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Estimation of Preferred Habitats and Total Catch Amount of the Round Scad *Decapterus maruadsi* and Five Other Scad Species in the East China Sea and Sea of Japan

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Abstract

The preferred habitats of the round scad *Decapterus maruadsi* and five other scads (amberstripe scad *D. muroadsi*, mackerel scad *D. macarellus*, red scad *D. akaadsi*, roughear scad *D. tabl*, and shortfin scad *D. macrosoma*) in the East China Sea (ECS) and the Sea of Japan were examined based on catch records of Japanese large- and medium-type purse seine fisheries from 1993 to 2020. Delta-lognormal generalized additive models indicated that the habitats of the round scad and the other five scads were clearly segregated. A high round scad catch per unit effort (CPUE) was observed in the southwestern ECS on the continental shelf and coastal waters around Kyusyu, whereas for the other five scads, a high CPUE was observed around the shelf break and Kuroshio area. The standardized annual CPUEs of the scads decreased after 2010. Based on the proportion of round scad to all six scads calculated by spatial standardized CPUEs for each fishery grid, the total catch amount of round and the other five scads including coastal fisheries was approximately 2,071-13,382 tons and 3,496-24,617 tons, respectively. These estimates are important for scad stock assessment and developing effective management strategies.

Discipline: Fisheries

Additional key words: Carangidae, catch per unit effort, delta-lognormal model, purse seine fisheries

Introduction

Fish of the family Carangidae, including the genus *Decapterus*, are important for tropical and subtropical fisheries worldwide (Shiraishi et al. 2010). There are six scads (round scad *D. maruadsi*, amberstripe scad *D. muroadsi*, mackerel scad *D. macarellus*, red scad *D. akaadsi*, roughear scad *D. tabl,* and shortfin scad *D. macrosoma*) in the East China Sea (ECS) and Sea of Japan (SJ). These scads are caught in coastal and offshore waters mainly by large- and medium-type purse seine fisheries (LMPS) and coastal fisheries (e.g., medium-small type purse seine fisheries and fixed net fisheries), although the fishers' main target species are chub mackerel (*Scomber japonicus*), jack mackerel (*Trachurus japonicus*), Japanese sardine (*Sardinops melanostictus*), and others (Ohshimo et al. 2014). The round scad is the most valuable of the six scads because it is a substitute for jack mackerel. The annual total catch amount of the six scads in the ECS was more than 30,000 tons in the 1980s, but it decreased gradually to approximately 5,000 tons in 2020.

Previous studies (Ohshimo et al. 2006, 2014; Shiraishi et al. 2010) have reported on the biological characteristics of scads in the ECS and SJ, such as growth and maturation. Kishida (1972) also argued that there are two local stocks of round scad in the western ECS and coastal waters along Kyusyu, Japan, accounting for the differences in body length-weight relationships and the counts of the second dorsal and anal fin rays. In addition, the specific habitats of the other five scads (excluding round scad) were reviewed by Kishida (1974). These habitats included areas around islands or reefs (amberstripe and mackerel scads), offshore waters shallower than the continental shelf south of 30°N (red and roughear scads), and around the edge of the continental shelf (shortfin scad); however, their biological studies were limited when compared to studies on round scad (Kishida 1974).

The accuracy of the Japanese stock assessments

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for scads is problematic because the catch amount in the official catch statistics from the Japanese government and coastal fisheries in local prefectures are not segregated according to the six scad species, due to the smaller catch amounts and lower economic value of these scads compared to the other main fishery resources. However, the LMPS logbooks and the catch records of the Akune and Makurazaki ports in Kagoshima Prefecture (the most landed fishery ports for the six scads in Japan) record the catch amounts of round scads and the other five scads separately. Consequently, to conduct more accurate stock assessments, this study estimates the catch amounts of round scad and the other five scads of coastal fisheries using the information on the standardized catch per unit effort (CPUE) of the LMPS in common fishing areas. Herein, the standardized CPUE at each fishing area was defined as the spatial standardized CPUE (SSCPUE), calculated to remove the bias caused by factors other than spatial effects.

To calculate the allowable biological catch for Japanese fisheries, two types of harvest control rules were considered (Ohshimo & Yamakawa 2018). One is based on controlling the fishing coefficient by comparing it to a biological reference point derived from a certain population dynamic model (the Type I model-based rule), and the other is based on controlling the catch amount directly by using information such as the current trends in stock abundance indices (i.e., CPUE, the Type II empirical rule). The stock abundance indices should be standardized, since nominal CPUEs could be biased by factors other than abundance itself (Maunder & Punt 2004). For the round scad in the ECS and western SJ, and the other five scads in the ECS, the Type II rule plans to be applied due to the limited information on the fisheries and lack of scientific knowledge to construct population dynamic models. However, not only the total catch amount but also the trend of annual standardized CPUE (ASCPUE) of the round scad and the other five scads were unavailable. Therefore, this study aimed to (1) estimate the SSCPUE and ASCPUE of round scad and five other scads from Japanese LMPS catch and effort records using a statistical model, and (2) separate the aggregated total catch amount of six scads into round scad and five other scads, respectively based on the estimated proportion of round scad in local fishing areas.

Materials and methods

1. Fishery data

The catch and effort records from 1993 to 2020 from the Japanese LMPS in the ECS and SJ, including the Yellow Sea, were analyzed. The LMPS are regulated by the Japanese government, and fishing vessels are required to provide daily operation reports on the catch weights of each species, operating position (latitude and longitude at a resolution of 10'), and fishing effort (number of tows per day) (Ohshimo et al. 2021). To focus on the main fishery grounds of the six scads, catch records in the central and northern SJ (north of 37°N and west of 137°E) were omitted from the analysis. Additionally, water temperatures at a 50-m depth from the operating position were used from the FRA-ROMS dataset (Kuroda et al. 2017). In total, 169,963 records were analyzed for the present study.

