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Catch, weight, and maturity at age of the chub mackerel of Japan

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Summary

Stock assessment of chub mackerel in the Northwest Pacific has long been conducted by tuned virtual population analysis (VPA) in Japan. For nearly half a century, the length and age data of chub mackerel are collected based on the catch from the Pacific coast of Japan. Catch data are collected by month, prefecture, and gear type. Measurement of length data is obtained from the major landing port and roughly 60000 individual length data are obtained annually. Length data are sorted and reported by month, prefecture, location, and gear type. Length frequency of the catch data is expanded from the length measurement data and developed by month, prefecture, and gear type basis. Age data are obtained from the subsample of mackerels which fork length are measured and annulus of scale or annual increments of otolith are counted. The age data are subdivided into the northeastern and southwestern part of Pacific coastal prefectures of Japan to construct age-length key using "forward age-length key" method. Age-length key is applied to the catch at size to calculate catch at age for VPA analysis. Weight at age is estimated using the estimated catch at age in weight and catch at age in number of fish. Maturity at age for different stock levels are used for the domestic stock assessment according to the previous study.

Introduction

Stock assessment of chub mackerel (*Scomber japonicus*) in the northwest Pacific Ocean has long been conducted by tuned Virtual Population Analysis (VPA) in Japan. Age-structured stock assessment using tuned VPA allows the estimation of impact of fishery activity to each cohort of chub mackerels however the application of tuned VPA requires the estimation of catch at age distribution of chub mackerel (Ichinokawa and Okamura 2014). Not only catch at age data lead the understanding of demographic pattern, catch at age data provide information on growth, mortality, reproductive potential, and response to exploitation (Jennings et al. 1998, Coggins et al. 2013). Obtaining reliable catch at age data can lead to more assured stock assessment and sustainable fishery for chub mackerel.

In this document we summarized the methodology for estimating catch at size, catch at age, and weight at age of chub mackerel in the Northwest Pacific Ocean estimated and utilized for the present stock assessment in Japan. This document also describes the methodology to derive maturity at age data used for the stock assessment. Additionally, this document presents the example of age-length key using data from 2019.

Method

Catch data

Catch data of chub mackerel are collected from 19 prefectures along the Pacific coast of Japan. The data are collected at the major landing ports by the local prefectural fisheries research institutions. The catch data are categorized by prefecture, month, and gear type. In some prefectures, the catch data of chub mackerel and blue mackerel (*S. australasicus*) are combined and reported as the “mackerels”. In such case, the proportion of chub mackerels and blue mackerels are estimated by sorting the subsample of the catch every month. Then the monthly catch of chub mackerel is estimated by applying the monthly chub-blue ratio to the catch of mackerels of the same month.

Length, weight, and age data

Length frequency data are collected from each prefecture by month. Since the selectivity of gear type is not the same throughout different gear types, the length frequency data are treated differently for each gear type. The sample for length frequency measurement is obtained by spill sampling from the catch at the major landing port and fork length (FL) is measured up to 1 millimeter. Likewise, weight data are measured from the same sample up to 0.1 gram. The measured length and weight data are combined by each prefecture level every year and length-weight relationship is estimated every year for each prefecture as $w = aL^b$, where w is body weight, L is FL, and a and b are coefficients.

Each set of length frequency data are gathered by prefecture, month and gear. Using the length-weight relationship, the mean length and the mean weight of the sample are calculated as follows:

$$\bar{L} = \sum_{j=5}^{j}\left(\left(\frac{s_j}{\sum_{j=5}^{j} s_j}\right)j\right) \quad (1)$$

$$\bar{w} = \sum_{j=5}^{j}\left((aj^b)\left(\frac{s_j}{\sum_{j=5}^{j} s_j}\right)\right) \quad (2)$$

where j is the length bin of the length frequency of sample, s_j is number of fishes in the length bin j.

Next, Number of fishes caught N_c are calculated as:

$$N_c = \frac{c}{\bar{w}} \quad (3)$$

where c is the catch in weight of the same prefecture, month, and gear of the equivalent length frequency data. The number of fishes is multiplied by the length composition ratio to calculate catch at size as:

$$c_j = N_C \frac{s_j}{\sum_{j=5}^{j} s_j} \quad (4)$$

where c_j is catch number of length j. Using the length-weight relationship, the catch at size in weight is calculated as:

$$W_j = N_C \frac{s_j}{\sum_{j=5}^{j} s_j}(aj^b) \quad (5)$$

where W_j is the catch of length j in weight.

Age data are collected from each prefecture. Sample for age estimation are subsampled at random from the length sample and increments of otolith or annulus of scale are counted to estimate the age. For fish with age of 7 or older, age is categorized as 7+ owing to the difficulty of age estimation and small proportion within the samples.

Age-length keys and catch at age

To construct age-length key for chub mackerel, length and age data from each prefecture are combined and subdivided by quarter-year: January to March, April to June, July to September, and October to December. Since the stock of chub mackerel migrates seasonally, the age-length data are subdivided into two geographical groups: northeastern and southwestern part of Pacific coast of Japan (fig 1). Northeastern and southwestern groups consist of catches from East of Shizuoka Prefecture and West of Mie Prefecture, respectively.

