漁獲データに基づくガストロ *Gasterochisma melampus* の生物特性：分布、漁獲量、体長、CPUE

Biological aspects of the butterfly kingfish *Gasterochisma melampus*: distribution, total catch, size composition and CPUE

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要約

20 年以上の日本延縄漁業及び調査のデータを利用してガストロの資源生物特性を解析した。本種は南緯 35 度から 45 度間で周極的に連続分布し，その南限は亜南極フロントに対応した。推定した世界の漁獲量は平均で 1859 トンであり，日本が平均 64%と最大であった。産卵場である南東太平洋には大型魚が分布し，大西洋からインド洋を通じて南西太平洋までは小型の未成魚の摂餌海域であった。摂餌場の 1993 年から 2016 年までの釣獲率の変化並びに 1970 年の釣獲率との比較は，本種資源が抑圧されていないことを示唆した。

Summary

Biological aspects of butterfly kingfish *Gasterochisma melampus* were examined using Japanese longline fishery data and research data collected for over 20 years. Butterfly kingfish were distributed in a continuous band around the circumpolar region between 35°S and 45°S. The southern limit of distribution corresponded with the sub-Antarctic front. The estimated global total annual catch for butterfly kingfish ranged from 613 to 3699t (mean 1859t) with Japan taking the largest proportion of the total catch. Large, adult butterfly kingfish spawn in the south-eastern Pacific, whereas smaller, immature fish are distributed in feeding grounds in the area extending across the Atlantic and Indian Oceans to the south-western Pacific Ocean. Catch per unit effort (CPUE) data for fish in the feeding grounds from 1993 to 2016 were compared with the CPUE value from 1970. These data indicate that the stock is currently not likely to be depleted.

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Biological aspects of the butterfly kingfish *Gasterochisma melampus*: distribution, total catch, size composition and CPUE

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Abstract
Biological aspects of butterfly kingfish *Gasterochisma melampus* were examined using Japanese longline fishery data and research data collected for over 20 years. Butterfly kingfish were distributed in a continuous band around the circumpolar region between 35°S and 45°S. The southern limit of distribution corresponded with the sub-Antarctic front. The estimated global total annual catch for butterfly kingfish ranged from 613 to 3699 t (mean 1859 t) with Japan taking the largest proportion of the total catch. Large, adult butterfly kingfish spawn in the south-eastern Pacific, whereas smaller, immature fish are distributed in feeding grounds in the area extending across the Atlantic and Indian Oceans to the south-western Pacific Ocean. Catch per unit effort (CPUE) data for fish in the feeding grounds from 1993 to 2016 were compared with the CPUE value from 1970. These data indicate that the stock is currently not likely to be depleted.

Keywords Catch-per-unit-effort · GLM · Scombridae · Sea surface temperature

Introduction

The butterfly kingfish *Gasterochisma melampus* (hereafter BUK) is a pelagic species of the family Scombridae, which inhabits the southern hemisphere. It is a large species with a fork length (FL) of up to 190 cm. *Gasterochisma* is a monotypic genus, and the distinctive morphological characteristics and phylogenetic position of BUK in the Scombridae have attracted the attention of osteological and molecular biologists (Block et al. 1993; Collette et al. 2001; Kohno 1984; Miya et al. 2013; Qiu et al. 2014). It is commonly recognized that BUK belongs to the Scombridae; however, some scientists suggest that BUK could form an independent subfamily (Collette et al. 2001). Studies suggest that BUK has a brain heater organ, and interest in the phylogenetic positioning of this species has also been raised in studies on the evolution of endothermy in the Scombridae, including tuna species (Carey 1982; Collette et al. 2001).

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In the late 1960s BUK began to be caught as bycatch in the Japanese longline fishery for southern bluefin tuna *Thunnus maccoyii* (SBT), when fishing operations expanded from the subtropics to a latitude of 40°S. Warashina and Hisada (1972) reported on the general distribution of the species, catch rates (catch per unit effort; CPUE), size composition and sea surface temperature (SST), based on catch data from 1969 and 1970. Subsequently, there have been several studies of BUK catches outside the typical distributional range for the species (Ito et al. 1994; Rotundo et al. 2015; Santos and Nunan 2015); however, details of distribution, density and factors that may restrict distribution are not fully understood.

Butterfly kingfish are caught as a bycatch species by longline fisheries targeting SBT, then are retained on vessels and sold on the Japanese market. The annual catches of BUK found in the statistics by the Food and Agriculture Organisation (FAO) are, however, only 4–40 t, reported by New Zealand and Portugal (FAO Fisheries and Aquaculture Department 2016). This is clearly under-reporting of worldwide BUK catch. This is probably because the economic importance of BUK is low, so comprehensive reporting on this species has not been done.

The SBT stock has largely decreased since 1970, but recently started increasing again (Anonymous 2017a).

According to the code of conduct for responsible fisheries produced by the FAO, management measures should not only ensure the conservation of target species, but also of associated species (FAO 1995). To ensure the sustainability of the SBT fishery, it is necessary to evaluate the stock status of bycatch species, including BUK. It is not clear whether there has been a change in the BUK stock that inhabits the same waters as SBT. Life history characteristics of BUK are also poorly understood. It was recently reported that BUK spawn in an area of the south-eastern Pacific Ocean (Itoh and Sawadaishi 2018). Following this finding, we are interested in understanding the relationship between BUK in the south-eastern Pacific, fish in the SBT fishing grounds, and migration patterns to and from the spawning ground.

Catch of BUK have been required to be reported by fishermen in the logbooks of Japanese longline fishers since 1993. Scientific onboard observers have been dispatched on about 10% of Japanese longline vessels fishing for SBT since 1993. These good quality fishery and research data sets have accumulated for more than 20 years. Therefore, in this study, I clarify the distribution, size structure, global catch, and stock status of BUK since 1970, using these data sets and information from the literature. Life history characteristics are also discussed.

