parts of the WS and most abundant in the St, 4x - 5x area of the WS.

The surveys in the middle part on line-B (St. Tx14 - Tx17) and the head on line-C (St. Tx17- Tx20) of the WS gave results similar to those on line-D.

Discussion

1. Warm streamers and northward migration of Japanese sardine.

Many observations were formerly made on WS that flows into warm-core rings (Inagake, 1991; Kawai and Saitoh, 1986). However, no oceanographic observations had been made on WSs flowing out of warm-core rings. This was due partly to their temporal and spatial irregularity and partly to their short-term fluctuations. Very little was known about the real nature of these WSs, their biological characteristics, and their biological relevance to fish schools.

Through the integrated use of acoustic aids, aircraft, and satellite image, the investigation of the WS that existed in the two-week period from 29 April to 15 May 1992 has yielded reliable information about the relationship between WSs and Japanese sardine schools. That is, WSs provide conditions vitally important to northward migrating Japanese sardine schools, and their movement enables Japanese sardines to migrate from offshore waters to Sanriku coastal waters and from there northward in pursuit of food.

2. The relationship between the Northward migration of Japanese sardine and the water temperature and zooplankton

It was found through our investigations that both phytoplankton and zooplankton are in plentiful supply in the WSs where temperature was higher (10°C) than the surrounding water. Since the majority of Japanese sardine schools distributed in warm-core ring are concentrated in its frontal areas, their movement probably follows the outflow-type WS, which is a part of the frontal wave generated in a frontal area. Japanese sardine schools live inside WSs for 10 - 15 days before reaching the coast. Judging from the distribution of phytoplankton ancl zooplankton in the WS, we may infer that the food supply inside WS is adequate during this period.

Fig. 6 shows a model of Japanese sardir~e sclwol mlgration in the Tohoku sea area. After spawning in the Kuroshio are (Kuroda, 1991), Japanese sardines move to the Southern Joban and Kuroshio Extension areas (Honzawa, 1990). Then via a WS, they enter the Sanriku and Joban warm-core rings and move north. Utilizing a WS that reaches towards the shore, the Japanese sardine schools then migrate towards the fishing ground off the Sanriku coast (Fig. 1). Later, they move towards an offshore warm-core ring via an offshore WS (Fig. 3). Using a northward WS, the Japanese sardine schools migrate further north and feed again in food-rich waters till the southward migration in autumn.

Table 3 shows the results of oceanographic observations using the RV "Tansel Maru". As this table shows, Wss provide the necessary current, water temperature and food conditions for the migration of fish schools toward food-rich coastal and northern waters, and can be called "fish way"

3. Acoustic observation: the direction of its development

It is difficult to detect warm streamers from a ship because of their dimensions, duration and variability. Remote sensing techniques from satellite and aircraft are appropriate to observe dynamics of warm streamers. Hence, acoustic observations from the research vessel in concert with satellite remote sensing were applied and revealed spatial distribution patterns of fish schools and zooplankton in relation to the WS.

Zooplankton samples were taken using a net in a different place near the acoustical transects. According to the data collected, the biological samples in WS showed that copepods accounted for about 80% of the total macrozooplankton in terms of wet weight. Aoki and Inagaki (1992) reported that intense and thick biological sound scattering layers were observed on the warm water side of the front of a Kuroshio warm-core ring off Sanriku. It is probable that the correlation between distributions of sardine schools and dense scattering layers in the WS is the result of active behavioral response of fish to food organisms as well as to temperature.

In this study because of limitation of our acoustic system, the SV values were not transformed to absolute abundance of zooplankton. On the other hand, dual-beam (Wiebe and Greene, 1994) and multi-frequency (Pieper, et al., 1990) systems have been developed for acoustic estimation of the size and abundance of zooplankton. An investigation with both acoustic aids and satellite remote sensing could improve understanding of the dynamics of spatial biomass distribution, including fish migration.

