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Density and Spatial Distribution of Kichiji Rockfish *Sebastolobus macrochir* Estimated with a Deep-Sea Video Monitoring System on a Towed Sledge

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Abstract

A deep-sea video monitoring system on a towed sledge was used in Pacific coastal waters of northern Japan at depths ranging from 440 to 700 m to estimate the density and the spatial distribution of kichiji rockfish *Sebastolobus macrochir*. Thirty observations were completed at 24 survey sites in daytime during May and June in 2001. A seafloor area of 86,160 m^2 was surveyed, and 253 kichiji rockfish were observed. Most of the fish showed no behavioral response to this system. Densities ranged from 0 to 11 fish/1,000 m^2 (mean 2.94 fish/1,000 m^2). Kichiji rockfish stayed on the seafloor as solitary individuals. Only 4.9% of kichiji rockfish was situated less than 5 m to other kichiji rockfish, 3.5% occurred between 5 and 10 m to other fish and the remaining 91.6% was more than 10 m away from other fish. Of the 253 kichiji rockfish, 209 were small (5–9.9 cm) and 44 were more than or equal to 10 cm. Most of the small fish were between one year and two years old. Kichiji rockfish would be distributed as solitary individuals at least from one year old. The method to estimate the density of the kichiji rockfish using this system is effective for stock assessment.

Discipline: Fisheries
Additional key words: stock assessment, underwater video camera

Introduction

Kichiji rockfish is one of the important target species for offshore trawl fisheries in Pacific coastal waters of northern Japan and the Sea of Okhotsk because of its high market value. Its stock abundance has been at an extremely low level due to over fishing[4,9,16]. To ensure long-term sustainable use of this resource, it is necessary to estimate the accurate stock abundance and to promote a better management strategy according to its stock abundance[9].

Since kichiji rockfish was readily distinguished from other species in video images and did not react to “Shinkai 2000” which is a manned deep-sea submersible and a towed deep-sea TV system (towed with an umbilical cable above the seafloor), the effectiveness of surveys with optical instruments has been demonstrated[8]. However, surveys with “Shinkai 2000” or towed deep-sea TV systems are not suitable for stock assessment because of requiring a large support vessel and limitations of the operation period and time. In this study, we investigated densities and spatial distributions of kichiji rockfish (subsequently “rockfish” is used interchangeably with “kichiji rockfish”) by applying the deep-sea video monitoring system on a towed sledge (subsequently referred to as “deep-sea monitoring system”) developed to estimate the density of snow crab *Chionoecetes opilio*[13,14].

Method

The survey for estimating the density of rockfish by using the deep-sea monitoring system (Fig. 1) was car-

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ried out in the daytime on the research vessel Kaiyo-maru No.3 (474 GT) from May 27 to June 6 in 2001 (Table 1). Thirty observations were completed at 24 survey sites (Fig. 2) in Pacific coastal waters of northern Japan in depths ranging between 440 and 700 m. The deep-sea monitoring system was an identical system to that used for observing snow crab (*Chonoecetes opilio*) distribution[13,14]. However, the towing method of the deep-sea monitoring system was different from that, i.e. a polypropylene cross rope (400 m in length, 30 mm in diameter, 0.91 in specific gravity) was inserted between the end of a trawl warp and the deep-sea monitoring system. The trawl warp was paid out as same as the water depth and the deep-sea monitoring system was towed at approximately 1 knot (practically, the towing speed varied due to sea conditions) on the seafloor (Table 1). Recording time of one observation was 55 min depending on the capacity of batteries. The depth of the water surveyed was measured with a fish finder (SIMRAD Co., Ltd. EK-500). Positions of the research vessel were mea-

Fig. 1. The deep-sea video monitoring system on a towed sledge on the R/V Kaiyo-maru No. 3