Materials and methods

Data used

The present study used three data sets obtained from fisheries or research: logbook data from the Japanese longline fishery, JAMARC research data (JAMARC was previously the Japan Marine Fishery Resources Research Center; it is now the Marine Fisheries Research and Development Center of the Japan Fisheries and Education Research Agency), and scientific observer data from the Japanese longline fishery. The logbook data contain reports from Japanese longline fishers from 1993, when BUK was added as a species to be reported, to 2016. The JAMARC research data include the results of research conducted by JAMARC from 1987 to 1996 in the south-eastern Pacific Ocean using chartered commercial tuna longline vessels, with the aim of exploring commercial fishing grounds for BUK (Itoh and Sawadaishi 2018). The scientific observer data consisted of records collected by the Japanese scientific observer program for SBT longline vessels from 1993 to 2016. Each data set contains information on the longline operation including latitude, longitude, the number of hooks used, and noon sea surface temperature (SST) values. The JAMARC research data and scientific observer data contained FL and processed body weight (head, viscera, skin, and tail removed) for each BUK individual and whole body weight for some individuals. The logbook data contained the number of fish caught and the total processed weight for BUK, for tuna species and for other commercially important species.

Logbook data were collected from oceans around the world. Scientific observer data, which was derived from SBT longline vessels, mainly included data from the SBT fishing grounds south of 30°S in the Atlantic, Indian and south-western Pacific oceans. The JAMARC research data set only included data from the south-east Pacific Ocean (from 75°W to 169°W and from 21°S to 59°S).

Analysis

To determine the distribution of BUK, nominal CPUE (number of BUK caught per 1000 hooks; nominal means unstandardized) was plotted on a map in $5° \times 5°$ squares of longitude and latitude, using a combined data set from the logbook and JAMARC data. Some caution was needed for some squares in which fewer than 20 longline operations were recorded, and when BUK were caught in only one operation, leading to an anomalously high CPUE value. Conversely, if there was a square in which many longline operations (≥ 20) were recorded but BUK were caught in only one operation, the result was likely to be a recording error in the logbook and the data were excluded. All data from the JAMARC data set were used, even when BUK were caught in only one fishing operation, because this data set was likely to be more accurate compared with the logbook data.

The total annual catch of BUK was calculated using the Japanese longline data from the logbooks. A factor to convert processed body weight data to whole body weight was calculated based on data from the scientific observer data set, where both weights were measured. Several catch records for BUK were found in the FAO statistics records (FAO Fisheries and Aquaculture Department 2016), reported by New Zealand from 2001 to 2015 and by Portugal in 2013 and 2014. Because, to our knowledge, the SBT longline fishery is the only fishery that catches BUK, unreported catch of BUK was estimated by multiplying the global catch of SBT (excluding the reported catch from Japan and New Zealand in the relevant years) by the catch ratio of BUK to SBT for Japan. The global catch of BUK was estimated by summing all relevant values.

A time series of nominal CPUE was examined as an index of population density by year, using the logbook data set. The nominal CPUE data for SBT were also calculated for comparison. Data used to calculate the SBT CPUE were limited to the main SBT fishing area [between 20°W and 180° longitude, and south of 35°S latitude (west of 140°E) or 30°S (east of 140°E)], during some seasons (between April and December). Nominal CPUE values for BUK were calculated in two series; one from the data prepared to calculate the SBT CPUE, and the other from the data collected from the area south of 40°S. The data from south of 40°S was focussed on the main distributional range of BUK (see "Results") and was used to compare with the results of Warashina and Hisada (1972). Warashina and Hisada (1972) derived CPUE values from 1969–1970 catch data (37°S–50°S and 10°W–175°E) in five areas (the south-eastern Atlantic Ocean, the south-western and the south-eastern Indian Ocean, the Tasman Sea, and around New Zealand), and their totals. Because the values described by Warashina and Hisada (1972) were the number of fish caught per fishing operation, this value was divided by 2100, the mean number of hooks used in the years 1969 and 1970, based on logbook data.

A log-normal generalized linear model (GLM) standardization was applied to CPUE data and a yearly trend (least square mean) was extracted by removing the impact of factors other than changes in stock abundance, because nominal CPUE may be affected by temporal and spatial bias of fisheries data (Maunder and Punt 2004; Shono 2004). The logbook data set was used for this and was limited to the main SBT fishing area and the months between April and December. Data records were aggregated by month, one degree of latitude and ten degrees of longitude. The number of fish caught was set as a response variable. The number of hooks used was treated as the offset so that the difference in the number of hooks by record was taken into account. The full GLM model was as follows:

$$\log(N + \text{const}) \sim \text{year} + \text{month} + \text{lat1} + \text{long10} + \text{lat1} * \text{long10} + \text{offset(hook)} + \varepsilon, \quad (1)$$

where N is the number of BUK caught, const is a constant, lat1 is latitude in 1° increments, long10 is longitude in 10° increments, lat1*lon10 is the interaction between them, hook (the offset term) is the number of hooks used, and ε is the error term following a Gaussian distribution. The added constant was used to avoid the logarithm of zero being undefined. A value of 0.1 was used for the constant, according to Campbell (2004), so that 10% of the number of fish correspond to the mean CPUE, allowing robust estimation. Year, month, and longitude were treated as categorical variables in the analysis. The best model was selected on the basis of the Akaike information criterion (AIC) using the *step* function of R (ver. 3.4.2, R Foundation for Statistical Computing, Vienna, Austria). Note that data from the south-eastern Pacific Ocean were excluded from the nominal CPUE comparison and CPUE standardization, because most of the data from that area were from the JAMARC data set (i.e., not a commercial fishery data set); and because the year range was limited and, unlike the fish from other areas, the fish in the south-eastern Pacific were spawning adults.

Size data for BUK were analysed using a combination of scientific observer data and JAMARC data. The nominal CPUE data were plotted in 5-cm length classes (FL), per 5° of longitude. To reduce the influence of greatly different fishing effort among areas (defined by longitude) and to prevent bias in the size composition of fish from areas with low densities, data were expressed as nominal CPUE. The size composition of BUK during each month (using average values per month for each year in which data were available) were plotted using the scientific observer data. The size composition data were used to define the month in which small fish were caught at the SBT fishing grounds, indicating recruitment from the spawning ground. Using the plots, a threshold for small fish was defined, and the area of occurrence of small fish was examined. The statistical software R was used for analysis and plots.

Results

Distribution and global catch

Butterfly kingfish were mainly caught from a continuous band between the latitudes of 35°S and 45°S, which is almost completely circumpolar (Fig. 1). The area in which BUK were caught extended north to 20°S in the south-eastern Indian Ocean (between the longitudes of 85°E and 105°E) and in the south-eastern Atlantic Ocean (between the longitudes of 10°W and 15°E). Catch area also extended south to 50°S off southern Australia. In the eastern Pacific Ocean, BUK were caught from a wide area that extended north to south between the latitudes of 20°S and 55°S. There was a discontinuity in catch in the area between 170°W and 180° of longitude, which is due to the absence of commercial tuna longline operations in that region. The southern limit of the BUK distribution corresponded with the sub-Antarctic front (SAF).