2. Model description

We independently modeled the round scad and the other five scads in the present study. First, to elucidate the habitats of the two species groups, delta-lognormal generalized additive models (GAMs) were constructed (Lo et al. 1992, Zuur 2012). We performed a 2-step (i.e., delta-type) analysis because the positive catch rates of both species groups were lower than 0.25 (Fig. 1c). The 2-step model consists of two parts, a binomial model for the probability of positive catch, *p*, and a positive lognormal model for the log-transformed CPUE. The binomial component of the delta-lognormal GAMs was as follows:

$$r \sim Bin\,(1, p) \tag{1}$$

$$\mathrm{Log}\,(p\,/\,(1-p)) = \alpha + \mathrm{f}\,(\mathrm{Grid}) + \mathrm{f}\,(\mathrm{Year}) + \mathrm{f}\,(\mathrm{Month}) + \mathrm{s}\,(\mathrm{Temp\ 50}) + \mathrm{f}\,(\mathrm{Year}) \times \mathrm{f}\,(\mathrm{Month}) \tag{2}$$

where r is the response variable for positive (r = 1) or zero (r = 0) catch, α, "Grid," "Year," "Month," and "Temp 50" correspond to intercepts, fishery grid (latitude and longitude at a resolution of 30'), year, month, and temperature at 50 m depth, respectively. The symbols "f," "s," and f(Year) × f(Month) indicate categorical variables, spline functions, and interaction terms of year and month, respectively. The positive lognormal component of the delta-lognormal GAMs was as follows:

$$\mathrm{Log}\ (\mathrm{CPUE}) \sim N\,(\mu, \sigma^2) \tag{3}$$

$$\mu = \beta + \mathrm{f}\,(\mathrm{Grid}) + \mathrm{f}\,(\mathrm{Year}) + \mathrm{f}\,(\mathrm{Month}) + \mathrm{s}\,(\mathrm{Temp\ 50}) + \mathrm{f}\,(\mathrm{Year}) \times \mathrm{f}\,(\mathrm{Month}) \tag{4}$$

where σ^2 and β represent variance and intercepts, respectively. The full GAMs excluded fishery grids with no positive catch and interactions between year and fishery grids, month and fishery grids because the binomial models did not converge. The models were fitted using the "mgcv" package in R version 4.0.0 (R Core Team 2020), and final models were selected based on the Bayesian information criterion (BIC). To calculate the generalized variance inflation factor (GVIF) of the full GAMs, the "car" package in R was used to judge multi-collinearity (Fox & Weisberg 2019).

Second, the proportion of the round scad to all six scads ($P_{round,\ i}$) for fishery grid, i, was defined by the proportion of SSCPUE of the round scad to that of all six scads for fishery grid, i, as follows:

$$P_{round,i} = SSCPUE_{round,i} \,/\, (SSCPUE_{round,i} + SSCPUE_{other,i}) \tag{5}$$

where $SSCPUE_{round,i}$ and $SSCPUE_{other,i}$ were calculated by the mean predicted SSCPUE of fishery grid i for round scad and the other five scads, respectively. The mean predicted values were calculated by all possible combinations of explainable variables for the final binomial and lognormal GAMs, using predict function in R. The $P_{round,}$ for fishery grids with no positive catches of round scad or the other five scads were represented as 0 or 1, respectively. ASCPUE of round and the other five scads were calculated by the mean predicted values of each year as well as SSCPUE. In addition, the 95% confidence intervals for the ASCPUE were calculated using bootstrapping with 1,000 resampling points with respect to a given stratum (i.e., grid, year, month, and temperature) in each bootstrap trial. 95% confidence intervals for the P_{round} of coastal fishery grids being calculated by bootstrapping 1,000 stratified resampling points for each grid because of limited catch records.

3. Estimation of the unrecorded catch amount by coastal fisheries

To estimate the catch amounts of round scad and the other five scads by coastal fisheries, the P_{round} values for each of the five main coastal prefectures facing the ECS and western SJ (Yamaguchi, Fukuoka, Saga, Nagasaki, Kumamoto) were calculated. The fishery grids for each prefecture were defined according to previous reports on the fishery grounds of each prefecture (Nakagawa et al. 1993, Kawano 2007, Takeshige et al. 2013, Terada & Umeda 2012) or the coastline of each prefecture. It should be noted that some grids could not provide P_{round} values, because SSCPUEs were unavailable due to the too shallow depth for LMPS operation. Fishery grounds for the Saga Prefecture were extended to adjacent grids (fishery grid no. 213, 214; Table 1) because catch records near the prefecture (fishery grid no. 203) were too limited to estimate P_{round} robustly. The catch amounts of round scad (CR_j) and the other five scads (CO_j) by coastal fisheries in prefecture j were calculated as follows:

$$CR_j = (CT_j - CTlmps_j) \times P_{round,j} \tag{6}$$

$$CO_j = (CT_j - CTlmps_j) \times (1 - P_{round,j}) \tag{7}$$

where CT_j and $CTlmps_j$ represent the total catch amount of all six scads by all types of fisheries from official statistics of the Japanese government and the catch amount by LMPS, respectively, and $P_{round,\ j}$ represents the estimated proportion of round scad in prefecture j. $P_{round,\ j}$ were calculated by arithmetic averaged value for $P_{round,\ i}$ of each fishery grids in Table 1.

To examine the validity of the estimates of $P_{round,\ j}$, we compared the model estimates with the observed P_{round} values around the fishing grounds of the Akune and Makurazaki ports in the Kagoshima Prefecture, since catches of round scad and the other five scads are reported separately at these two ports.