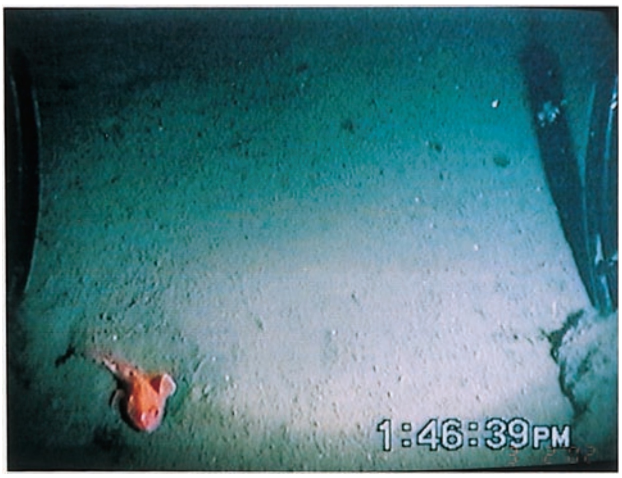

Fig. 3. Example of the video image recorded with the deep-sea video monitoring system on a towed sledge
Seventy-seven % of kichiji rockfish *Sebastolobus macrochir* did not respond to the towed sledge. Of the remaining 23%, almost all the fish started to avoid the sledge just before the towed sledge came close to them.

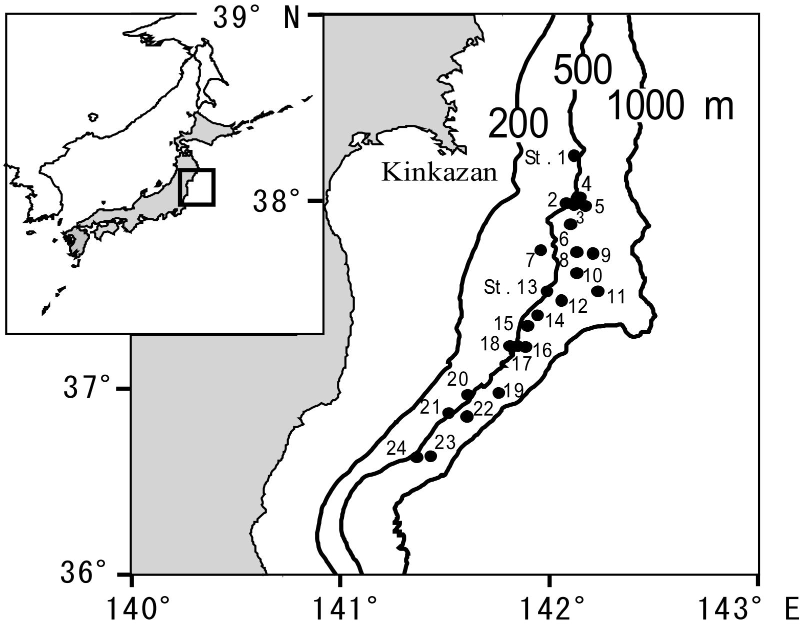

Fig. 2. Map of the survey sites in Pacific coastal waters of northern Japan

Table 1. Density of kichiji rockfish and towing characteristics of the deep-sea video monitoring system on a towed sledge