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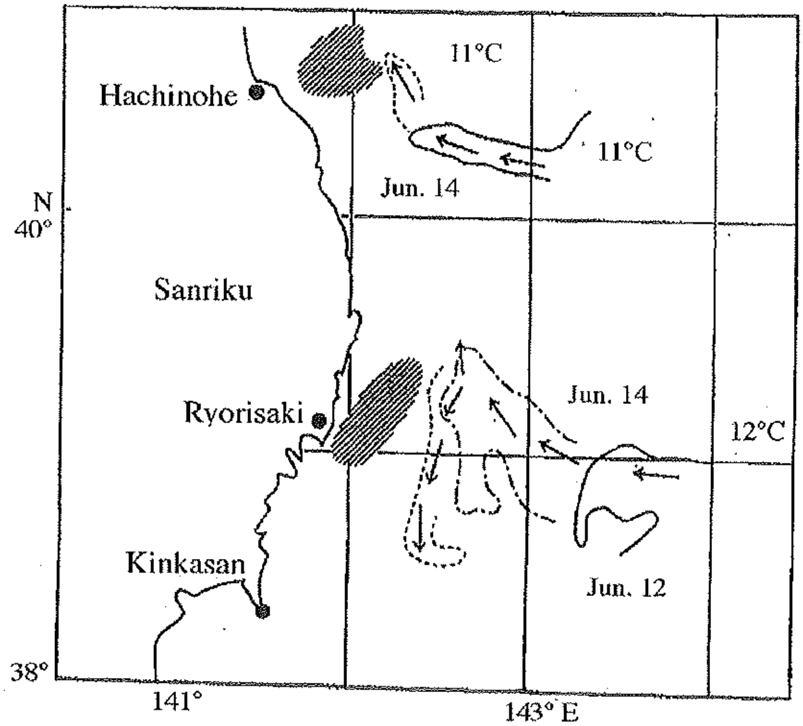

Fig. 1 Two warm streamers approaching the coast and Japanese sardine fishing grounds formed in connection with warm streamers, June 1989. The warm streamers are expressed by isotherms and their movement is given by different lines.
The hatched areas indicate fishing grounds.