Results

1. Fishery record of LMPS

The maximum catch of round scad was 11,062 tons in 1996, and that of the other five scads was 21,295 tons in 1995 (Fig. 1a). Annual catches of round scad and the other five scads fluctuated and decreased over time. The total effort also gradually decreased over time (Fig. 1b). The annual positive catch rates of round scad and the other five scads were always lower than 0.25 and decreased gradually after 2006 and 2010, respectively (Fig. 1c). Additionally, the nominal CPUE for both groups fluctuated and decreased to low levels after 2010 (Fig. 1d).

2. Spatial distribution of the CPUE

Catches of the six scads were widely observed in the ECS and coastal SJ, but not in the Yellow Sea and offshore in the SJ (Fig. 2a). The proportion of the round scad to all six scads at the positive catch positions by nominal CPUE clearly revealed that round scad was segregated from the other five scads (Fig. 2b), and the boundary was observed in coastal waters around southern Kyusyu and the offshore waters along the continental shelf break. In almost all the coastal waters around the SJ and northern Kyusyu, the proportion was higher than 0.8. In the offshore ECS, the proportion was lower (< 0.2) in deeper waters than along the continental shelf break, whereas it was higher than 0.4 in almost all waters shallower than the continental shelf break.

Changes in the spatial distribution of the nominal

Table 1. Fishery grids in the coastal waters around Kyusyu for estimation of catch amount by coastal fisheries

Fishery grid no.	Latitude (°N)	Longitude(°E)	Prefecture or port	P_{round}	95% confidence intervals
961	34.75	131.75	Ya	0.85	0.68-0.93
971	34.75	131.25	Ya	0.77	0.46-0.95
981	34.75	130.75	Ya	0.81	0.72-0.90
982	34.25	130.75	Ya, Fu	0.91	0.83-0.94
992	34.25	130.25	Fu	0.71	0.61-0.80
203	33.75	129.75	Sa	0.62	0.19-1.00
213	33.75	129.25	Sa	0.65	0.54-0.77
214	33.25	129.25	Na, Sa	0.95	0.90-0.98
224	33.25	128.75	Na	0.86	0.82-0.91
205	32.75	129.75	Na	0.98	0.95-0.99
215	32.75	129.25	Na	0.90	0.86-0.94
225	32.75	128.75	Na	0.86	0.82-0.91
696	32.25	130.25	Ku, Ak	0.75	0.13-1.00
206	32.25	129.75	Ku	0.95	0.94-0.97
697	31.75	130.25	Ak	0.95	0.92-0.97
678	31.25	131.25	Ma	0.51	0.36-0.68
688	31.25	130.75	Ma	0	—
698	31.25	130.25	Ma	0.72	0.58-0.85
679	30.75	131.25	Ma	0.06	0.02-0.15
689	30.75	130.75	Ma	0.10	0.05-0.21
699	30.75	130.25	Ma	0.02	0.01-0.05
680	30.25	131.25	Ma	0	—
690	30.25	130.75	Ma	< 0.01	0.00-0.01
700	30.25	130.25	Ma	0.01	0.00-0.13

Ya, Fu, Sa, Na, and Ku represent the fishery grids for the Yamaguchi, Fukuoka, Saga, Nagasaki, and Kumamoto Prefectures, respectively. Ak and Ma represent the fishery grids for the Akune and Makurazaki ports at the Kagoshima Prefecture. The arithmetic average P_{round} values for each prefecture or port were calculated as follows: Ya, 0.83; Fu, 0.81; Sa, 0.74; Na, 0.91; Ku, 0.85; Ak, 0.85; Ma, 0.16.

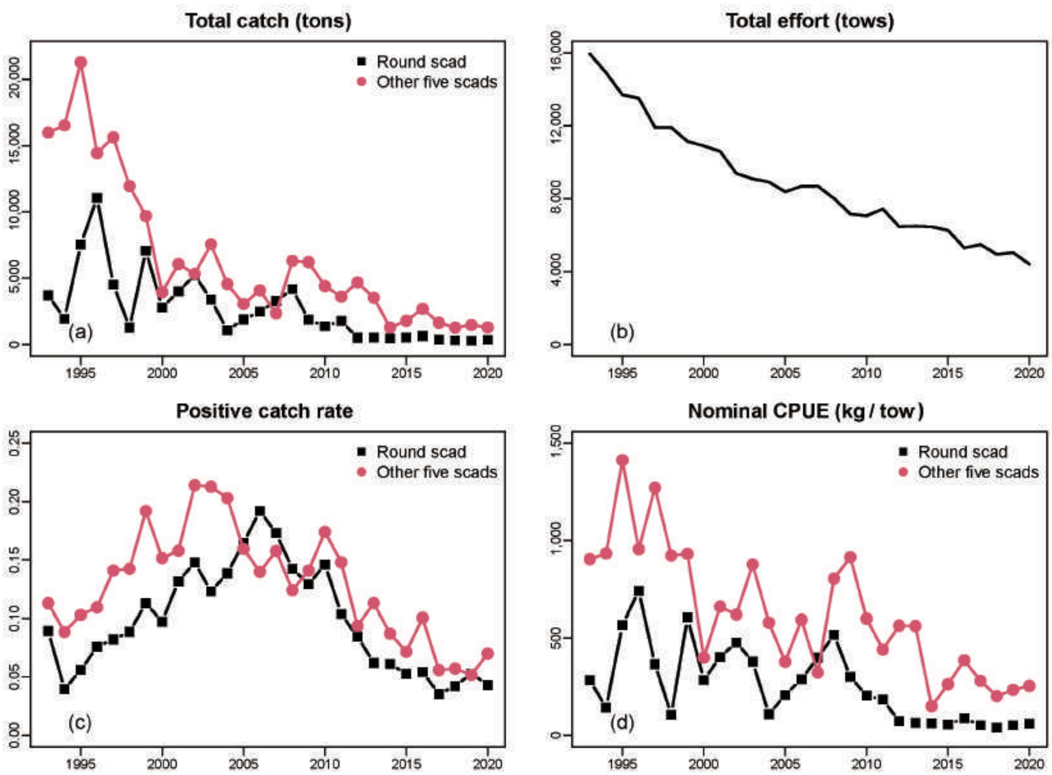

Fig. 1. Trends in the annual catch (a), total effort (b), positive catch rate (c), and nominal CPUE (d) by Japanese LMPS analyzed in this study