Age-length key is developed for each group and each quarter-year using the method of forward-age-length key, which describes the probability of age at given size (Fridriksson 1934, Ailloud and Hoenig 2019). Age and length data are sorted in 1 year old and 1 cm bins, respectively.

Catch at size data are also used to calculate catch at age data. The estimated catch at size (equation 4) for each prefecture, month, and gear are combined into northeastern and southwestern group for quarter-year basis. Age-length key is applied to the combined catch at size of the equivalent group and quarter-year-season to estimate the catch at age-length. By aggregating the catch by age for each group, annual catch at age is estimated. Likewise, using equation 5, catch at age in weight are estimated using similar methodology. With catch at age both in number of fishes and weight, the year-specific weight at age is estimated using the following equation.

$$\text{weight at age} = \frac{\text{catch at age in weight (ton)}}{\text{catch number at age (fish)}} \quad (6)$$

Maturity at age

For the stock assessment, maturity at age is derived based on Watanabe and Yatsu (2006) that studied the maturation of spawning chub mackerel in waters around Izu Islands and Joban area. Since the maturity at age is known to differ by the stock status as presented in Watanabe (2010), the observed maturity rate at age is averaged during the periods with similar stock levels (very high, high, medium, low, and extremely low) estimated from in the domestic stock assessment.

Results

Length frequency from major landing ports

As an example of data collection, length frequency distributions by 1 cm bin derived from the length measurement data of 2019 are shown in Fig 2. Length measurement data are collected every month from 19 prefectures and reported to our institute. The length frequency data from prefectures are aggregated for northeastern and southwestern Pacific coast of Japan. In year of 2019, 42974 and 22148 individuals are measured in northeastern and southwestern Pacific coast of Japan, respectively, thus a total of 65122 individuals are measured in fork length (Table 1). For a part of length measurement data, individual weight from 13728 individuals across the prefectures are measured concurrently (Table 2). Length-weight relationship are estimated for each prefecture with exception of Tokushima, Wakayama, and Aichi which used the length-weight relationship of adjoining prefecture with abundant data (Fig 3).

Age-length key and catch at age

In 2019, age is estimated for 2207 and 1708 individuals for northeastern and southwestern groups, respectively, which yield a total of 3915. The age-length keys are developed based on the age and length data for both northeastern and southwestern groups on quarter-year-intervals (Table 3). With the estimated age-length relationship and growth pattern of chub mackerels, age of individuals with less than 20 cm in FL are automatically categorized as 0 years old. The catch at age is calculated based on the age-length key and catch at size since 1970 (Fig 4). Although ages of 6 and older are categorized as 6+ group in the historical data, fig 4 summarizes 4 years old and above as 4+ group for clarity.

The year specific weight at age is estimated and shown in Table 4. In 2019, the weight at ages 2, 3, 4, 5, and 6+ are found to be the lowest since 1970 and weight of age 0 and 1 remain low compared to the other years.

Maturity at age

Table 5 shows the proportion of matured females at age used for the stock assessment in Japan. Maturity at ages are averaged during the period of each stock status; very high, high, medium, low, and extremely low. Years that represent each stock level are also described in Table 5.

The age of maturity shifts older when stock status is high and vice versa. When the stock status is very low, majority of females mature at age 2 and fully mature at age 3. Meanwhile when the stock status is medium and high, only a portion of age 2 females are matured; all fish are considered as fully matured at age 4 or above. In 2019, the proportion of maturity at age of very high stock level is used and set as 0 for age 0, 1, and 2, 0.3 for age 3, and 1 for age 4 and older.

Conclusions

This document summarized and overviewed the methodology to estimate the catch at age of chub mackerel caught in the northwestern Pacific Ocean by Japanese fleets (mostly within Japanese EEZ). The precise measurement of length, weight, and age of chub mackerel on the annual basis allows development of age-length key and estimation of catch at age with up-to-date demographics. As Hilborn and Walters (1992) states, age-length key is substantially affected by the strength of year class and change in growth pattern, it is vital for age-length key of chub mackerel to be developed annually with abundant data and standardized methodology. With nearly half a century long of collected data, appropriate stock assessment can be achieved as well as extensive research on the population dynamics of chub mackerel. Further sampling with standardized methodology shall be performed with finer scale to continue understanding the population of chub mackerel in the Northwestern Pacific Ocean.

