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Spatial distribution and biomass estimate of Chilean jack mackerel off South central Chile 2023

Republic of Chile

Spatial distribution and biomass estimate of Chilean jack mackerel off South-central Chile based on acoustic records from fishing vessels, year 2023

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Abstract

Spatial distribution, mean density and biomass estimates obtained from acoustic data recorded by 5 vessels of the Chilean jack mackerel (CJM) fishing fleet in their usual fishing operations during 2023 are presented and compared with previous years. The abundance calculation was made for 2019, 2020, 2021, 2022 and 2023 based on a completely random sampling design and applying geostatistical method. Acoustic data were obtained with eco-integration systems that allow digital recording of the information during the entire trip of each vessel from the harbour to the fishing grounds and back.

Results show a reduction in the spatial distribution of CJM observed between 2018 and 2020, then begin a slight increase in the latitudinal distribution in 2021 and 2022, to finally present a new latitudinal contraction in 2023 where CJM exhibited a particular positioning. In January, distributed between 35° to 36.5° S. However, by February, a noticeable shift occurred as CJM extended to the south, specifically between 38° and 38.5° S. This transition coincided with a gradual increase in its density in the southern area and the decrease in availability at the northern sector of its distribution area.

Since January to April of 2023, the average density of CJM was stable, presenting its maximum values in March and February, respectively. It is observed that January shows the highest density compared to previous years. In April of 2023, the CJM abundance and biomass estimated were lower than in 2022, with an abundance of 1.328 million of individuals and a biomass of 1,210,359 tons (CV= 17.95%), which represents a decrease of 11.82% and 20.75% in abundance and biomass, respectively. The decrease in the CJM abundance and biomass can be explained because the spatial distribution area of CJM during 2023 was lower too. Considering the size structure of CJM since 2019 to 2023, it is observed that CJM shows an increase in the time towards larger specimens, which has had consequently the sustained decrease in the abundance in the last five years.

Finally, a comparison was made between results obtained by the CJM annual hydroacoustic evaluation cruise (systematic sampling) in the south-central zone of Chile from 2017 to 2022 and the hydroacoustic evaluation carried out with data recorded by fishing vessels (random sampling) for the same years in the same zone. Results show a remarkable coincidence using both types of sampling.

Introduction

Chilean jack mackerel (*Trachurus murphyi*) is a transboundary species that has a wide geographic distribution in the South Pacific, from the Galapagos Islands to the southern region of Chile, in oceanic and coastal waters (Serra, 1991). In international waters it is distributed in large schools up to 160°W, mainly between 33°S and 48°S (Gretchina, 1992).

Its migration is mainly related to their spawning and feeding behaviour, with an annual cycle involving offshore migration in spring to spawn in oceanic waters returning to the coastal areas of Chile and Peru in summer-autumn related to the availability of food at the coast (Quiñones *et al*., 1997; Miranda *et al*., 1998). During autumn and winter, CJM aggregate in compact schools providing high availability mostly for the fishing fleet off the Chilean coast, particularly in the central-south zone of Chile (Serra, 1991; Arancibia *et al*., 1995a, b).

Traditionally, most acoustic research cruises aimed to estimate CJM abundance in the south-central zone of Chile have been executed on scientific vessels. Currently, a direct evaluation scientific cruise is carried out every two years to quantify the CJM stock (usually in June), within the framework of National Research Funding. Despite the existence of this study, it is still unknown to what fraction of the population it is estimated and there are considerations about the time window in which surveys are carried out. Also, this resource could change their structure of sizes and density of its main fishing grounds.

The need to obtain direct information by identifying and quantifying acoustic targets, together with the collection of biological and environmental information, requires specialized systems which are available on board of some fishing vessels and therefore, can be used to obtain a greater volume of information to strengthen current research tools, improving the predictability of the evaluation model, especially with the incorporation of independent indicators obtained from the fishing activity of the fleet. Consequently, the need to implement the acoustic evaluation method with vessels of the regional fleet to quantify the available CJM biomass and its variations throughout the year or during the fishing season is strongly recognized and supports this study. The objective of this contribution is estimating the levels of CJM abundance and biomass available in the south-central zone of Chile through acoustic information obtained from opportunity vessels of the CJM fishing fleet. The estimation of the available biomass is essential for the design and elaboration of independent indices of annual change of the biomass of the resource that allows introducing them as auxiliary indices of the stock assessment of CJM (Sepúlveda *et al*., 2004).