CPUE during every seven years are shown in Figure 3. The LMPS operated widely in the study area from 1993 to 1999 (Fig. 3a, e), but the operating area decreased over time, especially in the offshore waters of the Yellow Sea and ECS (Fig. 3d, h). High round scad CPUEs were observed in the southwestern ECS on the continental shelf and coastal waters around northern Kyusyu and the western SJ. In contrast, the high CPUE of the other five scads was observed in the continental shelf break and the Kuroshio area. High CPUE operation of round scad and the other five scads in the coastal and offshore waters decreased during every seven years in the study period (Fig. 3).

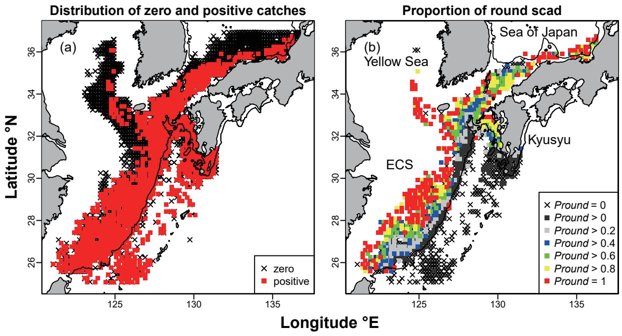

Fig. 2. Distribution of zero and positive catches by daily operation for all six scads in the study area (a), and the proportion of the round scad to all six scads at the positive catch positions of all six scads based on nominal CPUE (b)
The solid lines on each map show 200 m depth.

3. Delta-lognormal generalized additive models

The explanatory variables for all selected models with the lowest BIC included the fishery grid, year, month, and temperature (Tables 2, 3). The area under the curve (AUC) value of binomial models for round scad and the other five scads were 0.82 and 0.85, respectively, indicating moderate accuracy (Hosmer et al. 2013). The diagnostic results of the binomial and positive lognormal GAMs indicated that our models were reasonably

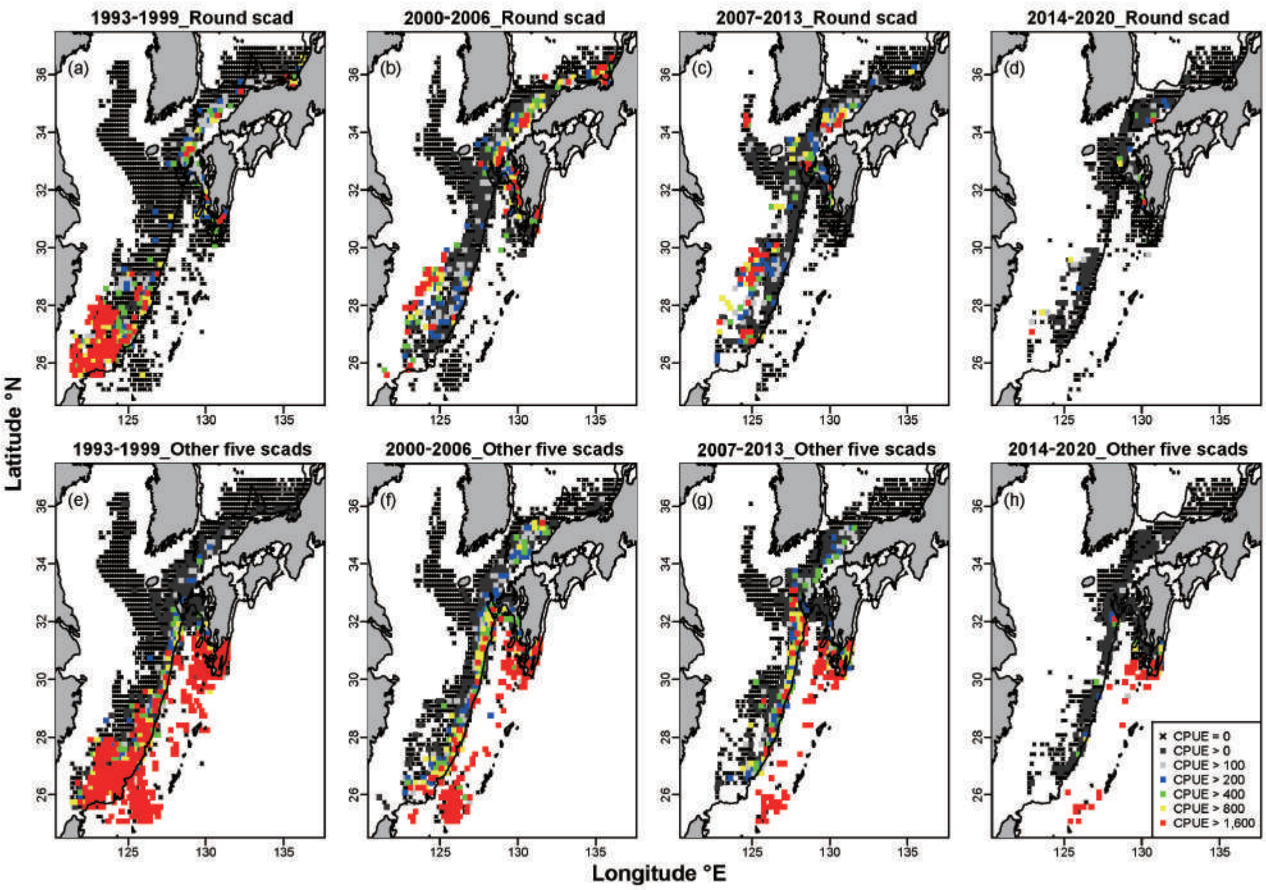

Fig. 3. Distribution of the nominal CPUE every seven years during 1993-2020 for round scad (a-d) and the other five scads (e-h)
The solid lines on each map show 200 m in depth.

acceptable (results not shown).