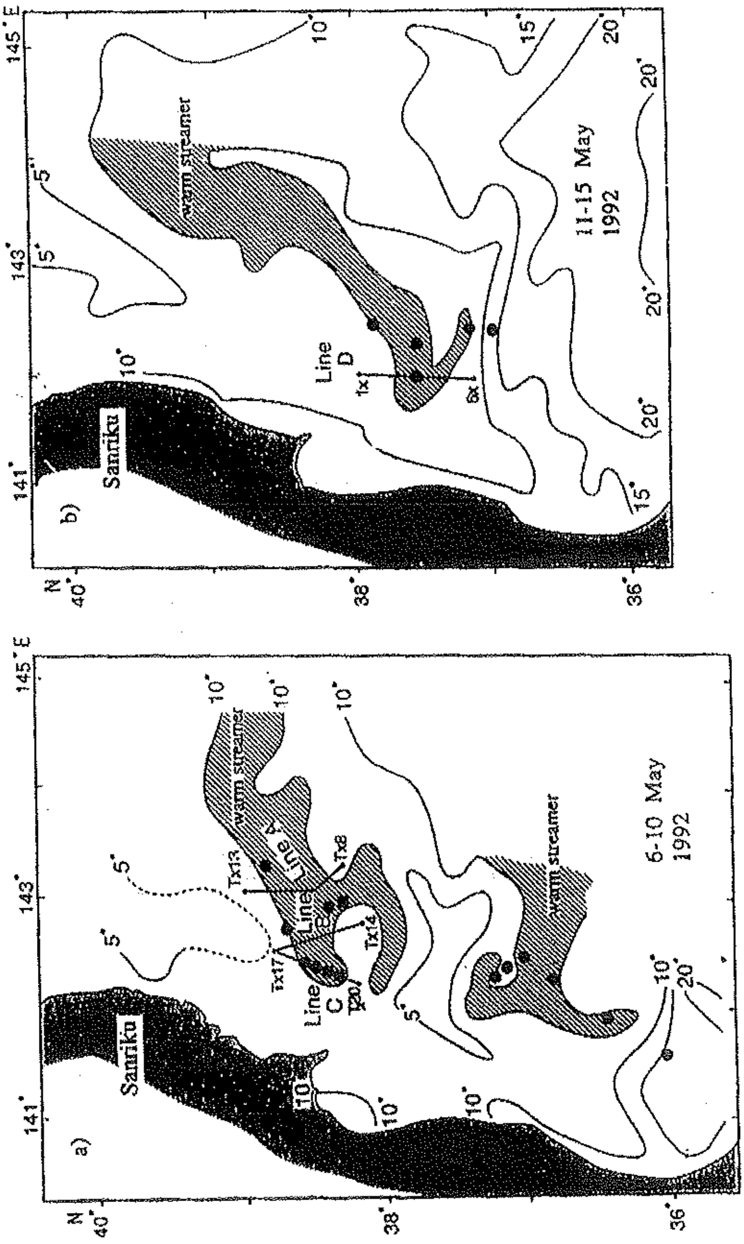

Fig. 2 Observation lines (line A: St. Tx8-Tx13, line B: St. Tx14-Tx17, line C: St. Tx17-T20, line D: St. 1x-6x) by the RV "Tansei-maru" and isotherms at 5°C intervals by which warm streamers area is shown, May 1992. Solid circles denote Japanese sardine schools found by the fish finder.