Material and Methods

Equipment and working platforms

The acoustic information was obtained from fishing trips made by 5 fishing vessels of the national fleet during 2023, all equipped with echosounders that allow recording information (Table 1). Some of the echosounders were previously calibrated following the recommendations of their manufacturer.

To compare the CJM abundance results obtained by the Instituto de Fomento Pesquero (IFOP) through systematic sampling, only data obtained by scientific echo sounders (model EK60) during June and July were used to estimate CJM abundance by random sampling, except the year 2023. This year we include data from April because still we are processing the data from June and July, we hope to update the information soon with the results of the analyses for the months of June and July.

Table 1. Vessels and equipment used to record acoustic information.

Vessel name	Manufacturer	Model	Frequency (kHz)
PAM Cazador	SIMRAD	EK60	38 and 120
PAM Don Manuel	SIMRAD	EK60	38 and 120
PAM Don Edmundo	SIMRAD	EK60	38 and 120
PAM Ventisquero	SIMRAD	ES80	38 and 120
PAM Don Julio	SIMRAD	EK60	38

Acoustic information analysis and abundance estimation

The acoustic information was processed using the Echoview echogram analysis software (v. 9.0). Acoustic data were filtered to eliminate all sources of noise. The concept of noise should be understood as any acoustic signal, whether biological, mechanical, and/or electrical interference that is not part of our interest or represents false measurements (i.e., double bottom echoes and transducer resonance). The analysed information was eco-integrated into Basic Sampling Units (UBMs) of 1 nautical mile (nm), obtaining the NASC (Nautical Area Scattering Coefficient) value for each cell and region, which was used to determine abundance and spatial distribution of CJM. The estimation was made based on a completely random sampling design through the geostatistical method. To obtain the estimates, ordinary kriging was used, four variogram models were evaluated: matern, spherical, exponential and Gaussian (Cressie, 1993), being adjusted to the experimental variogram data minimizing the sum according to the weighted least squares procedure (Cressie, 1993), a cross-validation was also carried out (Deutsch & Journel, 1998) of the parameters considered in the adjusted theoretical variogram and the parameters to be used in the interpolation by kriging (i.e. parameters of the theoretical variogram, search radius, maximum number of pairs to use in interpolation). The parameters of the theoretical variogram and the kriging selected after cross-validation were used to calculate the optimal weights to be assigned to each sampling point and to estimate the density using:

$$z^* = \sum_{i=1}^{N} \lambda_i z(x_i)$$

Where *N* is the number of samples, *i* is the weighting attributed to the sample *xi*, y:

$$\sum \lambda_i = 1$$

The N weights i were calculated to ensure that the estimator is unbiased, and that the estimation variance is minimal (Journel & Huijbregts, 1978; Petitgas, 1993).

The estimate of the mean density Z(V)* of CJM, was obtained by averaging the local estimates calculated in each of the grid nodes that covers the domain area of the estimation polygon (AV).

$$Z(V)^* = \frac{1}{N} \sum_i Z^*(x_i)$$

Total abundance (At) is the result of the product between the mean density obtained by kriging within the polygon and the area of the polygon (AV), divided by sigma (σ).

$$A_t = \frac{Z(V)^* \; A_V}{\sigma}$$

where,

$$\sigma = 4\pi \bullet 10^{(TS/10)}$$

and the Target Strenght, $TS = 20 \; \mathrm{Log}_{10} \; (\mathrm{LH}) - 68.91$ (Lillo *et al*, 1996)

where LH is the Fork Length of sampled fish.