The mean conversion factor from processed weight to whole body weight was 1.53 ($N = 1932$). The annual Japanese catch ranged from 371 to 2267 tonnes (t) between 1993 and 2016 (Table 1). From the FAO statistics, the catch range over the same period was 6 to 47 t for New Zealand and 4 and 5 t for Portugal. The total annual catch based on these data ranged from 384 to 2267 t (mean 1186 t). The estimated global total annual catch ranged from 613 to 3699 t (mean 1859 t). The estimated historical catch was high in the late 1990s, decreased until 2011, and then slightly increased thereafter. Japan catches the largest proportion of BUK, accounting for an average of 64% of the total global catch.

CPUE

The nominal CPUE for BUK from 1993 onward was similar to that in 1970 (Fig. 2). In contrast, the nominal CPUE of

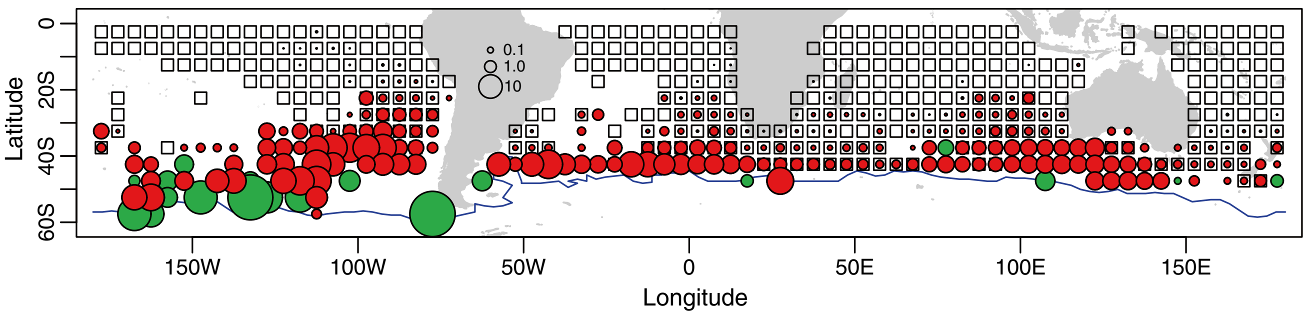

Fig. 1 Map of nominal catch number per unit effort (CPUE) of butterfly kingfish. Size of circles represents nominal CPUE. Squares represent areas where ≥20 longline operations occurred. Red circles represent areas where butterfly kingfish were caught in more than one longline operation. Green circles represent areas where butterfly kingfish were caught in only one longline operation and the total number of commercial fishing operations were <20, or butterfly kingfish were caught in JAMARC research operations. The blue line represents the sub-Antarctic front, based on the work of Belkin and Gordon (1996)

Table 1 Annual catches of butterfly kingfish by country, and estimated global catches

Year	Japan	New Zealand	Portugal	Subtotal	Total estimate
1993	1198			1198	2166
1994	1051			1051	1759
1995	1709			1709	3048
1996	1968			1968	3159
1997	1607			1607	2591
1998	2267			2267	3699
1999	2115			2115	3275
2000	1989			1989	3036
2001	1321	47		1368	1839
2002	1122	30		1152	1529
2003	1334	17		1351	1697
2004	797	11		808	1043
2005	1109	9		1118	1265
2006	1133	14		1147	1422
2007	823	13		836	1250
2008	1217	6		1223	2118
2009	1089	16		1105	2045
2010	371	13		384	761
2011	391	6		397	613
2012	527	8		535	861
2013	710	7	5	722	1338
2014	780	12	4	796	1353
2015	669	23		692	1071
2016	918			918	1675
Min	371	6	4	384	613
Max	2267	47	5	2267	3699
Mean	1176	15	5	1186	1859

Total estimate is based on the catch ratios of butterfly kingfish to southern bluefin tuna in Japan. Units are tonnes

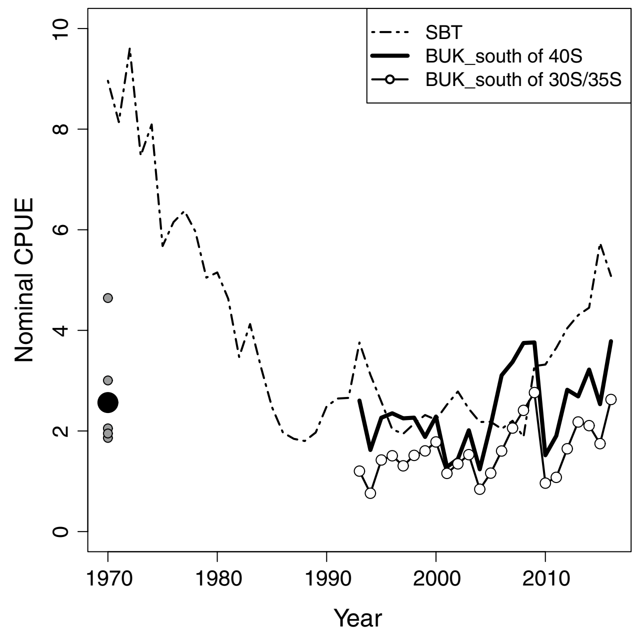

Fig. 2 Nominal catch per unit effort (CPUE; catch in number per 1000 hooks) for butterfly kingfish (*BUK*) and southern bluefin tuna (*SBT*). The thick line represents CPUE for butterfly kingfish in the area south of 40°S, which is the main distribution area for butterfly kingfish and corresponds to the CPUE values from Warashina and Hisada (1972). The line with open circles and the broken line represent the CPUE values for butterfly kingfish and southern bluefin tuna, respectively, in the area south of 35°S (west of 140°E) and south of 30°S (east of 140°E). Filled circles represent the nominal CPUE for 1969–1970 (plotted for 1970 for ease of interpretation), calculated from Warashina and Hisada (1972). The larger circle is the value for all areas combined, and the smaller circles represent each of five areas

SBT underwent large changes, with a large decrease from 1969 to the mid-1980s, and then an increase after 2009. There was no significant correlation between the nominal CPUE values of the two species ($r=0.266$, $t=1.295$, $df=22$, P value $=0.209$), for the same area. The mean value of the nominal CPUE of BUK was smaller than that of SBT (58% of the SBT CPUE for the same area, or 88% when the area was restricted to latitudes south of 40°S, where there was a relatively high CPUE value for BUK).