The partial effect plots of month as an explanatory variable are shown in Figure 4. The month term for both binomial and positive lognormal models for round scad and the other five scads showed lower effects around June than in other months, except for the binomial model for the round scad. The spline functions for round scad showed a habitat preference at lower (> 16°C) and higher (< 25°C) temperatures (Fig. 5a, b). The binomial GAM for the other five scads showed undulating with three modes (Fig. 5c), while the positive lognormal GAM showed simple proportional relationships with temperature (Fig. 5d).

4. ASCPUE trends and estimated catch amount

Before the 2010, the ASCPUE of round scad and the other five scads fluctuated annually, and the yearly trends differed slightly from the nominal CPUE (Fig. 6). However, both the trends in the ASCPUE and nominal CPUE decreased to low levels after 2010. The SSCPUE and P_{round} for each fishery grid are shown in Figure 7. SSCPUEs of round scad exceeding 200 were observed in two areas: the southwestern ECS on the continental shelf and around coastal Kyusyu (Fig. 7a). In contrast, the SSCPUE of the other five scads was higher in the ECS off the continental shelf and coastal waters around southern Kyusyu (Fig. 7b). High P_{round} areas were observed in the southwestern ECS on the continental shelf, the coastal SJ, and northern Kyushu. Low P_{round} areas were observed in the continental shelf break and Kuroshio area, including coastal waters in southern Kyushu (Fig. 7c, d).

The calculated P_{round} for each coastal fishery grid and the estimated total catch amount, including coastal fisheries, are shown in Table 1, Figure 7c and Figure 8, respectively. The estimated annual maximum total catch amounts of round scad and the other five scads were 13,382 tons in 1996 and 24,617 tons in 1995, and the minimum catch amounts were 2,071 tons in 2013 and 3,496 tons in 2015, respectively. Annual catches by coastal fisheries fluctuated, and the trends did not decrease as those of the LMPS did. In the early 1990s, the average proportion of catch amount by LMPS to total catch amount of round scad and the other five scads was around 0.7 and 0.8, but the proportion decreased below

Table 2. Model descriptions and BIC and Δ BIC values of the binomial component of the delta-lognormal GAMs for round scad and the other five scads used in this study

Species	Model description	BIC	ΔBIC
Round scad	Log (*p* / (1-*p*)) ~ Grid + Year + Month + Temp 50	84,580.6	—
	Log (*p* / (1-*p*)) ~ Grid + Year + Temp 50	84,878.1	297.5
	Log (*p* / (1-*p*)) ~ Grid + Year + Month	85,065.6	485.0
	Log (*p* / (1-*p*)) ~ Grid + Year + Month + Temp 50 + Year * Month	85,458.3	877.7
	Log (*p* / (1-*p*)) ~ Grid + Year + Month + Year * Month	85,859.0	1,278.4
The other five scads	Log (*p* / (1-*p*)) ~ Grid + Year + Month + Temp 50	66,005.5	—
	Log (*p* / (1-*p*)) ~ Grid + Year + Month	66,125.9	120.4
	Log (*p* / (1-*p*)) ~ Grid + Year + Month + Temp 50 + Year * Month	66,204.7	199.2
	Log (*p* / (1-*p*)) ~ Grid + Year + Month + Year * Month	66,334.3	328.8
	Log (*p* / (1-*p*)) ~ Grid + Year + Temp 50	66,504.0	498.5

Table 3. Model descriptions and BIC and Δ BIC values of the positive lognormal component of the delta-lognormal GAMs for round scad and the other five scads used in our study

Species	Model description	BIC	ΔBIC
Round scad	Log (CPUE) ~ Grid + Year + Month + Temp 50	92,226.5	—
	Log (CPUE) ~ Grid + Year + Month	92,369.3	142.8
	Log (CPUE) ~ Grid + Month + Temp 50	92,735.0	508.5
	Log (CPUE) ~ Grid + Month	92,858.9	632.4
	Log (CPUE) ~ Grid + Year + Temp 50	94,424.1	2,197.6
The other five scads	Log (CPUE) ~ Grid + Year + Month + Temp 50	85,451.1	—
	Log (CPUE) ~ Grid + Year + Month	85,462.7	11.6
	Log (CPUE) ~ Grid + Month + Temp 50	86,110.3	659.2
	Log (CPUE) ~ Grid + Month	86,141.4	690.3
	Log (CPUE) ~ Grid + Year + Temp 50	86,854.9	1,403.8