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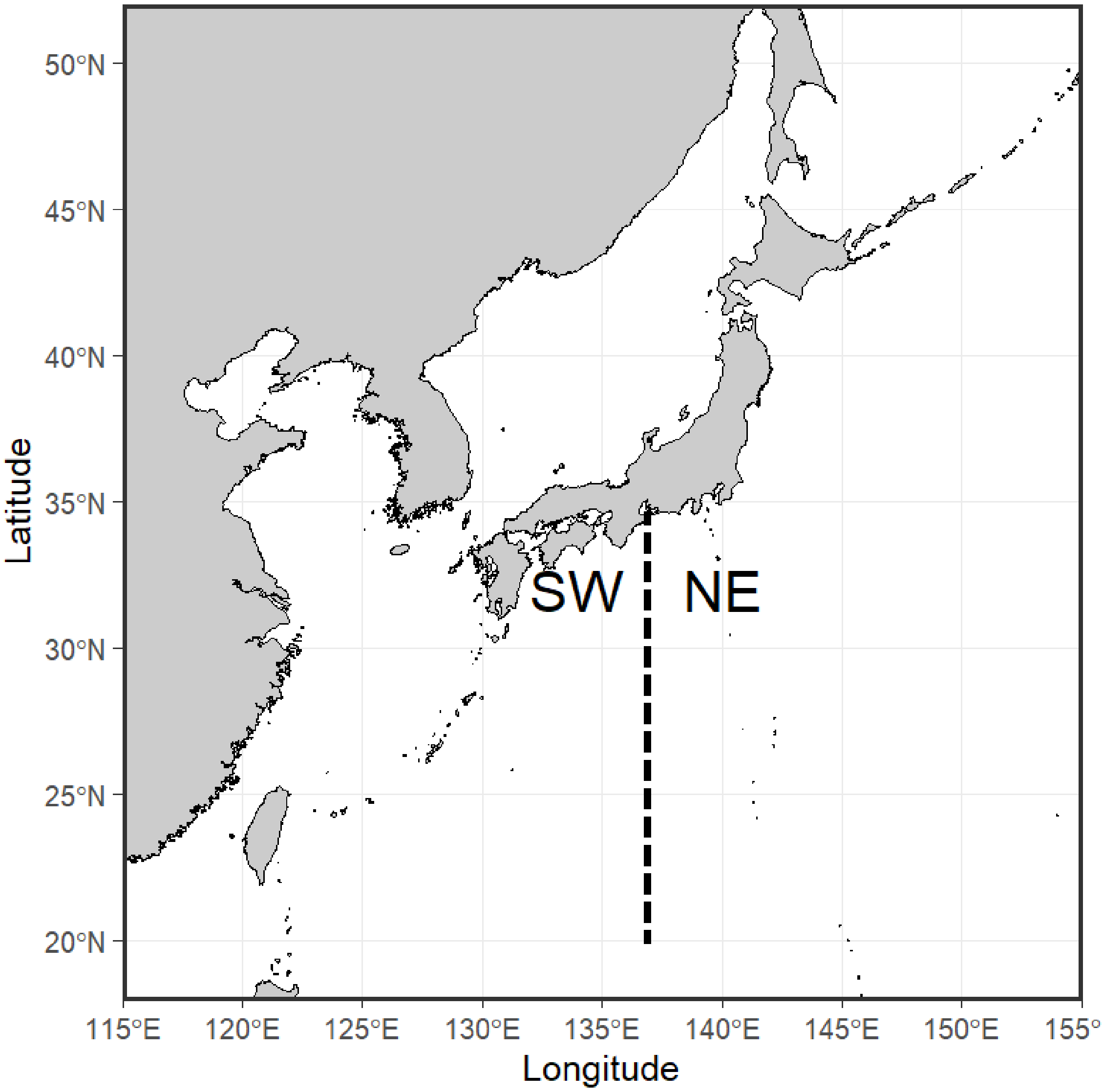


Fig 1. Area definition of northeastern (NE) and southwestern (SW) Pacific coast of Japan.