Station no.	Date of observation (in 2001)	Start time	Survey site Latitude(N) deg.	min	Longitude(E) deg.	min	Towing speed* (knot)	Bottom depth (m)	Observed distance (m)	Observed area (m^2)	No. of kichiji rockfish	Behavior of kichiji rockfish: No response No movement	Response Movement	Size of kichiji rockfish: Small 5–9.9 cm	Medium 10–20 cm	Large >20 cm	Density of kichiji rockfish (No./1,000 m^2)
1	May 27	13:51	38	14.861	142	6.108	1.0	440	1,800	2,990	3	2	1	2	1	0	1
2	May 28	8:25	37	59.967	142	4.183	1.0	440	1,850	3,070	5	5	0	5	0	0	2
2	June 6	13:58	37	59.704	142	4.001	1.0	440	1,840	3,050	2	1	1	2	0	0	1
3	May 29	13:09	37	59.841	142	6.017	0.9	550	1,710	2,840	3	3	0	3	0	0	1
3	June 6	12:02	37	59.958	142	6.100	1.1	550	1,990	3,300	8	8	0	8	0	0	2
4	May 29	8:30	38	1.306	142	8.489	0.9	670	1,740	2,890	7	6	1	6	1	0	2
4	June 6	10:05	38	1.363	142	8.513	1.1	670	2,060	3,420	4	3	1	4	0	0	1
5	May 29	10:50	37	59.394	142	8.741	0.9	690	1,650	2,740	5	5	0	3	0	2	2
6	May 28	10:45	37	52.861	142	4.893	0.7	600	1,380	2,290	15	11	4	14	1	0	6.6
6	June 6	7:23	37	53.058	142	4.872	0.9	600	1,740	2,890	21	13	8	19	1	1	7.3
7	May 28	13:33	37	44.783	141	56.725	0.8	450	1,530	2,540	9	9	0	7	2	0	4
8	May 30	8:28	37	44.324	142	6.903	0.9	600	1,650	2,740	3	3	0	3	0	0	1
9	June 1	15:10	37	43.839	142	11.318	1.0	700	1,840	3,050	1	0	1	1	0	0	0.3
10	May 30	13:23	37	37.613	142	6.878	0.7	560	1,260	2,090	5	5	0	3	0	2	2
10	June 5	17:25	37	37.626	142	6.861	0.8	550	1,540	2,560	3	3	0	1	1	1	1
11	June 1	12:06	37	31.876	142	12.872	0.8	690	1,540	2,560	1	1	0	0	0	1	0.4
12	June 1	9:30	37	28.782	142	2.891	0.9	590	1,730	2,870	8	8	0	8	0	0	3
13	June 1	7:22	37	31.781	141	58.335	1.0	500	1,820	3,020	14	12	2	13	1	0	4.6
14	June 2	7:24	37	24.167	141	55.752	0.8	550	1,480	2,460	5	5	0	4	1	0	2
15	June 2	9:32	37	20.866	141	53.315	1.0	560	1,770	2,940	13	10	3	13	0	0	4.4
16	June 3	15:15	37	14.106	141	51.882	0.9	580	1,640	2,720	12	11	1	12	0	0	4.4
17	June 2	14:01	37	14.094	141	50.157	0.8	530	1,480	2,460	9	8	1	7	1	1	4
18	June 2	12:02	37	14.378	141	48.743	0.9	480	1,700	2,820	17	12	5	12	3	2	6.0
19	June 5	7:26	36	58.783	141	44.274	0.8	680	1,390	2,310	0	0	0	0	0	0	0
20	June 3	9:40	36	57.974	141	35.482	1.2	440	2,150	3,570	17	11	6	6	10	1	4.8
21	June 3	7:22	36	52.185	141	29.864	1.0	450	1,820	3,020	25	18	7	22	3	0	8.3
21	June 5	10:33	36	52.250	141	29.999	0.8	450	1,520	2,520	27	16	11	24	2	1	11
22	June 4	15:15	36	51.222	141	35.698	0.8	650	1,420	2,360	0	0	0	0	0	0	0
23	June 4	11:40	36	39.832	141	26.058	1.7	640	3,090	5,130	6	3	3	4	0	2	1
24	June 4	7:23	36	38.013	141	21.120	1.0	550	1,770	2,940	5	4	1	3	0	2	2
Total									51,900	86,160	253	196	57	209	28	16	2.94

* ground speed.

sured with a differential GPS receiver (Global Positioning System Furuno Co., Ltd. GP-35) and recorded positions at the beginning and end of an observation as well as every 5 min during observation. The timers of the underwater video camera and of the underwater light were turned on simultaneously immediately before the deep-sea monitoring system was put into the sea. Photography was started after 20 or 30 min, because the deep-sea monitoring system required such a time interval to stabilize the towing condition. Densities of rockfish (individual number observed per 1,000 m^2) at each site surveyed were estimated from counts of rockfish and the seafloor area surveyed (see Watanabe[13], Watanabe & Hirose[14], details were described). Three sizes of rockfish were also estimated from the sledge width (10 cm) of the deep-sea monitoring system; small (5–9.9 cm), medium (10–20 cm), and large (> 20 cm).

We considered that the noise of friction and vibration generated by the sledge of the deep-sea monitoring system used in this study were higher and stronger than those of the towed deep sea TV system used by Kitagawa et al.[8], and both noise and vibration had presumably an effect on the behavior of rockfish. To examine the effect on rockfish behavior of both noise and vibration generated by the sledge when approached by the deep-sea monitoring system, the rockfish behavior was categorized into 2 groups as follows (Table 1): (1) No response (no movement; immobile just before the deep-sea monitoring system approached), (2) Response (movement; moved when approached by the deep-sea monitoring system). Since the deep-sea monitoring system approaching speed to the rockfish varied according to towing speed of the deep-sea monitoring system, the proportion of moving rockfish to the total individual number observed was calculated by towing speed. The relationship between towing speed of the deep-sea monitoring system and proportion of responding individuals was described graphically and the correlation coefficient was calculated.