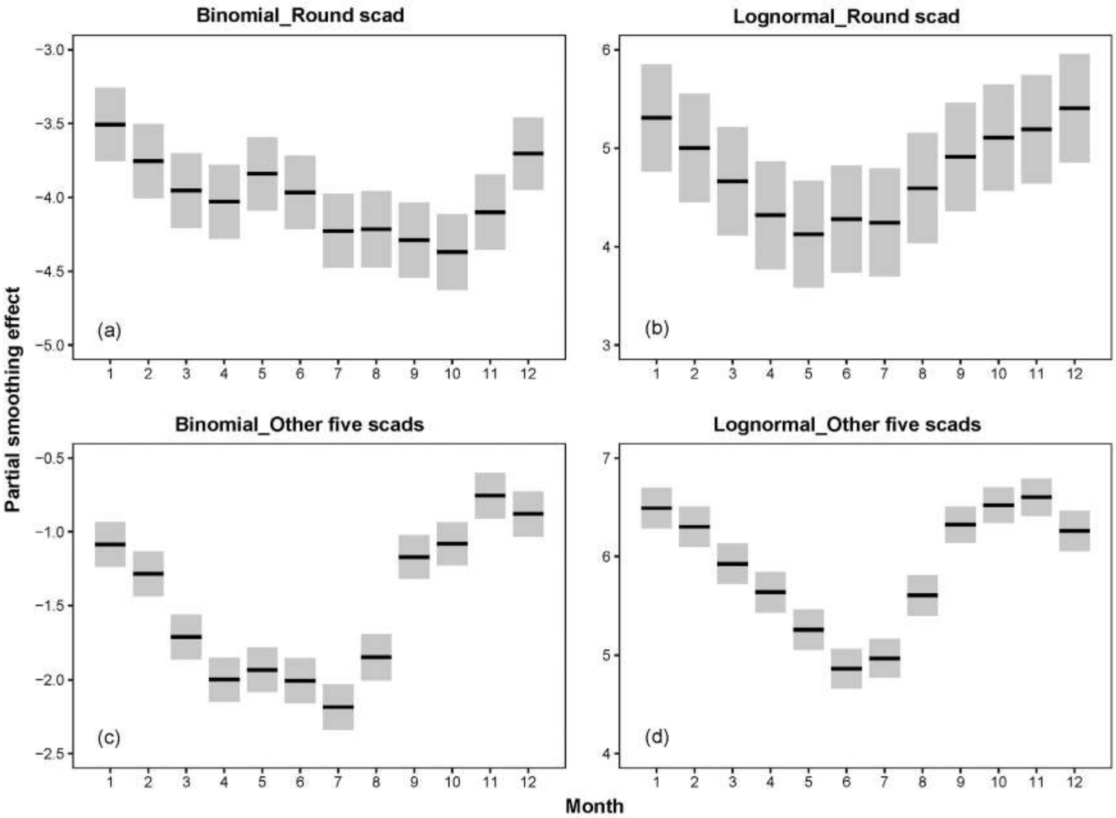

Fig. 4. Partial effect plots of month as an explanatory variable derived from the binomial and positive lognormal GAMs for round scad (a, b) and the other five scads (c, d)

The black lines and shaded areas indicate fitted values and 95% confidence intervals of the partial effects, respectively.

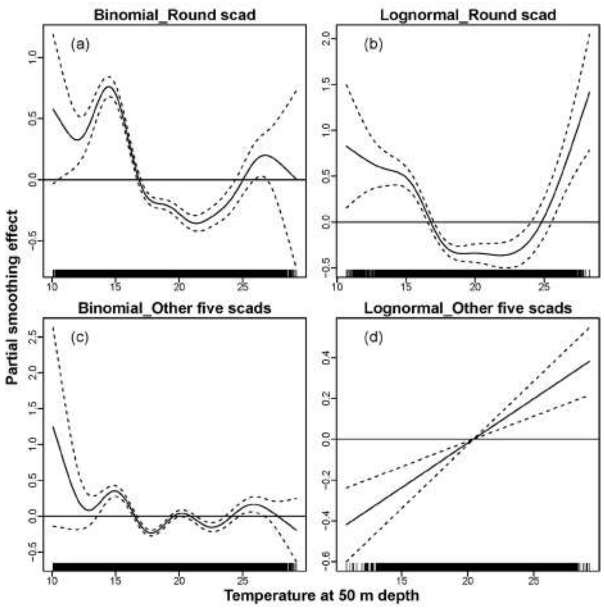

Fig. 5. Smoothed fits of temperature at a 50-m depth to the binomial and positive lognormal GAMs for round scad (a, b) and the other five scads (c, d)

Dashed lines indicate 95% confidence intervals.

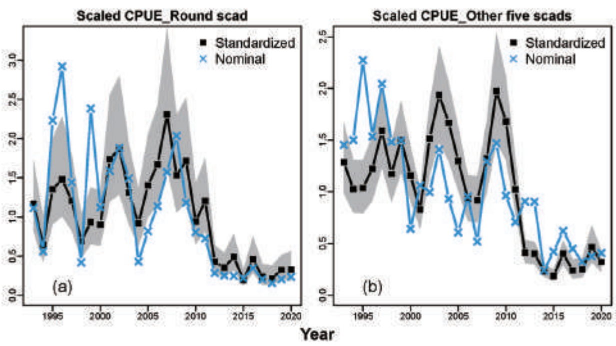

Fig. 6. Time-series of the standardized (black lines) and nominal annual CPUE (blue lines) of round scad (a) and the other five scads (b)

Values were scaled by dividing them using their means. Gray colors indicate 95% confidence intervals.