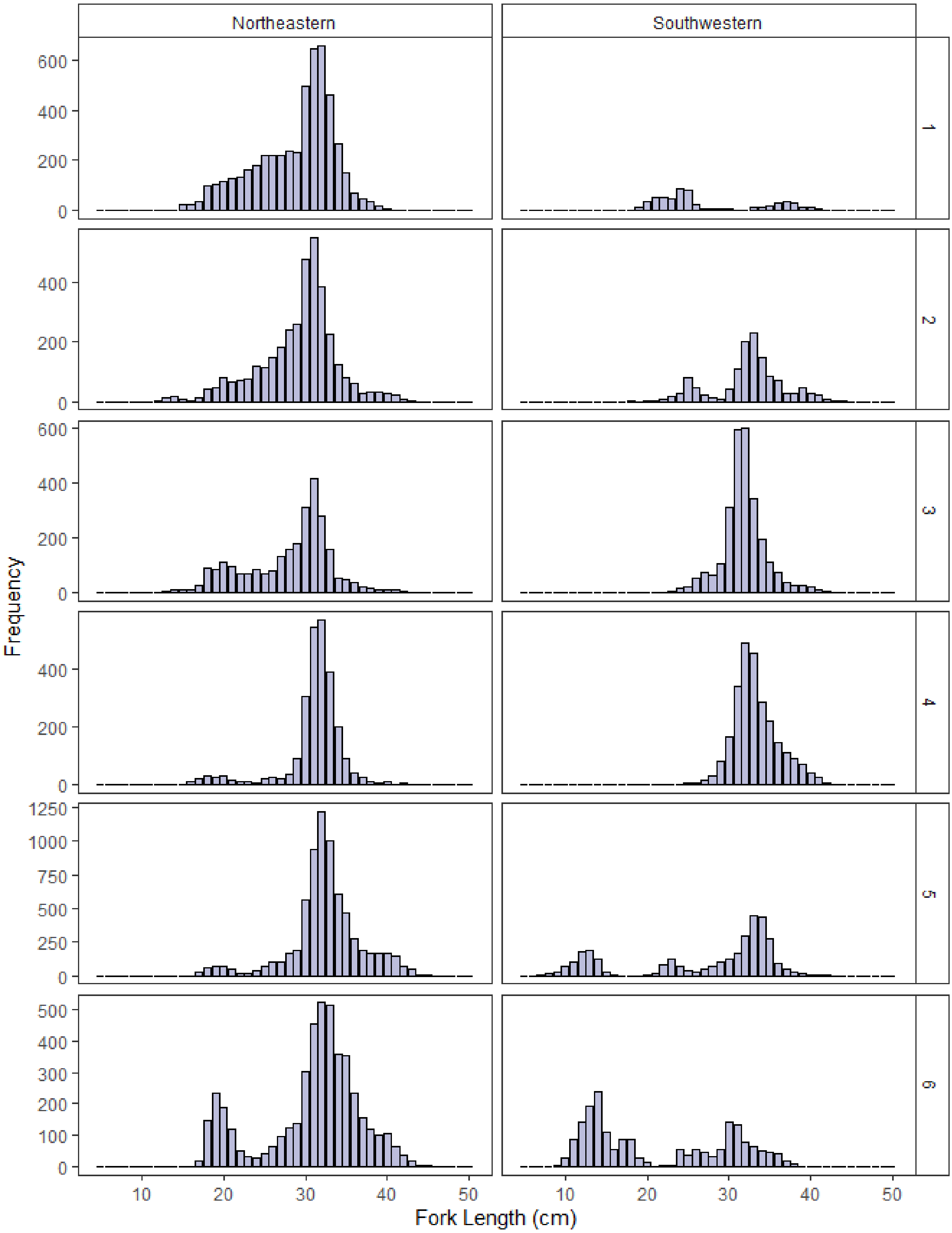
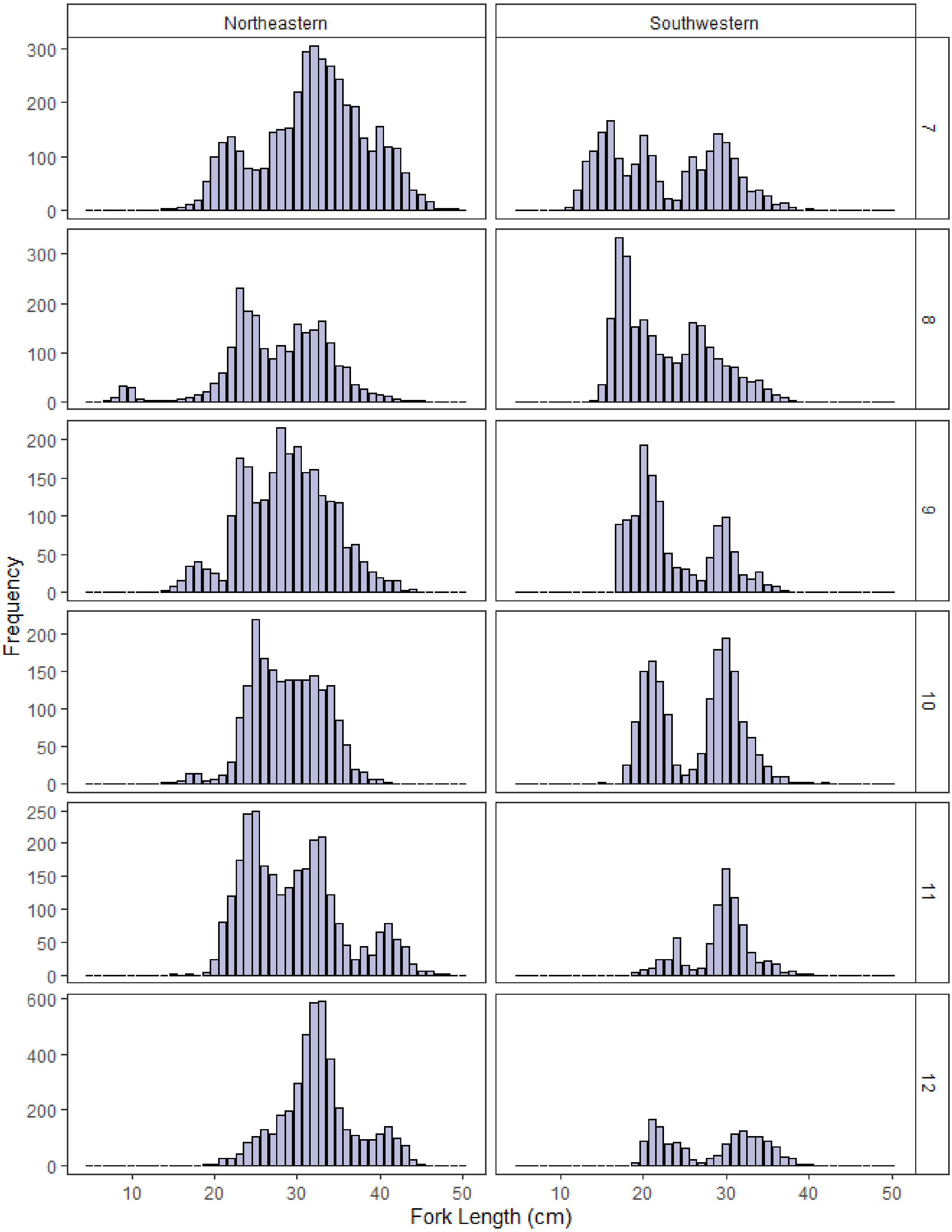