Total biomass (B_t) is the result of the product between total abundance and mean CJM weight, obtained from sampling.

$$B_t = A_t \cdot \overline{W}$$

The results obtained were used to update the historical series of estimates of relative abundance that INPESCA has been estimated since 2004.

<u>Sampling and determination of biological indicators</u>

In the vessels, operational information was recorded corresponding to each catch, where logbooks were completed with operational data associated with CJM structural indicators. The operational information recorded during each fishing set is detailed below:

a. - Position of the catch (Latitude and Longitude).

b. - Date and time of the catch.

c. - Catch obtained.

Biological-specific sampling and length frequencies of fishing sets were considered to generate base information to account for:

a. - The size composition of the catches,

b. - The mean weights to size,

The information obtained was used to estimate abundance and CJM biomass.

Results

Spatial distribution of Chilean Jack mackerel from 2018 to 2023

Figure 1 shows the spatial distribution of CJM schools along with the navigation track followed by fishing vessels during fishing trips between 2018 and 2023. In 2018, a larger westward and southward distribution area was observed, finding high-density aggregations southern 42.5°S. Since 2019, a contraction towards the coast of the CJM schools was observed, with highest densities between 37° and 39.2° S, finding lower concentration focus northern 34° S almost reaching the EEZ limit (78° W). Between 2020 and 2023, CJM schools were found exclusively near the coast, especially in 2020, with acoustic detections distributed in a small area, between 35.5° and 37°S, the year 2021 begins a slight latitudinal expansion of the distribution area of the CJM schools, confirming this expansion in the year 2022, where aggregations of CJM were detected near the coast between 33° and 40° south latitude. In particular, the expansion of the distribution area towards the north in 2022 was due to the search for smaller CJM. Finally, unlike previous two years, during the year 2023 (between January and April) the CJM had a spatial contraction, concentrating high densities close to the coast in a small area, between 34.5° S and 38.5° S.

In summary, a reduction in the westward distribution of CJM was observed between 2018 and 2023, locating near the coast, then a slight increase in its latitudinal distribution began between 2021 and 2022, to finally present a new latitudinal contraction during 2023.