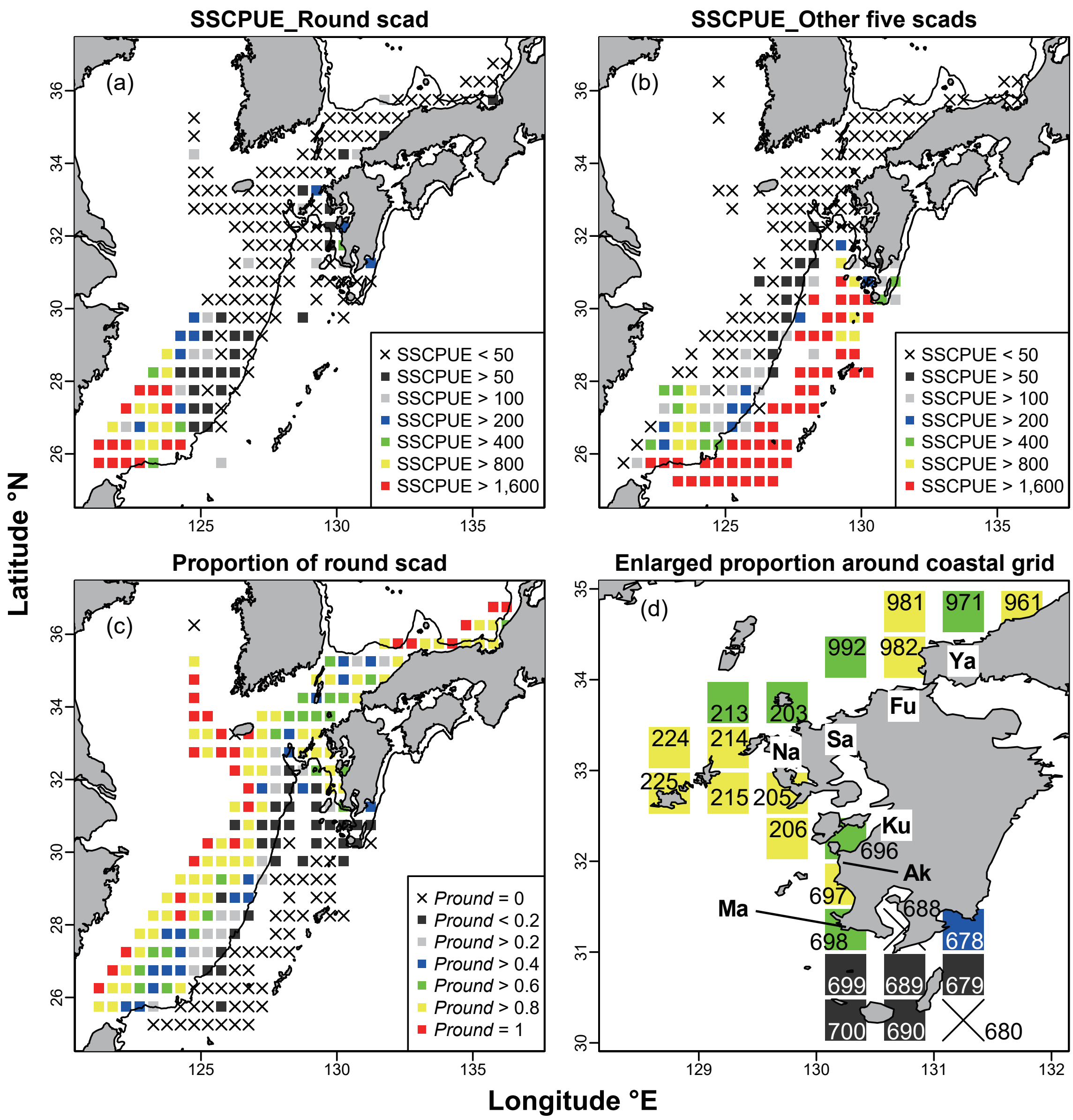

Fig. 7. ASCPUE for each fishery grid by delta-lognormal GAMs for round scad (a) and the other five scads (b). P_{round} for each fishery grid (c), and an enlarged picture for the P_{round} around coastal waters around the fishery grid numbers in Table 1 (d)

Ya, Fu, Sa, Na, Ku represent the fishery grid for the Yamaguchi, Fukuoka, Saga, Nagasaki, and Kumamoto Prefectures, respectively. Ak and Ma represent the fishery grid for the Akune and Makurazaki ports at Kagoshima Prefecture, respectively. The solid lines on each map show 200 m in depth.

0.3 after 2012 and 0.4 after 2016, respectively.

The P_{round} of the Akune and Makurazaki ports was estimated at 0.85 and 0.16, respectively (Table 1, Fig. 7d). The estimated P_{round} of the Akune port was almost equal to the actual catch record by medium- and small-type purse-seine fisheries during 1999-2020 (0.87), whereas that of the Makurazaki port differed from the actual catch record (0.02) to some degree, and the proportion was lower than that of the Akune port.

Discussion

This study is the first to report the preferred habitats of round and the other five scads based on the standardized catch record of Japanese LMPS in the ECS and SJ. The results indicated that habitats of round and the other five scads were clearly segregated. Moreover, this study provides not only ASCPUE but also separated aggregated total catch amounts of six scads into round scad and the other five scads, respectively. Therefore, the results are important for the assessment and management of scad stocks.

Seasonal changes in the binomial and positive lognormal models of round scad and the other five scads decreased around June, except for the binomial model for round scad (Fig. 4). In the ECS, the first maturation ages for round scad and mackerel scad, roughear scad, and shortfin scad were 2 years old, and their main spawning season was around June, although there were some differences among species (Kishida 1978; Ohshimo et al. 2006, 2014; Shiraishi et al. 2010). The lower partial parametric effects on the positive lognormal model for round scad in the spawning season might be related to migration to spawning grounds in coastal shallower waters (10 m-30 m; Kishida 1986), which are too shallow to be fished by LMPS. In addition, Kishida (1978) considered the main spawning grounds of red scad, roughear scad, and shortfin scad in the southern ECS but did not report on amberstripe scad and mackerel scad. In the northern South China Sea (NSCS), eggs of mackerel scad, roughear scad, and shortfin scad were observed in coastal waters south of 22°N, and spawning grounds of shortfin scad were located further south (Hou et al. 2020). Therefore, the lower partial parametric effects on the binomial and positive lognormal models for the other five scads during the spawning season might be related to migration to the main spawning ground around the southern ECS, outside the LMPS operation range. In fact, Hino et al. (2019) considered the spawning migration of mackerel scad from the Hachijyo-jima Island in the Pacific Ocean (PO) to other areas might affect the relationship between monthly changes in age composition.