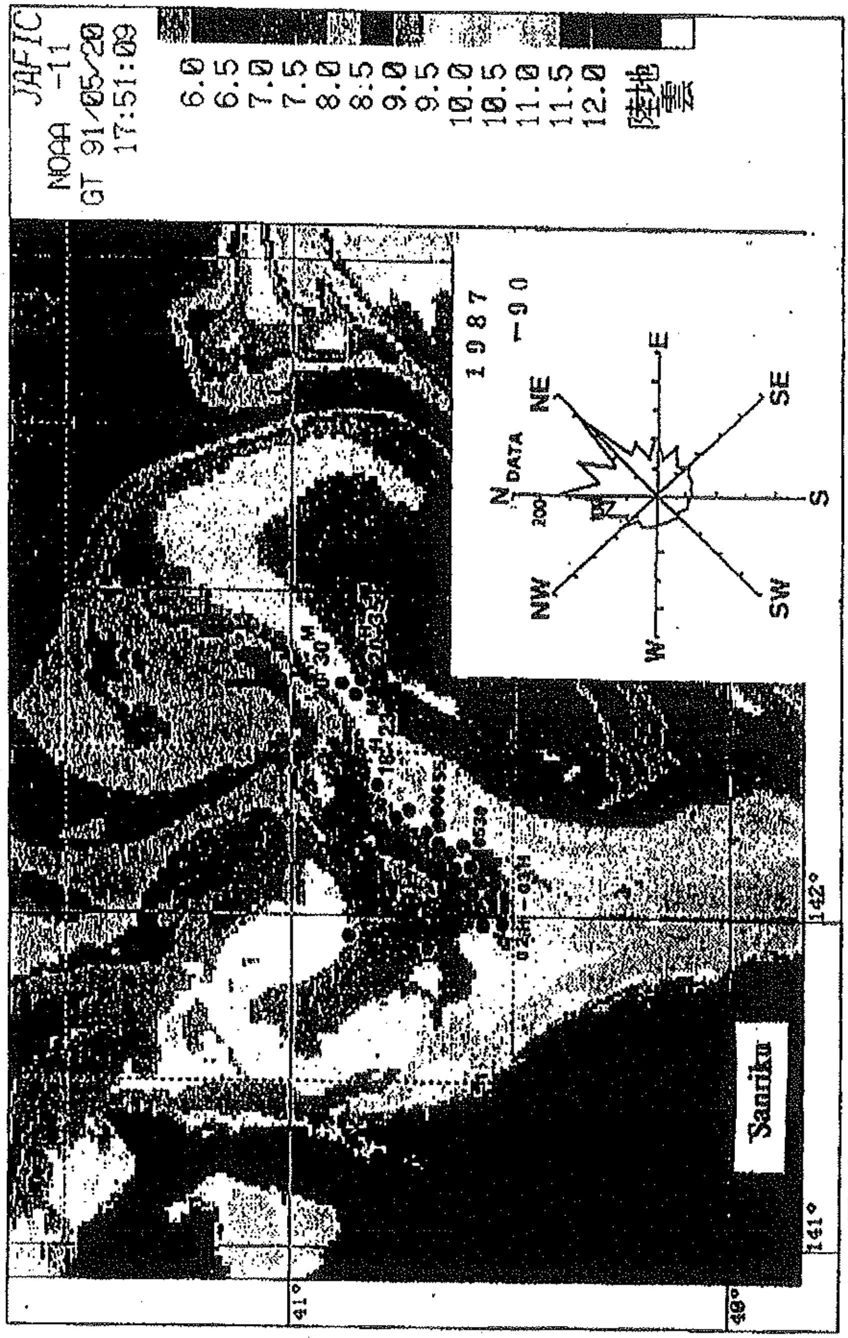

Fig. 3 NOAA satellite image showing the warm streamer extended to NE from the Sanriku coast (white part with the tip vending). Solid circles denote fishing grounds formed on the same 21 May 1991. The inset shows relative frequencies of moving directions of Japanese sardine schools.