Subsequently spatial distribution of rockfish was examined. The position assigned to an individual rockfish in geographical coordinates was obtained as the point of time that it emerged in the video image with a time display. The positions of the observing lines and of the individual rockfish were mapped on GRASS geographic information system (GRASS development team). The length of the observing lines and the distance between individual rockfish on each line in cases where more than or equal to 2 individuals occurred together were measured on the map, using built-in capabilities of the software.

Results

Seafloor substrates at most of the surveyed sites were primarily mud and sometimes mud with sand excluding St-20 (rock substrate). The bottom contour was relatively flat. The video images were recorded for 1,650 min in total. A seafloor area of 86,160 m^2 was surveyed. Rockfish was readily distinguished from other species on video images and 253 rockfish were observed. Of the 253 rockfish, 209 were small, 28 medium, and 16 large. Table 1 shows the towing characteristics such as the position of the survey site, towing speed, towing distance, sweeping area, number of rockfish, sizes and number of individuals per 1,000 m^2, etc. Since a significant figure corresponded to one digit in the survey site where the number of observed rockfish was less than 10 individuals, similarly, the number of individuals per 1,000 m^2 was indicated by one digit. Sweeping area in the survey sites ranged from 2,090 m^2 to 5,130 m^2. The number of individuals observed in each survey site ranged from 0 to 27 individuals. The densities of rockfish ranged from 0 to 11 individuals/1,000 m^2 (mean 2.94 individuals / 1,000 m^2).

Of the 253 rockfish observed, 196 did not respond to the towed sledge when it came close to them (Fig. 3) and the remaining 57 moved. Of the moving individuals, almost all the rockfish moved just before the towed sledge came close to them and they were at or very near the passing sledge. Fig. 4 shows the relationship between

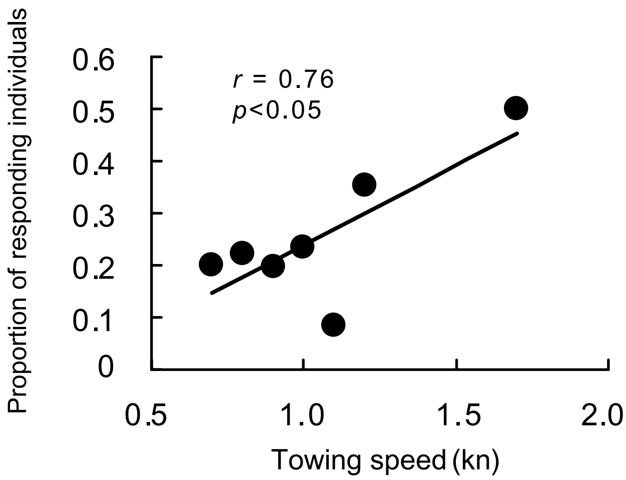

Fig. 4. Relationship between towing speed of the deep-sea video monitoring system on a towed sledge and proportion of responding individuals
Proportion of responding individuals was obtained by dividing the number of responding individuals by the total number of kichiji rockfish observed at various towing speeds.