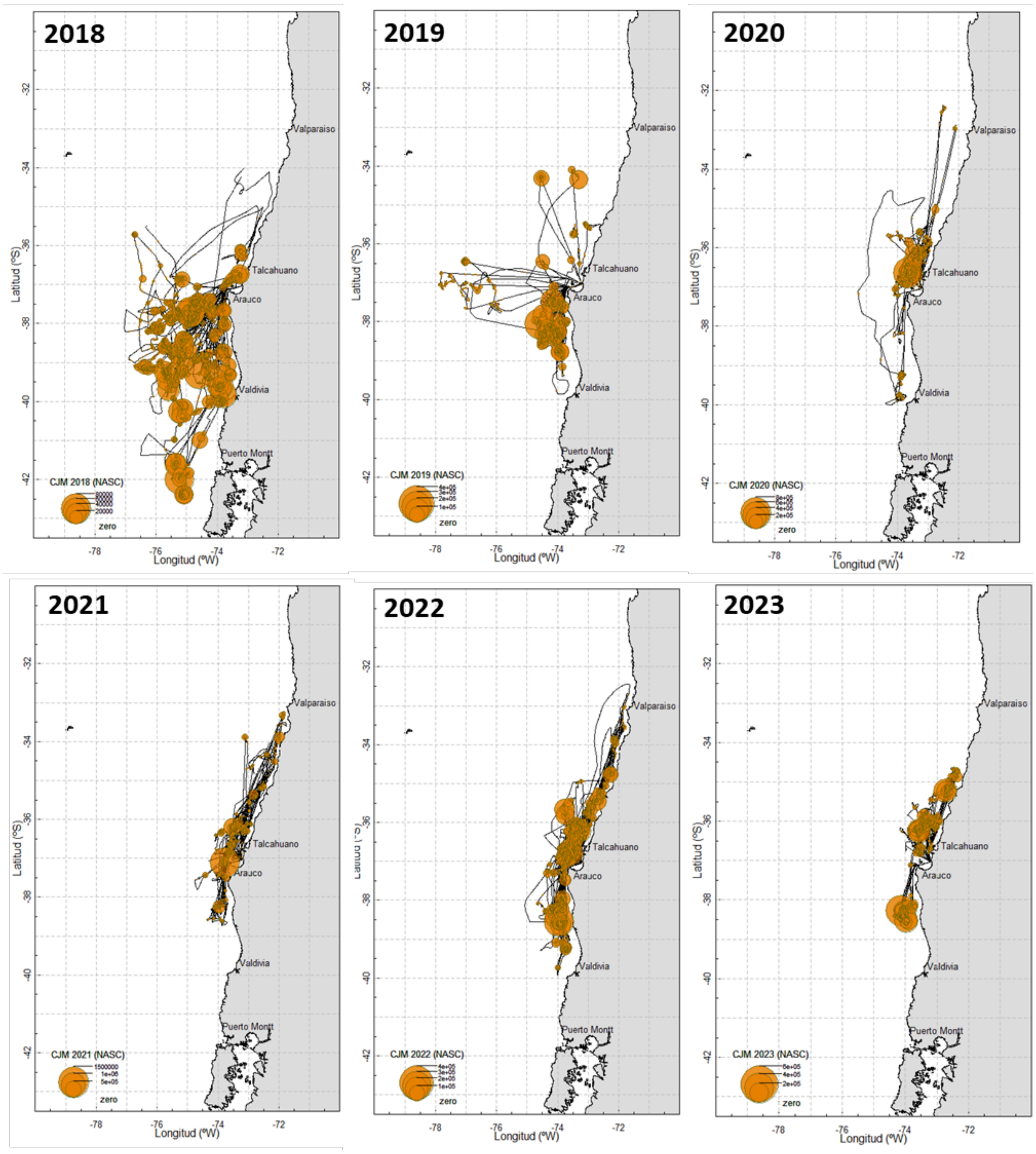

Figure 1. Spatial distribution of Chilean jack mackerel acoustic density between 2018 and 2023.

In the year 2023, the CJM exhibited a particular positioning. In January, it occupied the geographical range of 35° to 36.5° S. However, by February, a noticeable shift occurred as the CJM's presence extended to the south, specifically between 38° and 38.5° S. This transition coincided with a gradual surge in its density, occurring in tandem with a decrease in availability within the northern sector of its distribution area. (Figure 2).

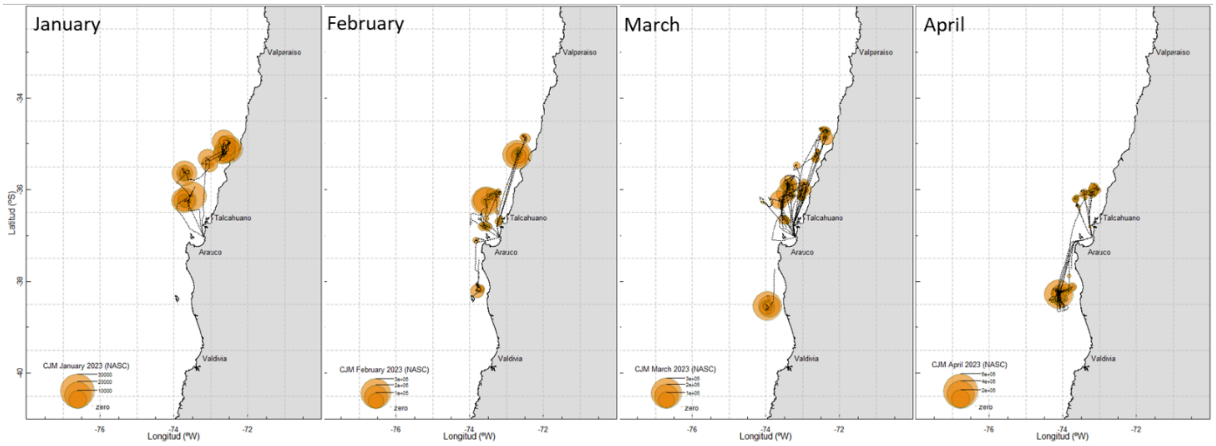

Figure 2. Spatial distribution of Chilean jack mackerel acoustic density by month during 2023.