Fig 2. Example of length frequency of chub mackerel caught in northeastern and southwestern part of Pacific coast of Japan in 2018. Number in the left box represents month when samples are collected.



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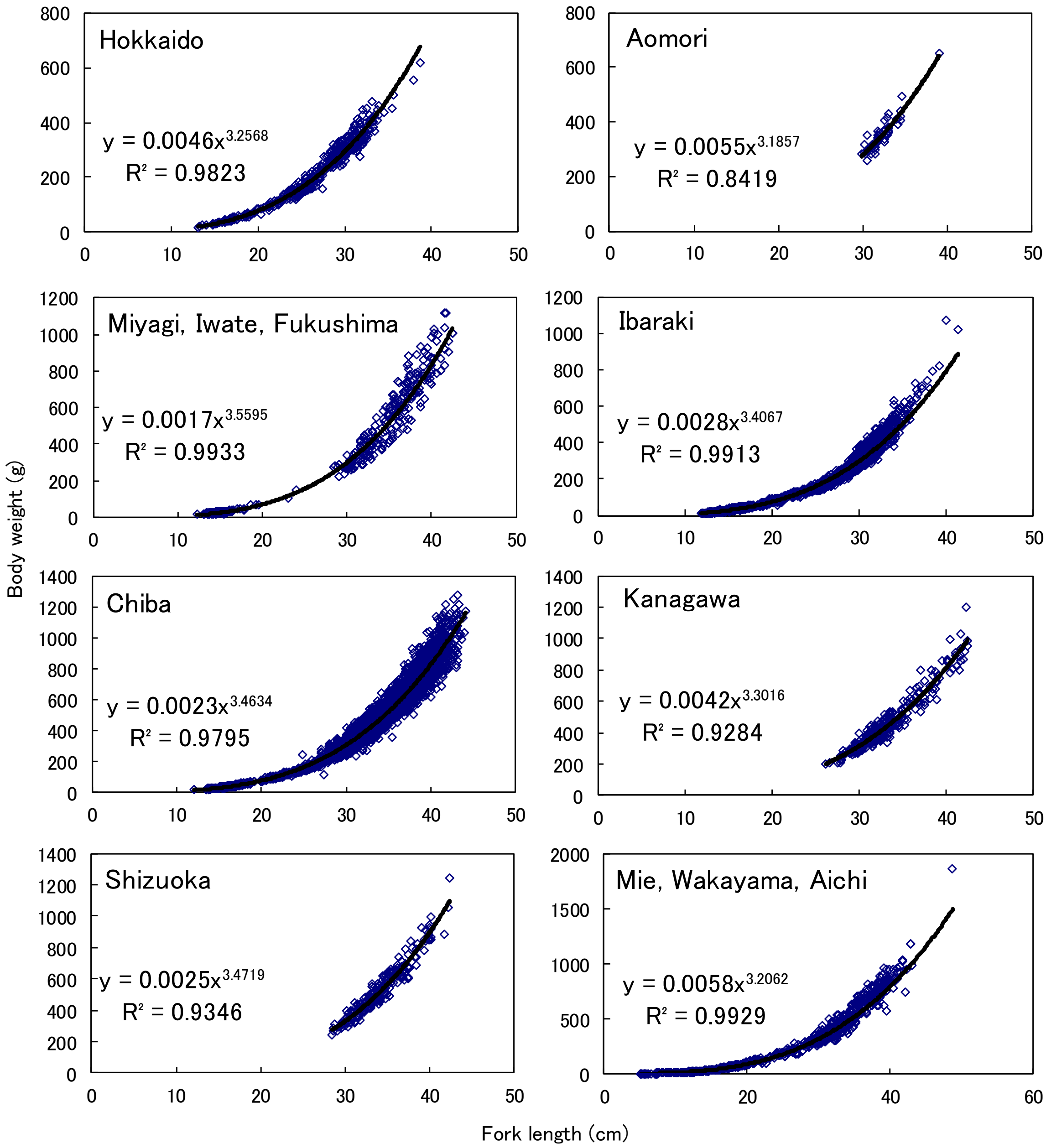
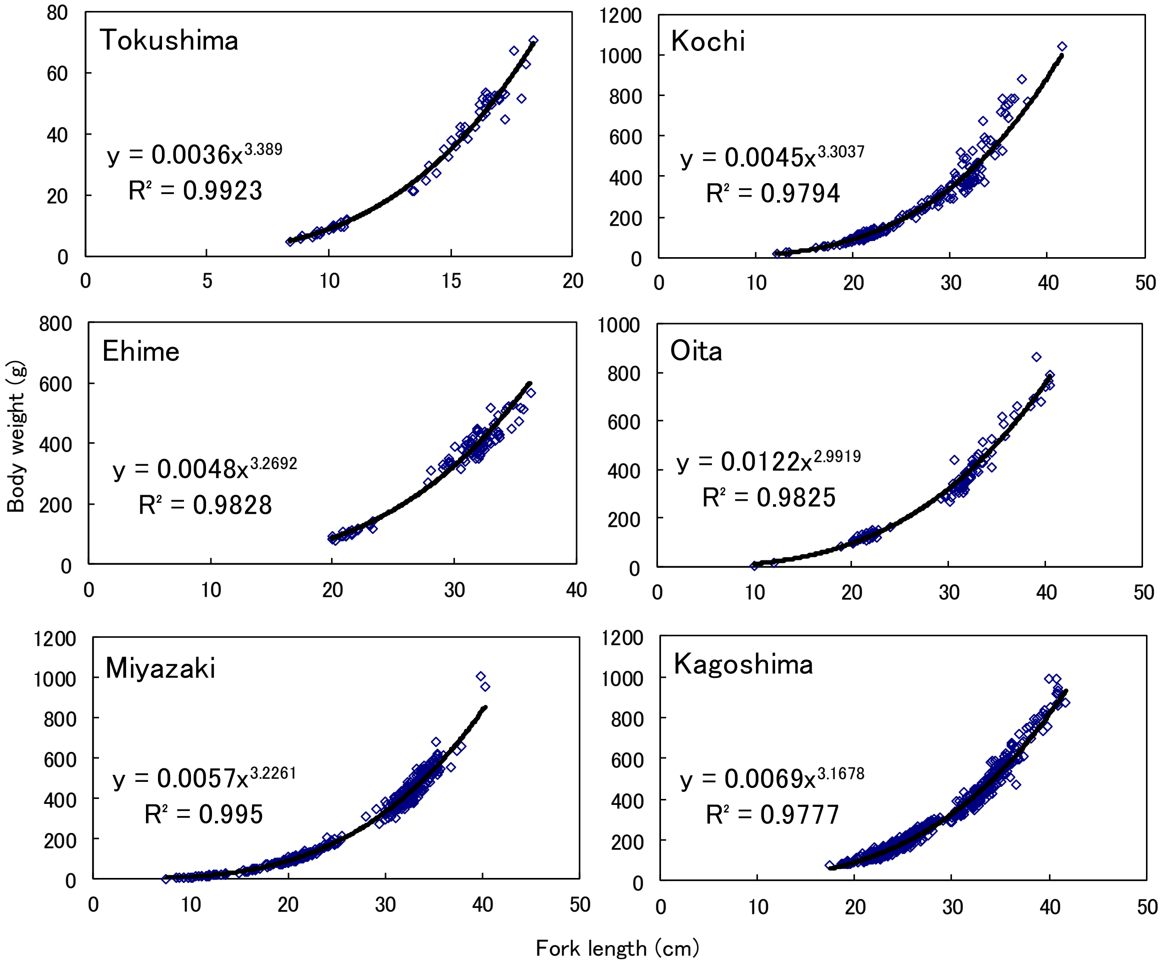