Nominal CPUEs were standardized using a GLM. The full model was selected based on the AIC. The quantile–quantile plot demonstrated that the fit of the model was generally good except at both ends (Fig. 3). The time series of standardized CPUE by year fluctuated annually and showed no consistent increasing or decreasing trend (Fig. 4). Standardized CPUE was relatively low in the early 1990s, but high in the 2000s and 2016.

Size

Butterfly kingfish caught in the Atlantic and Indian oceans were relatively small (< 140 cm FL), and fish from both locations had a similar size composition (Fig. 5). Fish from the south-east Pacific were larger (120–190 cm FL). Fish from a longitude of about 155°W, an area geographically intermediate between these two regions, were intermediate in size (100–160 cm FL).

The dominant length class in the scientific observer data (between 20°W and 160°E) was about 110–120 cm FL in all surveyed months (Fig. 6). The size distribution of fish that were larger than 110–120 cm FL was similar among all months except in April, when the data came from few years. Smaller fish were more common between May and August than in the other months. Fish with a FL < 90 cm were defined as "small fish" for the purposes of subsequent analysis. Small fish were observed in the area from south of South Africa to the south-eastern Indian Ocean (Fig. 7). Large CPUE values for small fish were observed in the area with a longitude of between 10°W and 39°E and a latitude of 42°S and 45°S. Small fish also occurred from 90°E to 119°E and 130°E to 139°E, although the CPUE

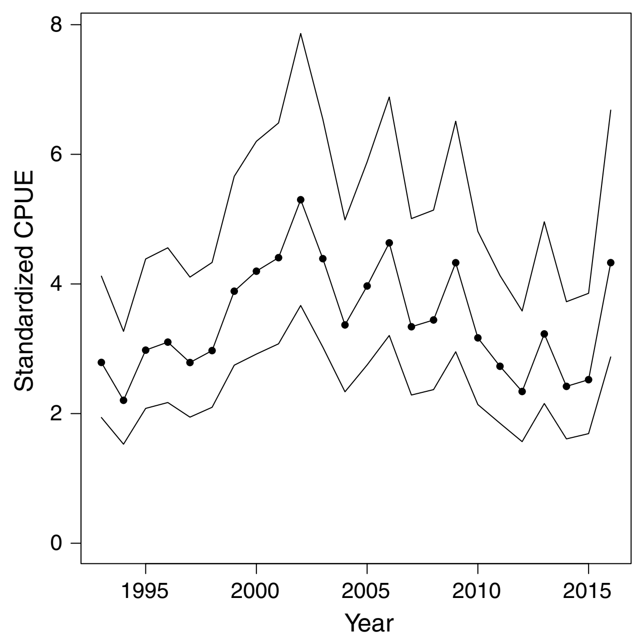

Fig. 4 Time series of annual catch per unit effort (CPUE) for butterfly kingfish, standardized by using a generalized linear model. The range is mean ± 1 standard error

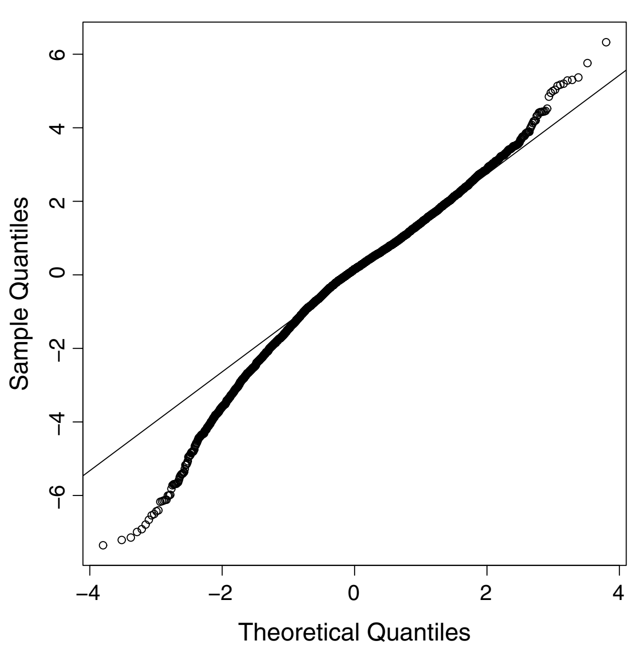

Fig. 3 Quantile-quantile plot of standardization of catch per unit effort for butterfly kingfish using a generalized linear model

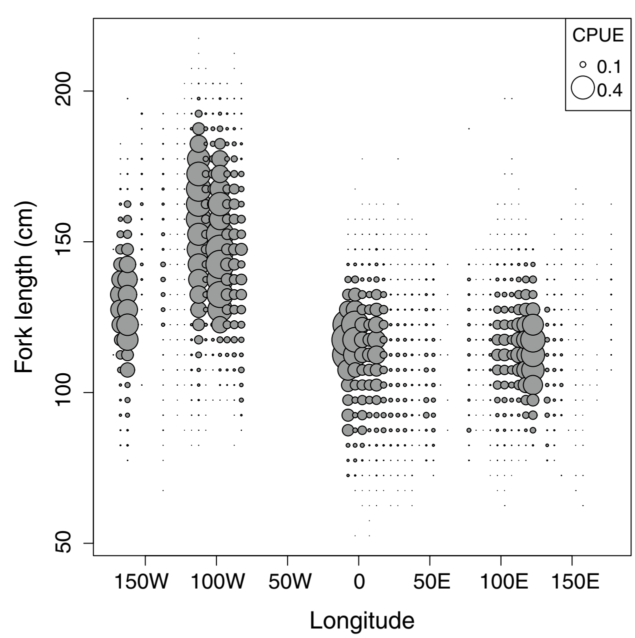

Fig. 5 Size composition based on the fork length of butterfly kingfish, at different areas of longitude. Circle size represents the nominal catch per unit effort. Data are grouped in units of 5° longitude and length classes of 5 cm (fork length)