Variations in Chilean jack mackerel mean density between 2021 and 2023

The results of comparison of mean density by month between 2021 and 2023 (Figure 3), show a higher density in 2022 only during January and March (March shows the highest value of the analysed time-series). It should be considered that the monthly mean density of 2021 during the CJM fishing season was the highest since 2018 (Alegría and Sepúlveda, 2021). In addition, a significant decrease of mean density was observed during April-July, which coincides with the extent of the distributional area towards the south in April-May, and towards the north in June (looking for smaller fish) (Figure 2), to finally present a slight increase in density in July due to the detection of dense CJM schools southward 38°S. In the first four months of 2023 the average density of CJM was stable, presenting its maximum values in March and February, respectively. It is observed that January shows the highest density compared to previous years (Figure 2).

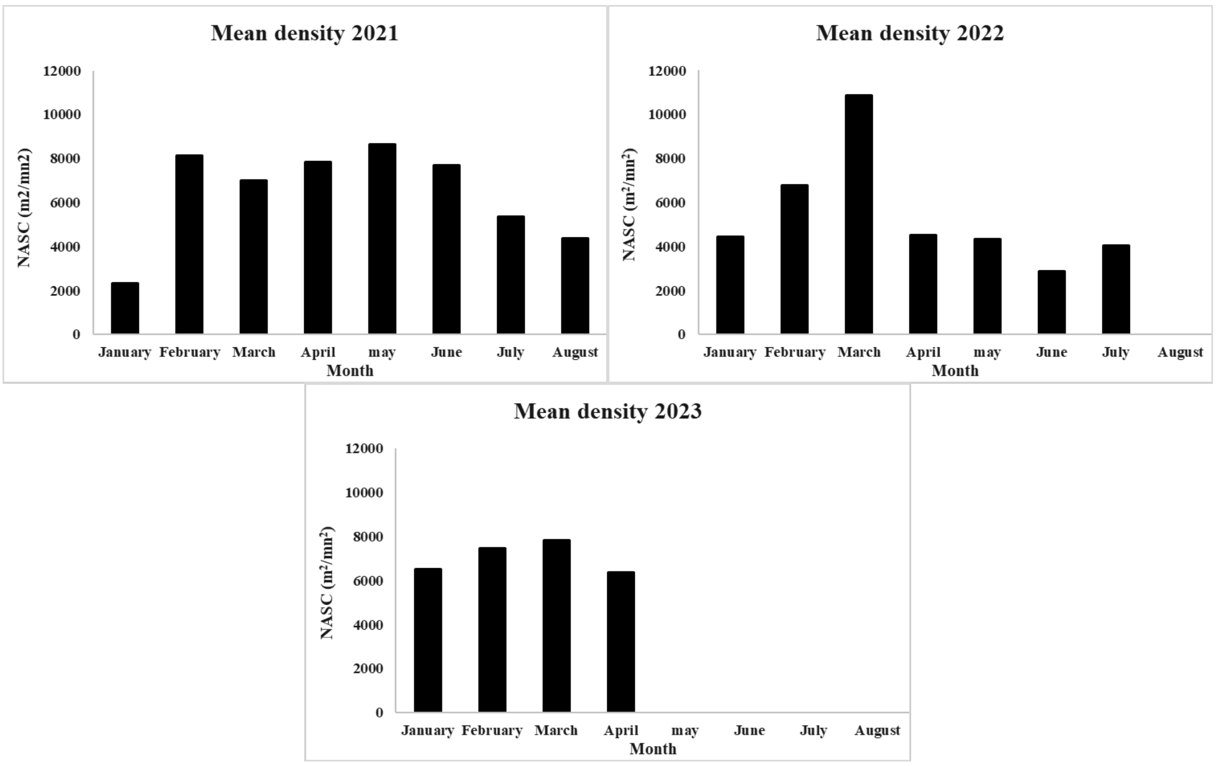

Figure 3. Mean monthly acoustic density during the years 2021 and 2023.