Fig 3 Example of the length-weight relationship of chub mackerel caught in 2018 from prefectures along the Pacific coast of Japan.



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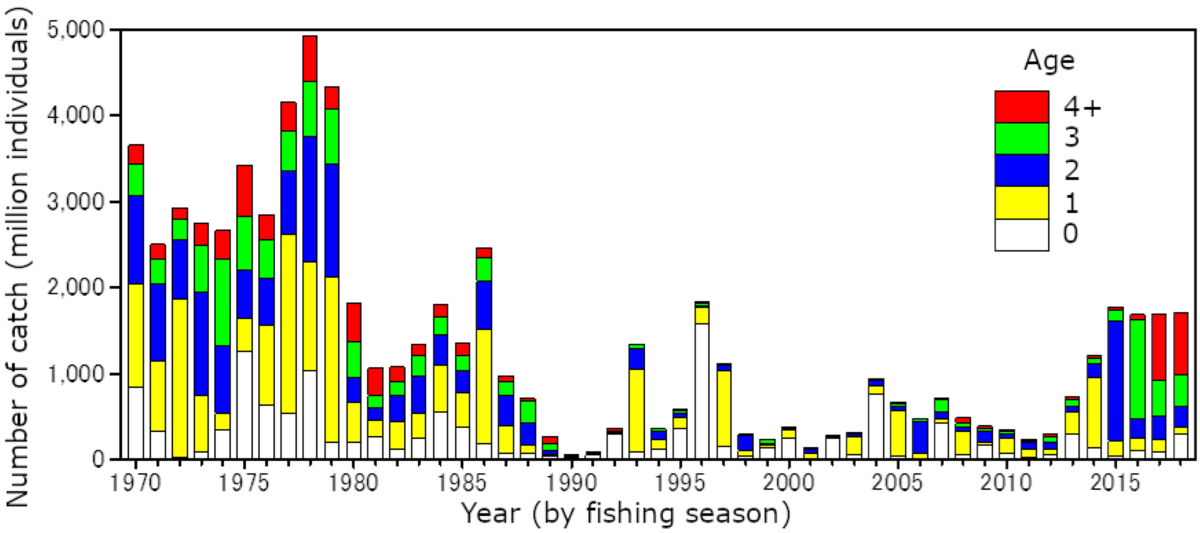