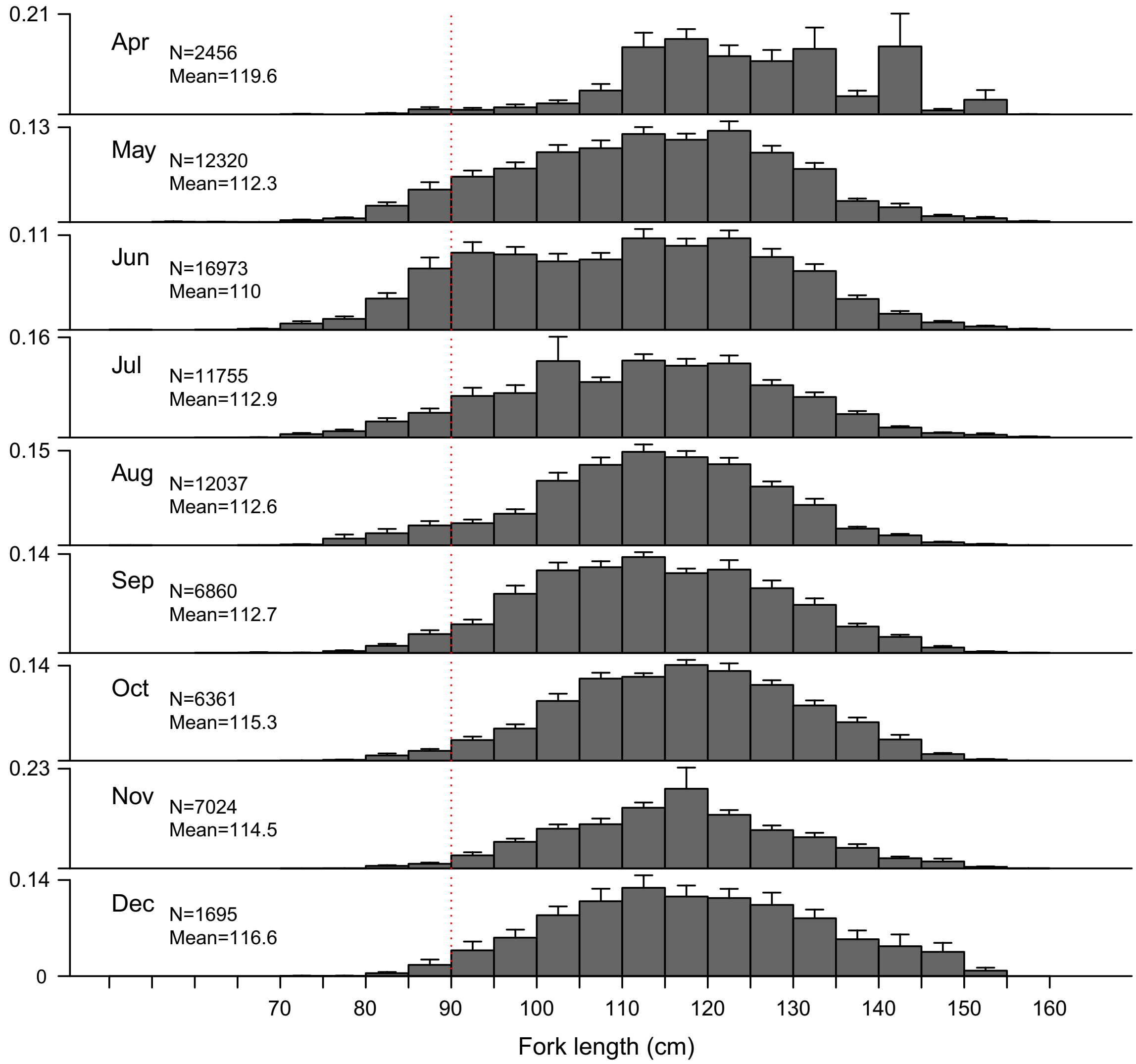

Fig. 6 Size composition based on the fork length of butterfly kingfish, in 5-cm length classes. Data are annual means + standard errors presented for each month of commercial fishing. The vertical red line denotes 90 cm fork length, which was used to define the threshold for small fish

values were not as high as in the former area. CPUE for small fish tended to be higher in southern areas.

The SST in regions where BUK were caught ranged from 6.2 to 20.6 °C with a median value of 10.6 °C (Fig. 8). Sea surface temperature was lower in regions where BUK were smaller (< 90 cm FL) compared with regions where larger BUK were caught (≥ 90 cm FL).

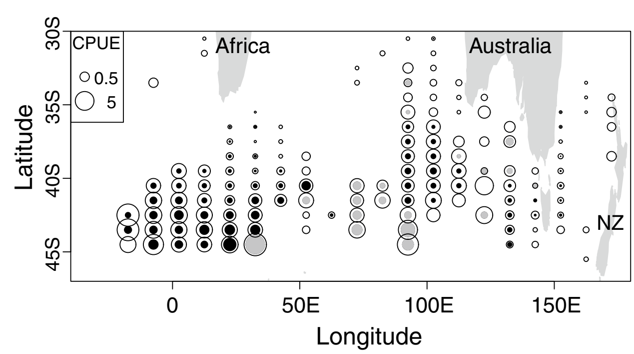

Fig. 7 Nominal catch per unit effort (CPUE) for butterfly kingfish < 90 cm fork length, in increments of 5° longitude and 1° latitude. Black solid circles represent CPUE of fish < 90 cm fork length. Grey solid circles represent the same parameter where fishing effort was small (< 30,000 hooks). Open circles represent the CPUE value for fish of all sizes. Data are for the period May to August

Discussion

The distribution of BUK has been previously studied using data from commercial fisheries and research surveys (Collette and Nauen 1983; Itoh and Sawadaishi 2018; Warashina and Hisada 1972). The results of the present study support previous findings, showing that the distribution