Interannual variability in Chilean jack mackerel density (2004 and 2023)

Table 2 shows the results of the CJM density calculations (ton/nm2) during the month of May of each year since 2004 to 2023, considering positive mean density (only values greater than zero) and the mean density including zeros. In addition, the results of the total sum of the densities, the number of days with register and the number of schools detected for each year in the month of May are presented, except the last year where the month analysed was April. In this regard, the highest mean densities occurred in the years 2005, 2009, 2018, 2019, 2021, 2022 and 2023, where the value of average density was the highest in the series; however, when comparing the CJM mean density of with the number of detected schools, it was observed that during the years 2005, 2009, 2018 and 2022 a large number of schools were detected, while in 2021 and 2023 despite the amount of schools was lower, they registered the highest mean density of the series, which can be associated with the detection of larger and denser schools during those year. The same pattern was observed when comparing the positive mean densities (greater than zero) principally during the years 2012, 2013 and 2014, where few schools were detected but with high values of positive density, which would indicate that during those years the vessels were traveling greater distances to find commercial fishing areas and therefore there was a greater number of UBMs without schools. In 2020, a lower mean density was observed compared to 2019, however represents the third highest in the last 10 years. In addition, when comparing the number of schools detected, an increased number of schools in 2020 was observed. In 2021 an increase in the mean density of CJM was observed, achieving the highest value of the series with 337.55 (ton/nm2), the mean density considering only positive values presented a value of 2,696.40 (ton/nm2) positioning itself as the second highest value of the series, finally, it can be inferred that the schools registered in 2021 presented high densities because the sum of the densities turned out to be the highest value of the series (1,356,291 ton/nm2) considering a low number of schools of CJM. The increase in CJM densities in 2021 can be explained by a high density in schools in a small area of distribution. In 2022, a lower mean density was obtained than in 2021, but the third highest in the series. Regarding the total density, the second highest value of the series was obtained, below the year 2021. In the year 2022, values of mean density, total density, and mean density only positive, was lower than the previous year, but they are still high within the series, the decrease in that values has to do with an increase in the distribution area of CJM schools compared to 2021, due to the search for smaller CJM, which produced an increase in the UBMs without positive data. The year 2023 had a higher mean density positive, mean density and total density compared with 2022. In addition, the 2023 is the year with highest mean density, the second place in total density and a low number of schools, that could represent larger and denser schools and a great quantity of CJM in a small area.

Table 2. Annual Chilean jack mackerel density from 2004 to 2023.

Year	Analysed days	Number of Schools	Mean Density positive (t/mn^2)	Mean Density (t/mn^2)	Total Density (t/mn^2)
2004	6	99	366.3	66.8	36,264
2005	15	1,098	462.4	122.8	507,722
2009	25	1,350	462.9	119.4	623,553
2010	24	1,474	70.0	38.2	103,182
2011	22	42	792.1	15.6	33,270
2012	18	62	1,714.6	71.6	106,308
2013	7	21	1,045.9	70.3	106,248
2014	7	24	1,526.7	42.4	36,642
2015	25	592	190.8	27.8	112,943
2016	35	655	341.0	42.1	223,365
2017	7	123	439.9	72.4	54,103
2018	19	2,871	168.1	106.1	482,744
2019	15	173	3,046.9	268.5	527,110
2020	15	520	594.8	93.4	309,274
2021	23	503	2,696.4	337.6	1,356,291
2022	22	1011	1,008.2	249.2	851,579
2023	20	593	2,126.4	531.4	1,260,948

Chilean Jack mackerel abundance from 2019 to 2023

To estimate abundance and biomass of CJM, the data obtained between June and July to each year were used, except the last year where the data used were from April.