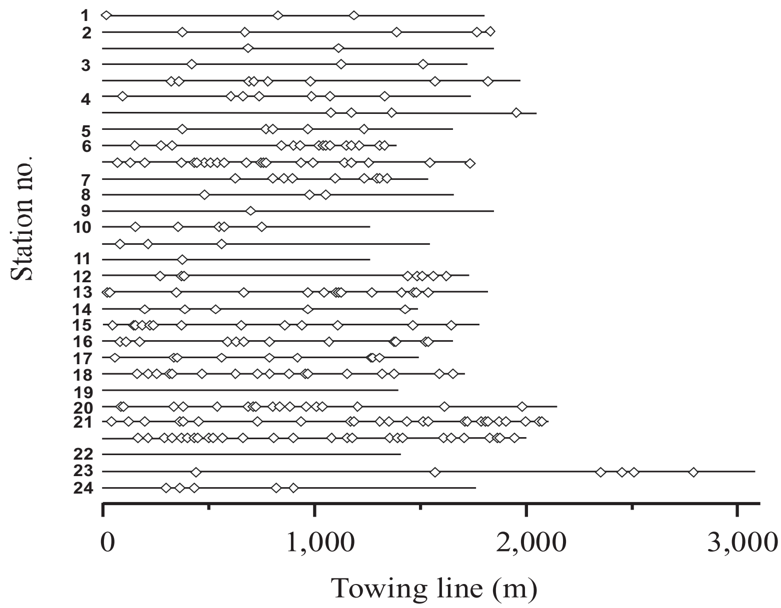

Fig. 5. Position of kichiji rockfish on the line towed
Difference in length of the lines was the result of difficulty in maintaining ship speed steady at 1 knot.

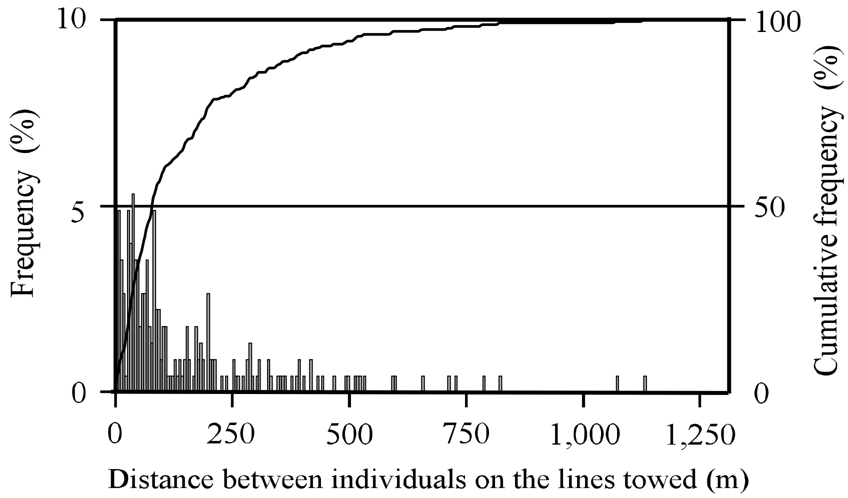

Fig. 6. Frequency distribution (histogram, left axis) and cumulative frequency (line graph, right axis) for distance between individuals on the lines towed

towing speeds of the deep-sea monitoring system and the proportions of responding individuals. Towing speed was correlated (r = 0.76, p<0.05) with the proportion of responding individuals.

We estimated a total of 225 distances between individuals. Fig. 5 shows the position assigned to an individual rockfish in geographical coordinates for each survey line. The rockfish emerged per 1,000 m was 0 to 12 individuals (mean 4.5 individuals/1,000 m). Fig. 6 shows the relationship among frequency of rockfish observed, cumulative frequency and distance separating adjacent individuals on the lines towed. Only 4.9% of rockfish was situated less than 5 m to other rockfish. They were more than 1 m away from other rockfish and were not observed with a definite mutual attraction between individuals. Three point five % of rockfish occurred between 5 and 10 m to other rockfish and the remaining 91.6% was more than 10 m away from other rockfish. Conversely, 94.2% of rockfish occurred within 500 m to other rockfish. Therefore all rockfish stayed on the seafloor as solitary individuals.