Fig 4. Time series of number of catch at age composition of chub mackerel in the Pacific coast of Japan from 1970 to 2018.

Table 1. Example of data collection of length frequency data. Number represents the count of length frequency data obtained from each prefecture in 2019. Prefecture with * represents that estimated age-length key is reported instead of length frequency data.

Prefecture	Gear type					
	Purse seine	Set net	Dip net	Fishing	Trawl	Sum
Hokkaido	153	349				502
Aomori	281	701				982
Iwate		7143			100	7243
Miyagi	1568	3621			18075	23264
Fukushima	395					395
Ibaraki	780	360				1140
Chiba	3860	422	2668	28		6978
Kanagawa		1054	1416			2470
Shizuoka*						0
Aichi	23					23
Mie	8722	3358				12080
Wakayama	1705					1705
Tokushima		35				35
Kochi	459	444		63		966
Ehime	337					337
Oita	584					584
Miyazaki	1808	617				2425
Kagoshima	3920		73			3993
Sum	24595	18104	4157	91	18175	65122

Table 2. Example of data collection of weight of chub mackerel. Number on the table represents number of fish measured in weight from each prefecture in 2019. Prefecture with * represents the length-weight relationship from the adjoining prefecture is used.

Prefecture	Number of fish measured in weight
Hokkaido	351
Aomori	1248
Iwate	240
Miyagi	849
Fukushima	395
Ibaraki	1083
Chiba	4339
Kanagawa	515
Shizuoka	590
Aichi *	0
Mie	1104
Wakayama *	0
Tokushima *	30
Kochi	344
Ehime	199
Oita	390
Miyazaki	1396
Kagoshima	655
Sum	13728

Table 3. Example of age-length key used for the stock assessment in Japan. Age-length keys of chub mackerel for eastern and southwestern part of Pacific coast of Japan developed by the measurement data obtained in 2019 are shown.

Northeastern

Age	FL (cm)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	sum
Jan - Mar																												
0																												0
1		4	1	3	1					3																		12
2									2	14	10	12	15	6	2													61
3							1	2	10	11	19	18	39	18	16	6	3		1									144
4									2	6	12	32	48	39	38	15	13	6	4	1								216
5											5	23	45	53	30	21	14	12	5	10	2	3	2	1				226
6											3	8	13	20	20	15	10	4	6	5	7	6	3		2			122
7+																		1	1	1			2					5
sum		4	1	3	1	0	1	2	14	34	49	93	160	136	106	57	40	23	17	17	9	9	7	1	2	0	0	786
Apr - Jun																												
0																												0
1		8	5	1		1																						15
2					1	2	4	2	2	2	3	2	1	1														20
3							1	2	4	4	6	15	18	10	11	2	1											74
4										1	2	8	22	18	12	18	9	2	1									93
5											2	9	12	19	16	15	12	6	6	2	8	1						108
6												5	9	16	25	14	7	3	1	2	3	5	3					93
7+																1	11	8	7	10	5	4	6	6	3		1	62
sum		8	5	1	1	3	5	4	6	7	13	39	62	64	64	50	40	19	15	14	16	10	9	6	3	0	1	465
Jul - Sep																												
0		1																										1
1		5	4	14	13	13	3																					52
2			3	5	20	17	12	7	5	3	2	1																75
3						1		4	5	3	3	7	7	3	1													34
4											1		1	2	4	2	5	1	2					1				19
5													1	1	4	6	6	4	3		4	1	2	1	1			34
6														1	2	4	1	3	5		1	2			1			20
7+																							2	1		1		4
sum		6	7	19	33	31	15	11	10	6	6	8	9	7	11	12	12	8	10	0	5	3	4	3	2	1	0	239
Oct - Dec																												
0		2	14	4	5	3	1																					29
1			3	9	34	16	26	14	4																			106
2				1	1	2	9	5	2	3	5	9	13	9	5													64
3								1	2	1	5	4	13	11	9	10												56
4											1	2	11	12	13	7	6	1										53
5													4	6	15	10	7	1	2			1						46
6											1		3	6	12	19	5	4	1	1		1		1				54
7+																1	3	3	3	3	2	2	1					18
sum		2	17	14	40	21	36	20	8	4	12	15	44	44	54	47	21	9	6	4	2	4	1	1	0	0	0	426

Table 3 continued.