Binomial and positive lognormal GAMs for round scad indicated that their thermal habitats were divided into areas of low and high temperatures (Fig. 5a, b). The divided habitats were probably related to the two local groups in the study area, as previously indicated (Kishida 1972). In contrast, the positive lognormal GAM of the other five scads indicated proportional relationships between the CPUE and temperature, whereas the binomial GAM indicated undulating with three modes between the positive catch rate and temperature (Fig. 5c, d). The proportional and undulating with three modes might be related to differences in the preferred thermal habitats among the five scads (Kishida 1974). In the NSCS, due to some significant biological differences, it is considered that there are seven different stocks of round scad, although their genetic diversity was low (Niu et al. 2019). In the ECS, based on the monthly size distribution of fork length, Ohshimo et al. (2006) implied that there was a movement of round scad from the southwestern ECS to the coastal waters around Kyusyu. Therefore, genetic studies and scientific surveys focusing on seasonal distribution of scads are needed in the future to elucidate stock structures in more detail.

The ASCPUE of round scad and the other five scads fluctuated annually but decreased after 2010 (Fig. 7). Notably, the present ASCPUE has not considered a bias caused by the six scads being rarely targeted by fishers, as catchability might differ based on which species is being targeted (Okamura et al. 2017). The spatial ranges and numbers of spatial strata should be defined appropriately via methods such as the area stratification methods (e.g., delta-GLM-tree, Hashimoto et al. 2019), since selecting appropriate spatial strata is important for ASCPUE (Ichinokawa & Brodziak 2010). However, the present study analyzed large numbers of conventional fishery grids (177 for round scad; 201 for the other five scads) as spatial strata to calculate the P_{round}. Therefore, further consideration of the targeting issue and improvement of spatial strata is essential to develop stock assessment for scads.

In Japan, Takeda et al. (2021) reported a stock assessment of round scad in the Kii Channel and adjacent waters in the PO based on virtual population analysis. The stock differs from the ECS based on its biological characteristics (Takeda 2002). The authors reported decreases in stock abundance after the late 1990s. Moreover, they considered the current low stock abundance to be not only the result of high fishing pressure but also decreases in reproduction rate influenced by changes in environmental factors because the harvest rate remained at around 10% and has been decreasing recently. In China, the round scad was the most-caught species in the NSCS, but the average catch decreased by 28%, relegating it to the third rank during 2008-2018 (Hou et al. 2020). In addition, previous studies have examined environmental factors that could be affecting the distribution of round scad in the NSCS (Yu et al. 2019, Zhao et al. 2021). To elucidate the current decreases in the stock abundance of round scad in the northwestern PO, cooperative exchanges of information among researchers in Japan, China, Korea, and Taiwan is essential. In addition, Hino et al. (2019) reported decreases in the stock abundance of mackerel scad based on the analysis of catch records around the Hachijyo-jima Island; however, there are no reports on the stock abundance of amberstripe scad, red scad, roughear scad, and shortfin scad in Japan. Although the catch amount of each scad by LMPS has not been recorded, standardization of the CPUE should be performed if the data become available in the future.

The P_{round} clearly revealed spatial segregation between round scad and the other five scads (Fig. 7c). The estimated P_{round} for each prefecture was higher than 0.7; this is considered reasonable because these fishery grids are located at the northern boundary ($P_{round} < 0.2$) of the five other scads' distribution in coastal waters, and the estimated P_{round} of the Akune port was found to be almost equal to the observed one. The differences between the estimated and actual P_{round} of the Makurazaki port might be related to the fact that the location is near the boundary of P_{round} (Fig. 7d). The annual catch trends of round scad and the other five scads by coastal fisheries did not decrease like those of the LMPS (Fig. 8), and recent decreases in the proportion of the catch amount by LMPS to the total catch is due to reductions in the operations of LMPS in high-CPUE areas.

The estimated SSCPUE, ASCPUE and the total catch amounts of round scad and the other five scads are important for the assessment and management of scad stocks. To develop assessment and management strategies, improvement of ASCPUE such as consideration of target species and improvement of spatial strata, in addition to genetic studies and scientific surveys focusing on the stock structure are essential.

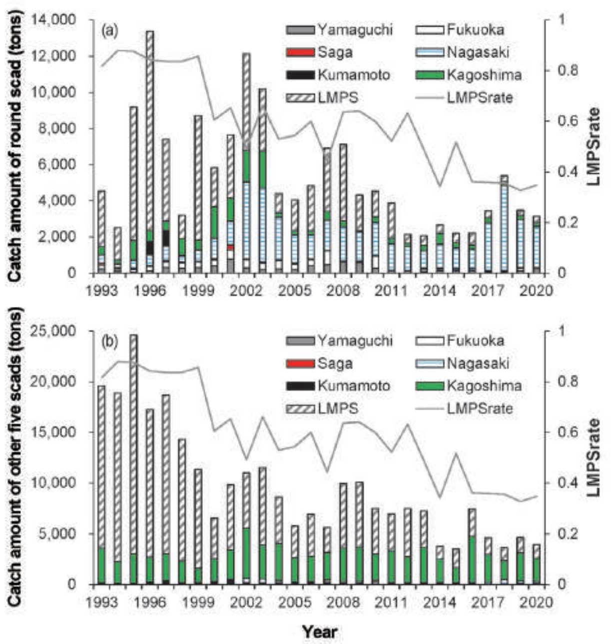

Fig. 8. Estimated total catch amount of round scad (a) and the other five scads (b) with unrecorded catch amount by coastal fisheries for each prefecture, and the recorded catch amount by LMPS (dashed grey bars) and the Kagoshima Prefecture (green bars)

The solid lines indicate the rate of catch amount by LMPS to total catch amount, including LMPS and coastal fisheries.

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