Discussion

For underwater observation with ordinary optical instruments used for fisheries science at present, lights are required in the places without daylight[6,12]. Underwater observation with lights have been used as an effective method when lights do not have an effect on the behavior of the target species[13,14]. First, we determined whether the light and the approach of the towed sledges affected rockfish behavior or not. The response of *Sebastolobus* spp. to an ROV (remotely operated vehicle) equipped with a light had been studied by Adams et al.[1]. In that study, of the 193 *Sebastolobus* spp. observed, 2 slowly moved into the frame of the ROV, 173 did not move, 8 slowly moved out of the frame of the ROV, and the remaining 10 rapidly moved out of the frame[1]. Responding *Sebastolobus* spp. to the ROV accounted for only 10% of all individuals observed. For the ROV, there were no vibration and fricative sound caused by the sledge of the deep-sea monitoring system because the ROV was towed above the sea bottom. Therefore rockfish reaction to the ROV was considered as a reaction to both the light and the sound generated from a driving portion of the ROV. When Kitagawa et al.[8] observed rockfish with a towed deep-sea TV system, rockfish reacted when the chain and the sinker contacted the seafloor near rockfish. The chain and the sinker were suspended from the towed deep-sea TV system and kept the towed deep-sea TV system at a constant altitude from the seafloor to maintain the observable swath constant. However, most of the rockfish did not respond when the towed deep-sea TV system passed over them[8]. Similarly rockfish did not respond when approached within 1 m by the "Shinkai 2000"[8]. Therefore we think the light and the sound generated from a driving portion of the ROV have no effect on rockfish behavior.

In this paper, rockfish responding to the deep-sea monitoring system accounted for 23% of the total individuals observed, and this rate was higher than that observed by Adams et al.[1] (chi-square $P<0.01$). We think that the higher responding rate than that of Adams et al. [1] is due to the differences in the towing method. Since the deep-sea monitoring system was towed on the seafloor, vibration and fricative sound generated by the sledge of the deep-sea monitoring system threatened rockfish. However, most of the rockfish that had moved when the towed sledge approached them began to move just before the towed sledge came close to them and were near the passing sledge. Almost all the rockfish stayed immobile just before the towed sledge came close to them. Previous studies reported that light would have hardly any effect on the behavior of rockfish[1,8]. Therefore the number of individual rockfish per 1,000 m^2 that was estimated in Table 1 indicates the abundance of rockfish.

Subsequently, the factors affecting the estimation accuracy of the density was investigated. Of the 24 survey sites, 17 survey sites were observed with less than 10 rockfish and these were estimate values with lower accuracy. For example, since the seafloor surveys were performed 2 times at sites 3 and 4, by integrating the survey results performed 2 times, it was possible to calculate the significant figure to 2 digits. Therefore it is possible to improve the estimation accuracy by increasing the sweeping area (i.e. increasing the observation frequency to increase the number of observed individuals) in areas with a low population density[13,14]. The distribution of rockfish changes due to migrating with growth[7], and therefore it is necessary to shorten the time interval between seafloor surveys at the same survey site.

The proportion of reacting rockfish to the deep-sea monitoring system increased with increasing towing speed of the deep-sea monitoring system. The proportion of reacting rockfish to the total of observed rockfish ranged from 20 to 25% when towing speeds were less than or equal to 1 knot, and its fluctuation was relatively stable. On the other hand, the proportion of reacting rockfish ranged from 10 to 50% and considerably fluctuated when towing speeds were more than 1 knot. Therefore the suitable towing speed is less than or equal to 1 knot.

It appears that rockfish are distributed separately from the larval stage because rockfish in schools were not observed by a manned submersible[5]. Of the 253 rockfish observed in this study, 209 were small (5–9.9 cm) and 44 were more than or equal to 10 cm. Most of the small rockfish were between one year and two years old. All rockfish stayed on the seafloor as solitary individuals. Ninety one point six % of rockfish observed was more than 10 m away from other rockfish. Consequently, our result indicates that rockfish is distributed as solitary individuals at least from one year old.

As above mentioned, we confirmed that the deep-sea monitoring system can be used to estimate the abundance of kichiji rockfish and its advantage for stock assessments had already been reported[13–15]. However, to utilize this equipment as a quantitative survey method for kichiji rockfish, it is necessary to improve the estimation accuracy of the population density in consideration of the characteristics of this equipment. The stock abundance of kichiji rockfish has been estimated based on trawl surveys[5]. Catch amount obtained from trawl surveys are converted to stock abundance by assuming a 100% sampling efficiency for the area swept by the trawl[2,11]. However, it is clear that the sampling efficiency is not 100% from previous studies[3,10,11]. The sampling efficiencies of survey trawls have not been sufficiently measured. To improve the accuracy of estimating the population density of the kichiji rockfish from survey trawls, we will estimate the sampling efficiency by using the deep-sea monitoring system observation prior to trawling over the same ground.

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