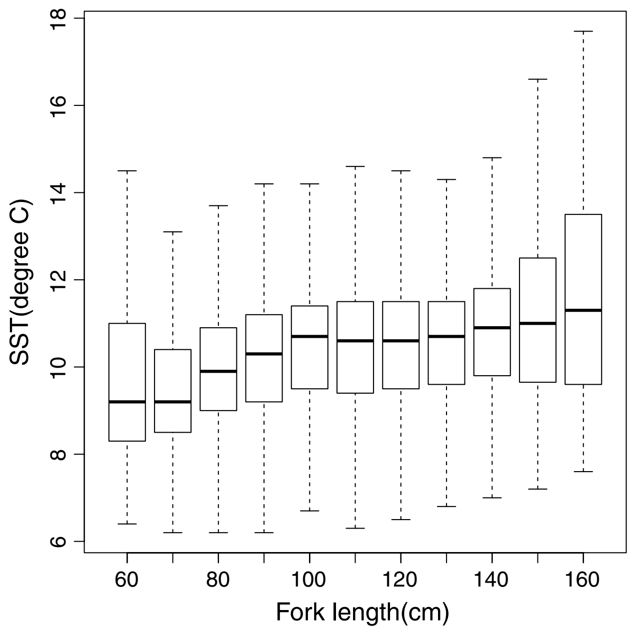

Fig. 8 Sea surface temperature (SST) for butterfly kingfish of different fork lengths (10-cm length classes). Each box shows the range of the first and third quartiles, with the median as a thick horizontal line. Whisker length represents 1.5 times the interquartile range

of BUK extends in a nearly continuous circumpolar band across three oceans. Although there was a lack of data for the area between 170°W to 180° in the present study, Yatsu (1995) reported catch in this region in latitudes of between 40°S and 56°S using driftnet catch data from a research survey. The present study used nominal CPUE to quantitatively represent population density, taking into account the difference of fishing efforts by area, rather than showing the areas where catches were recorded or showing total number of catches by area.

It is unlikely that BUK occur in the region to the north of the typical distribution zone, because historically, enormous efforts have been put into longline fisheries in this region. However, a few BUK have been caught off Hawaii, Ecuador, and Brazil and these catches were reported because of their rarity (Ito et al. 1994; Rotundo et al. 2015; Santos and Nunan 2015). The southern limit of BUK distribution corresponds with the SAF. The location of the SAF does not change seasonally. To the south of the SAF, the high-volume Antarctic Current flows from west to east, and the water temperature and salinity are much lower (< 5 °C and < 34, respectively), compared with the waters north of the SAF (Belkin and Gordon 1996). South of the SAF, the absence of BUK has not been validated as there are a lack of tuna longline operations in this area; however, the different water characteristics and the lack of BUK in catch records from fisheries in the area suggests that BUK are absent in this region.

Butterfly kingfish are well adapted to cold water (Collette and Nauen 1983). Sea surface temperatures at locations where BUK were caught were reported to be 6–20 °C in the south-eastern Pacific Ocean and 14–18 °C for fish with mature ovaries from the same area (Itoh and Sawadaishi 2018). Warashina and Hisada (1972) reported SSTs of 5–18 °C (most frequent range 8–10 °C) in the SBT fishing grounds, where BUK were caught. Yatsu (1995) reported a SST range of 5–19 °C, with higher CPUE values of BUK occurring at temperatures of less than 15 °C, in a drift-net research study in the south-eastern Pacific Ocean. The SSTs in BUK catch areas in the current study, ranging from 6.2 to 20.6 °C with a median of 10.6 °C, were consistent with the results of previous studies. Average SSTs were lower at the feeding ground. This suggests that BUK use cold water for feeding and move to warmer waters to spawn.

The circumpolar distribution of BUK is similar to that of SBT in southern temperate waters (Caton 1994). Both species are similar in that they use warmer waters for spawning; however, they reproduce in different oceans. Butterfly kingfish spawn in the south-eastern Pacific Ocean and SBT use the eastern Indian Ocean. Butterfly kingfish are widely distributed in the south-eastern Pacific Ocean, whereas SBT are seldom found there; moreover, BUK have a distribution that is skewed to the south. This southern-skewed distribution is similar to that of the porbeagle *Lamna nasus* and the slender tuna *Allothunnus fallai* (Semba et al. 2013; Warashina and Hisada 1972; Yatsu 1995; Itoh T., unpublished data).

The estimated annual catch of BUK was about 1200 t on average by the Japanese longline fleet and about 1900 t on average across the globe. To the author's knowledge, this is the first estimate of the global catch for this species. The BUK catch has some economic importance as a supplementary product in the SBT longline fishery. However, because the average catch weight is 16% that of SBT, and the market price is much less than that of SBT, the economic gain from this bycatch is relatively small (Warashina and Hisada 1972). The estimate of global catch is probably an overestimate. Among longline fleets that fish for SBT, vessels from Taiwan and some Australian vessels operate in northern areas where BUK density is lower than in the areas where the Japanese longline fleet fishes. The true value of the global catch is probably within the range of the summed reported catch value and catch estimates. The estimation could be improved by actual reporting of BUK catches or effort data at a detailed resolution, especially at the latitudes of these fisheries.

Butterfly kingfish spawn off the coast of Chile in the south-eastern Pacific Ocean (Itoh and Sawadaishi 2018). Only one spawning ground has been identified and fish with developed ovaries have not been reported from the Atlantic Ocean or the Indian Ocean. This suggests that BUK comprise a single stock. Observations of gonads reveal that females mature at 140 cm FL and males at 110 cm FL (Itoh and Sawadaishi 2018). Therefore, BUK in the south-eastern Pacific are defined as mature, and fish in the Atlantic, Indian and south-western Pacific oceans are defined as immature fish in the feeding grounds. The existence of one separate population area for small fish and one area for large fish suggests that BUK migrate ontogenetically within the distribution area. Butterfly kingfish migrate to the feeding grounds in the area that extends from the Atlantic Ocean to the south-west Pacific Ocean when < 90 cm FL. Fish stay there for an unknown period, (age and growth of BUK is not understood), before moving to the southeast Pacific Ocean after reaching maturity. The absence of large fish at the feeding ground suggests that fish do not return to the Atlantic Ocean or the Indian Ocean. An overwhelming proportion (about 80%) of BUK are female, and larger fish are biased toward females. In other species (e.g., marlins) there is a distribution difference by sex and a size difference among areas (Shimose et al. 2012). There is no apparent difference in the distribution of BUK based on sex, therefore the difference in the distribution of different sized fish is relevant to the life history of the species (Itoh and Sawadaishi 2018; Itoh T., unpublished data). There were few differences in the size composition of BUK populations from May to December, except in the timing of recruitment of small fish. The area in which the longline fisheries for SBT operate varies by season. From April to August the fishery is based in the areas off South Africa, in the Tasman Sea, and around New Zealand, and then moves to the south-eastern Indian Ocean for fishing from August to December. Therefore, the similarity in the monthly size composition of BUK that are more than 110–120 cm in length suggests that fish that recruit to the feeding ground immediately disperse widely across the whole area or migrate seasonally in an east to west direction. It is not yet known which of these occurs. Although seasonal migration in an east to west or west to east direction for long distances in short periods has been reported for SBT (Gunn and Block 2001), no information on the migration of individual BUK has yet been obtained.