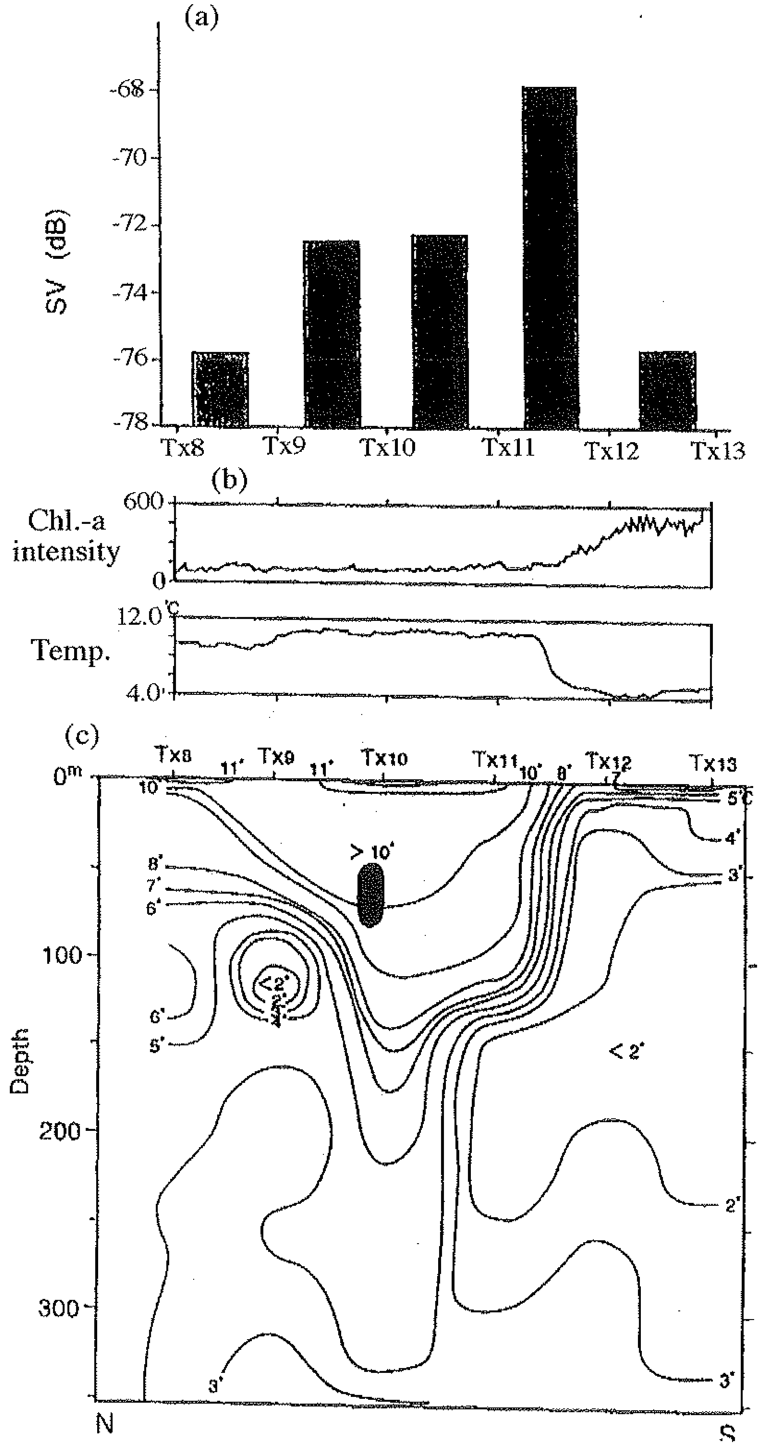

Fig. 4 Observational result of line A on 8 May, 1992
(a) Volume scattering strength at 200 kHz (in dB)
(b) Chlorophyll-a intensity and temperature at sea surface.
(c) Vertical temperature profile and Japanese sardine schools detected (shaded part).

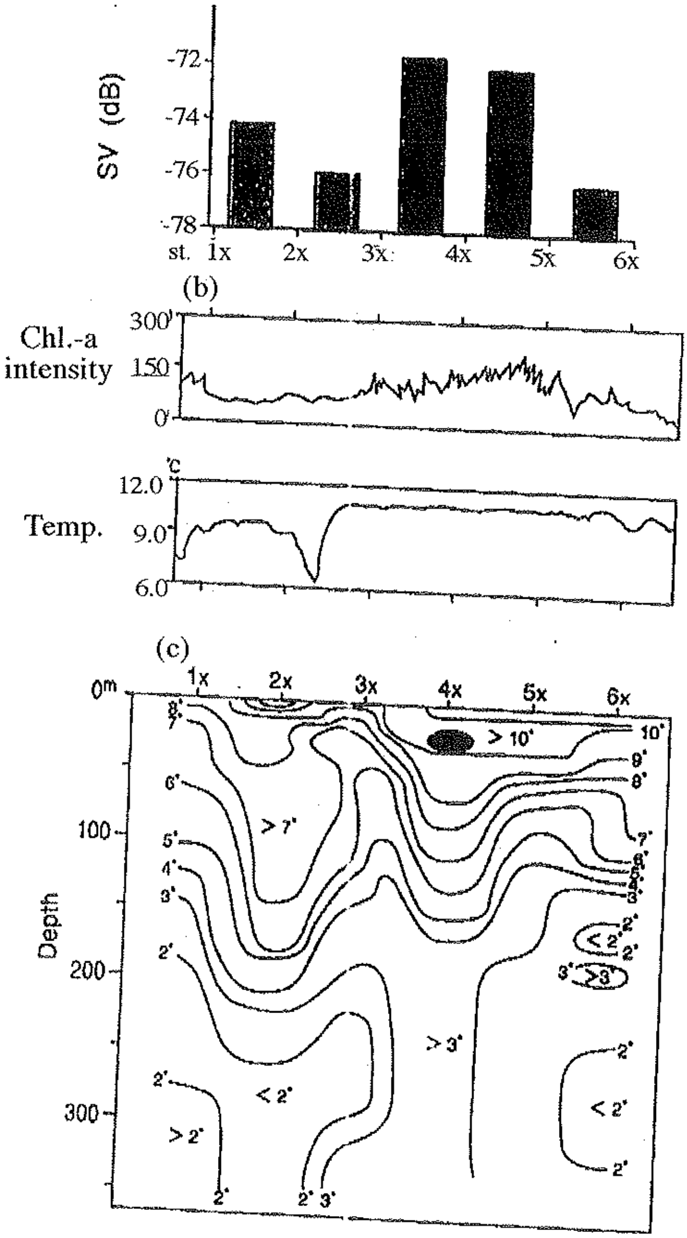

Fig. 5 Observational results of line D on 12-13 May, 1992
(a), (b), (c); Same as Fig. 4.