Southeastern

Age	FL (cm)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	sum
Jan - Mar																												
0																												0
1		1	8	5	9	13	9	12	21	2	1																	81
2						1		1	3	2	3	2	1	1	3	1	1											19
3									4	2	8	12	15	19	10	7	4		1									82
4									1	1	2	10	15	34	28	24	18	10	1	2	1	1						148
5											1	20	24	38	27	26	20	16	9	7	5	2	1					196
6										2	2	4	31	40	29	14	12	8	5	9	10	5	6		1	1		179
7+													1	3	7	3	2	1	2	1	8	12	8	2	1	1	2	54
sum		1	8	5	9	14	9	13	29	9	17	48	87	135	104	75	57	35	18	19	24	20	15	2	2	2	2	759
Apr - Jun																												
0				1																								1
1				6	8	9	7	9	11	9	4		1															64
2					3	1	7	2	1		1	3	3	1	1													23
3						2	7	4	3	1	2	9	8	10	6	9												61
4										1	2	6	7	17	25	16	6	3	1									84
5												7	15	25	28	24	17	11	4	3	2							136
6												6	16	37	24	12	22	7	3	4	1	1		1				134
7+												1	6	6	6	6	8		1	1	1							36
sum		0	0	7	11	12	21	15	15	11	9	32	56	96	90	67	53	21	9	8	4	1	0	1	0	0	0	539
Jul - Sep																												
0		5	3	1																								9
1					1	3	14	14	6	3																		41
2							2	1		1			1															5
3																												0
4																												0
5																												0
6																												0
7+																												0
sum		5	3	1	1	3	16	15	6	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55
Oct - Dec																												
0		5	2	1																								8
1									2	6	10	2																20
2										1	2	14	15	9	4													45
3												1	3	6	4	6	2											22
4															1	1	1	2										5
5																	1											1
6																			1									1
7+																												0
sum		5	2	1	0	0	0	0	2	7	12	17	18	15	9	7	4	2	1	0	0	0	0	0	0	0	0	102

Table 4. Year-specific weight at age from 1970 to 2019 used for stock assessment as an example.

	Age						
Year	0	1	2	3	4	5	6+
1970	76	188	288	404	532	655	731
1971	64	203	385	551	811	1066	1242
1972	78	226	339	459	592	737	843
1973	101	235	286	354	443	611	908
1974	71	236	330	390	484	699	946
1975	45	183	332	429	484	567	768
1976	76	154	290	453	530	683	917
1977	90	186	305	450	563	668	847
1978	97	261	308	397	515	601	893
1979	70	219	317	431	536	648	738
1980	62	164	332	448	544	675	954
1981	107	211	322	439	628	732	1067
1982	113	233	276	439	583	681	758
1983	77	200	307	402	475	576	645
1984	120	223	362	547	656	768	993
1985	82	241	376	489	741	855	943
1986	98	199	281	407	572	755	947
1987	86	244	336	446	644	838	1112
1988	168	255	341	440	654	886	1066
1989	207	325	426	537	599	814	1034
1990	170	365	582	661	828	954	1101
1991	169	305	488	585	654	790	957
1992	143	288	424	529	749	990	1114
1993	143	284	368	430	705	943	1115
1994	146	294	476	578	661	896	1116
1995	106	406	474	626	809	908	973
1996	118	260	451	545	633	743	819
1997	152	287	428	535	642	699	840
1998	165	325	446	523	787	879	970
1999	169	308	515	606	803	950	1099
2000	158	366	421	517	593	895	1031
2001	137	350	440	599	626	689	1078
2002	113	354	455	576	643	780	1126
2003	124	236	374	530	756	788	1078
2004	132	280	569	742	835	1011	1087
2005	118	316	477	578	787	1002	1089
2006	136	362	528	631	726	1013	1122
2007	121	314	469	537	683	745	921
2008	138	312	385	589	672	806	995
2009	120	377	503	557	599	694	838
2010	126	351	490	606	729	796	940
2011	181	393	488	614	701	842	909
2012	156	373	480	550	627	751	868
2013	123	314	489	612	672	747	886
2014	105	194	410	574	693	656	793
2015	94	199	238	436	637	624	761
2016	81	199	256	305	540	629	697
2017	69	216	296	328	349	529	724
2018	68	205	260	349	399	416	668
2019	100	169	258	313	333	379	466

Table 5. Maturity at age of chub mackerels for different stock status as an example.

		Age						
Stock level	Year	0	1	2	3	4	5	6+
Very high	2016-2019	0	0	0	0.3	1	1	1
High	1970-1975, 2015	0	0	0.2	0.8	1	1	1
Medium	1976-1986	0	0	0.3	0.9	1	1	1
Low	2005-2014	0	0	0.5	1	1	1	1
Very low	2000-2004	0	0.05	0.8	1	1	1	1