Changes in CPUE were examined over the 24 years between 1993 and 2016 and from 1970 by utilizing the work of Warashina and Hisada (1972). Japanese longline vessels began exploring SBT fishing grounds at about 40°S in the mid-1960s, so the fishery was relatively new in 1970 (Shingu 1970). The CPUE in 1970 can therefore be assumed to represent the initial stock status for BUK. This study is the first reported stock index for BUK, and the first step in a full stock assessment for this species. Comprehensive data were used, including numerous fishing operation records for BUK in their feeding grounds, which cover a wide area extending across the Atlantic, Indian, and south-western Pacific oceans. The data indicate that the CPUE values for BUK have not declined and the current BUK stock is not depleted. However, the CPUE values for the years since 1993 were standardized to correct for the effects of operational changes in time and space, whereas the CPUE in 1970 was a nominal value that was not corrected and could therefore be less accurate.

The CPUE and stock abundance of SBT, as estimated from a stock assessment model created and used by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT; a tuna regional fisheries management organization that manages SBT stock), had been decreasing but recently started increasing (Anonymous 2017a). Southern bluefin tuna and BUK were distributed across similar regions. The CPUE values for BUK did not increase in the 1990s and early 2000s, when SBT stock abundance was declining. This suggests that competition for resources (prey or habitat) between SBT and BUK was not sufficiently strong to be reflected in the CPUE values.

In contrast to the large changes in CPUE and stock abundance for SBT over time, the CPUE values for BUK have remained stable. The reasons for this are not clear, but there are a number of possibilities. First, BUK are caught as bycatch of the SBT longline fishery in the feeding grounds of immature BUK, and the area where adult fish are found (the south-eastern Pacific Ocean) is not fished by any of the tuna longline fisheries. Therefore, the adult BUK population has been protected from the longline fishery. Second, SBT stocks have declined not only because of the longline fishery catch but also because of the surface fishery catch in Australian coastal waters, whereas BUK have been caught only by offshore longline fisheries. Third, because BUK are mainly distributed in colder waters compared with SBT, and may also differ in vertical distribution patterns, the operational strategy of the longline fishery targeting SBT may not be optimised for catching BUK.

Simple comparisons of CPUE values may be inappropriate, because CPUE values may not reflect the stock population density of non-target species (BUK) as well as that of target species (SBT) (Maunder and Punt 2004), and the adult BUK population is located away from the feeding grounds of immature fish. However, the nominal CPUE value of immature BUK in their feeding grounds was lower than the nominal CPUE of SBT, which suggests that under a worst-case scenario, the BUK stock is not abundant. If stock abundance is low and the stock has low productivity, and if a commercial fishery were to aggressively target the BUK population in the future, then it is possible that the stock would collapse over a short time period. At present, there is no large-scale fishery operating in the area where BUK spawn. The catch of SBT is increasing and in 2018 will exceed that of the late 1980s, because the recovery of SBT stock prompted the CCSBT to allow an increase in the catch (Anonymous 2017b). Southern bluefin tuna stock are well monitored by the CCSBT, and the management procedure for this stock is based on a scientifically tested, adaptive rebuilding strategy for setting catch limits since 2011 (Hillary et al. 2015). It will be important to monitor the stock status of BUK as a bycatch species, as the SBT catch increases.

The size composition of stock was generally similar between the present study and the results reported by Warashina and Hisada (1972). However, Warashina and Hisada (1972) reported a difference in size between different areas of longitude in the 1969–1970 catch: large fish from 110 to 140 cm FL dominated in the region from the south-eastern Atlantic Ocean to the south-western Indian Ocean (longitude 20°W–50°E), whereas smaller fish from 90 to 114 cm FL dominated in the south-eastern Indian Ocean to the south-western Pacific Ocean (longitude 85°E–180°). The size composition of fish in the current study was similar at the same longitudes. Further study is warranted to see whether differences between the two research surveys are due to the specific year of sampling, the number of years for which there are data, sample sizes, or seasonal differences.

It is not clear when fish from the spawning ground in the southeast Pacific Ocean migrate to the feeding grounds. A BUK specimen of 20 cm in total length was collected at Wellington, New Zealand (Santos and Nunan 2015), but based on this single sample it cannot be concluded that BUK migrate from the east through the west Pacific. It is also possible that fish migrate from the west through Drake Strait, at the south end of South America. The current study showed that small fish (< 90 cm FL) recruit to the longline fishery from May to August. Small fish were identified in the southwest Indian Ocean and in the southeast Indian Ocean to southern Australia (130°E). From the area of occurrence, we could not narrow down the route of migration. The data indicated that small fish were found in regions with a low temperature. Larger individuals of tuna species can inhabit cooler waters due to the development of endothermy as they grow (Graham and Dickson 2001). However, BUK were associated with low temperature waters while they were relatively small. The constraints of water temperature may not determine migration routes, but as small BUK were found in low temperature regions, it is possible that small BUK could migrate through the cooler waters of Drake Strait in the south.

There is developing research interest in the migration of young BUK from the spawning area to the feeding grounds, the movement of fish within the feeding grounds, and migration back to the spawning grounds. However, any insights to be gained from fishery data are limited because of the highly seasonal concentration of longline operations in areas targeting SBT. Although conventional tagging and electronic tagging seem promising techniques to investigate migration patterns, BUK individuals die readily on longlines. In the scientific observer data set, only 22% of BUK individuals were still alive after retrieval to longline vessels several hours after being hooked. In contrast, 81% of SBT were still active after retrieval. Therefore, tagging is not an easy or suitable approach for this species. Although chemical analysis of otoliths for elemental composition or stable isotopes is another option (e.g., Campana 1999), BUK lack sagittal otoliths, so this approach is not possible (Gauldie and Radtke1990).