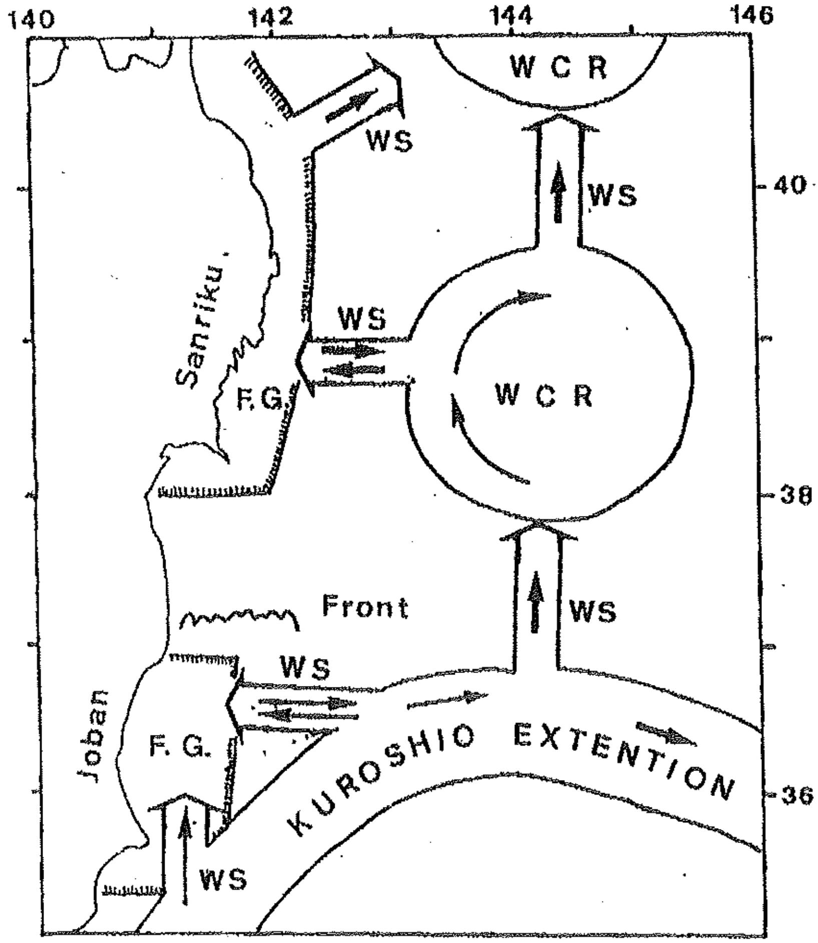

Fig. 6 Schematic view of northward migration of sardine in the Tohoku sea area. (F. G: Fishing ground, WS: Warm streamer, WCR: Warm-core ring)

Table 1. Detection rates of Japanese sardine schools by aerial observation in each segment (5 n. miles) in the different water areas.

area	**number of segment with sardine schools**	**total number of segments**	**persentage**
Oyashio area	25	385	6
nearshore warm water	16	146	11
warm streamer	101	384	26
warm-core ring	39	687	6
Kuroshio water	3	259	1

Table 2. Characteristics in relation to the warm streamer observed on 8-13 May 1982 off Sanriku.

		root (Linea A)	middle (Linea B)	head (Linea D)	end (Linea C)
detected group number of sardine schools		1	2	1 2	2
detected depth of sardine schools	depth water temp.	50 - 80 m 9 - 10°C	30 - 50 m 10 - 11°C	20 - 30 m 10°C	30 - 50 m 6 - 7°C
index of zooplankton (max. SV in dB)	10 - 50 m 50 - 100 m	-72 -67	-76 -65	-64 -63	-70 -80
chlorophyll-a	high density area relative intensity	northern part 150	southern part 150	whole area 225	end 230
depth of warm streamer	10°C 5°C	70 m 200 m	50 m 200 m	30 m 150 m	0 - 20 m 100 m
width of warm streamer		120 km	60 km	40 km	20 km
current velocity		0.5 - 1.0 knot	0 - 0.5 knot	1.0 - 2.0 knot	1.0 - 2.0 knot
water temp. in warm streamer	0 m 50 m 100 m 200 m	11°C 10°C 9°C 5°C	10°C 10°C 9°C 5°C	11°C 9°C 7°C 3°C	10°C 5°C 5°C 2°C
depth of thermocline in warm streamer (water temp.)		150 m (7° - 9°C)	150 m (6° - 9°C)	100 m (6° - 9°C)	50 m (6° ~ 8°C)