In conclusion, this study provides some basic biological information on BUK, that should improve our understanding of the ecosystems of the southern temperate waters that include BUK and SBT as top predators. The results of the current study will be enhanced as additional fisheries data become available in the future. Further studies examining several questions are warranted, including: further examination of fisheries data, investigation of age and growth, physiological features of individuals, and clarification of the position of BUK in ecosystems.

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References

Anonymous (2017a) Report of the twenty-second meeting of the scientific committee. The Commission for the Conservation of Southern Bluefin Tuna. https://www.ccsbt.org/sites/default/files/userfiles/file/docs_english/meetings/meeting_reports/ccsbt_24/report_of_SC22.pdf

Anonymous (2017b) Report of the twenty-fourth annual meeting of the commission. The Commission for the Conservation of Southern Bluefin Tuna. https://www.ccsbt.org/sites/default/files/userfiles/file/docs_english/meetings/meeting_reports/ccsbt_24/report_of_CCSBT24.pdf

Belkin IM, Gordon AL (1996) Southern ocean fronts from the Greenwich meridian to Tasmania. J Geophys Res 101:3675–3696

Block BA, Finnerty JR, Stewart AFR, Kidd J (1993) Evolution of endothermy in fish: mapping physiological traits on a molecular phylogeny. Science 260:210–214

Campana S (1999) Chemistry and composition of fish otoliths: pathways, mechanisms and applications. Mar Ecol Prog Ser 188:263–297

Campbell RA (2004) CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. Fish Res 70:209–227

Carey FG (1982) A brain heater in the swordfish. Science 216:1327–1329

Caton AE (ed) (1994) Review of aspects of southern bluefin tuna biology, population, and fisheries. In: Shomura J et al (eds) Interactions of Pacific tuna fisheries. Proceedings of the first FAO expert consultation on interactions of Pacific tuna fisheries. FAO, Rome, FAO Fisheries Technical Paper 336, vol 2, pp 296–343

Collette BB, Nauen CE (1983) FAO species catalogue. Vol. 2 Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species know to date, vol 2. FAO Fisheries Synopsis, Rome, pp 1–137

Collette BB, Reeb C, Block BA (2001) Systematics of the tunas and mackerels (Scombridae). In: Block BA, Stevens ED (eds) Fish physiology: tuna: physiology, ecology, and evolution. Academic Press, San Diego, pp 1–33

FAO (1995) Code of conduct for responsible fisheries. FAO, Rome, pp 1–41

FAO Fisheries and Aquaculture Department (2016) FishStatJ—software for fishery statistical time series [online]. Rome. Updated 21 July 2016

Gauldie RW, Radtke RL (1990) Using the physical dimensions of the semicircular canal as a probe to evaluate inner ear function in fishes. Comp Biochem Physiol A 96:199–203

Graham JB, Dickson KA (2001) Anatomical and physiological specializations for endothermy. In: Block BA, Stevens ED (eds) Fish physiology: tuna: physiology, ecology, and evolution. Academic Press, San Diego, pp 121–165

Gunn J, Block BA (2001) Advances in acoustic, archival and pop-up satellite tagging of tunas. In: Block BA, Stevens ED (eds) Fish physiology: tuna: physiology, ecology, and evolution. Academic Press, San Diego, pp 167–224

Hillary RM, Preece AL, Davies CR, Kurota H, Sakai O, Itoh T, Branch TA (2015) A scientific alternative to moratoria for rebuilding depleted international tuna stocks. Fish Fish 17:469–482

Ito RY, Hawn DR, Collette BB (1994) First record of the butterfly kingfish *Gasterochisma melampus* (Scombridae) from the north Pacific Ocean. Gyoruigaku Zasshi 40:482–486

Itoh T, Sawadaishi S (2018) Spawning area and season of butterfly kingfish (*Gasterochisma melampus*), a large scombrid adapted to cooler temperate southern water. Mar Freshw Res 69:16–23

Kohno H (1984) Osteology and systematic position of the butterfly mackerel, *Gasterochisma melampus*. Gyoruigaku Zasshi 31:268–286

Maunder MN, Punt AE (2004) Standardizing catch and effort data: a review of recent approaches. Fish Res 70:141–159

Miya M, Friedman M, Satoh TP, Takeshima H, Sado T, Iwasaki W, Nishida M (2013) Evolutionary originof the Scombridae (tunas and mackerels): members of a paleogene adaptive radiation with 14 other pelagic fish families. PLoS One 8:e73535

Qiu F, Kitchen A, Burleigh JG, Miyamoto MM (2014) Scombroid fishes provide novel insights into the trait/rate associations of molecular evolution. J Mol Evol 78:338–348

Rotundo MM, Júnior TV, Van Sebroeck Doria DMA (2015) Report of the butterfly kingfish, *Gasterochisma melampus* (Scombridae: Gasterochismatinae) in southeastern Brazil. PanAm J Aquat Sci 10:293–296

Santos SR, Nunan GW (2015) A record of the Southern Ocean *Gasterochisma melampus* (Teleostei: Scombridae) in the tropical south-western Atlantic, with comments on previous records. Mar Biodivers Rec 8:e27

Semba Y, Yokawa K, Matsunaga H, Shono H (2013) Distribution and trend in abundance of the porbeagle (*Lamna nasus*) in the southern hemisphere. Mar Freshw Res 64:518–529

Shimose T, Yokawa K, Saito H, Tachihara K (2012) Sexual difference in the migration pattern of blue marlin, *Makaira nigricans*, related to spawning and feeding activities in the western and central North Pacific Ocean. Bull Mar Sci 88:231–249

Shingu C (1970) Studies relevant to distribution and migration of the southern bluefin tuna. Bull Far Seas Fish Res Lab 3:57–113

Shono H (2004) A review of some statistical approaches used for CPUE standardization. Bull Jpn Soc Fish Oceanogr 68:106–120

Warashina I, Hisada K (1972) Geographical distribution and body length composition of two tuna-like fishes, *Gasterochisma melampus* Richardson and *Allothunnus fallai* Serventy, taken by Japanese tuna longline fishery. Bull Far Seas Fish Res Lab 6:51–75

Yatsu A (1995) Zoogeography of the epipelagic fishes in the South Pacific Ocean and the Pacific sector of the Subantarctic, with special reference to the ecological role of slender tuna, *Allothunnus fallai*. Bull Far Seas Fish Res Lab 32:1–145