Results of the estimations of abundance and biomass of CJM by length bins since 2019 to 2023 are presented in table 3 and table 4. Total abundance calculations for 2019 were about 2,664 million individuals, representing a total biomass of 1,081,072 tons in the south-central zone of Chile with a coefficient of variation of 12.29%. In 2020 the abundance calculation was 2,476 million individuals, representing a biomass of 1,424,990 tons of CJM, with a coefficient of variation of 15.08%. In 2021 the abundance was 1,857 million individuals, which represents a biomass of 1,295,440 tons, the coefficient of variation calculated for 2021 was 15.23%. For 2022, the estimated abundance of CJM was 1,506 million individuals, which represents a biomass of 1,527,320 tons, with a calculated CV of 8.26%. The biomass of CJM estimated in 2022 had an increase of 18% compared to 2021, however the abundance had a decrease of 23.33%. In April of 2023, the CJM abundance and biomass estimated was lower than 2022, with an abundance of 1,328 million of CJM and a biomass of 1,210,359 tons (CV= 17.95%), which represents a decrease in 11.82% and 20.75% in abundance and biomass respectively, this is mainly because in 2023 there was an increase in the size of CJM, finding specimens larger than 33 cm, with a mode centred on 45 cm.

Considering the size structure of CJM since 2019 to 2023, it is observed that the estimation of abundance (in millions of individuals) has had an increase in the time towards larger specimens (Figure 4), which has had consequently the sustained decrease in the abundance in the last five years (Figure 6).

The abundance obtained in 2019 was higher than calculated in 2020 due to a contribution of individuals between 29 and 31 cm FL (Figures 4 and 6). However, a wider range of sizes was observed in 2020 between 24 and 65 cm FL, with fish between 35 and 41 cm FL dominating with a contribution from larger fish. In 2021, a bimodal condition was observed in the size structure of CJM, whose peaks were located at 30 and 37 cm FL, with a large contribution of specimens above 40 cm FL. In 2022, CJM specimens between 33 and 59 cm FL were captured, with a mode of 42 cm FL. Finally, during 2023 the length frequency of CJM had a range between 26 and 59 cm FL, with a mode of 45 cm FL, showing a significant increase in the size of CJM specimens (Figures 4 and 5) compared to previous years. That increase in the size of the fish is directly related to the results of the biomass estimated during 2019, 2020, 2021 and 2022, since there has been an increase in the biomass of CJM obtained during those years (Figure 5 and 6), which indicates that in the months of June and July fewer but larger fish were detected, allowing an increase in the final estimate of biomass for the year 2022, however, in the year 2023 the biomass estimated was lower than 2022 (Figure 6), that can be explained because the spatial distribution area of CJM was lower too. In addition, in 2023 we used data from April, maybe the CJM behaviour in June/July is different.

Table 3. Results of the CJM abundance estimated between 2019 and 2023.

Fork Length (cm)	Abundance 2019 (Millions of CJM)	Abundance 2020 (Millions of CJM)	Abundance 2021 (Millions of CJM)	Abundance 2022 (Millions of CJM)	Abundance 2023 (Millions of CJM)
24	-	1	-	-	-
25	-	29	-	-	-
26	-	108	0	-	2
27	3	118	1	-	2
28	72	79	26	-	5
29	297	47	88	-	7
30	456	51	163	-	6
31	367	47	105	-	5
32	247	125	69	-	14
33	240	145	62	2	33
34	262	191	74	2	37
35	226	208	93	12	45
36	153	186	113	16	52
37	91	184	147	22	67
38	74	187	136	40	70
39	50	156	126	50	65
40	60	147	128	110	75
41	20	101	91	140	66
42	10	78	81	223	89
43	13	72	65	186	104
44	6	44	63	176	121
45	6	44	53	160	127
46	-	32	37	90	81
47	4	27	38	78	68
48	4	21	21	63	50
49	-	12	17	53	38
50	-	13	16	35	42
51	1	5	9	13	12
52	-	5	10	10	14
53	-	3	7	9	12
54	1	2	6	7	8
55	1	1	4	7	3
56	-	1	3	-	3
57	-	2	0	0	2
58	-	1	1	0	1
59	-	0	0	0	1

60	-	0	1	-	-
61	-	0	-	-	-
62	-	0	-	-	-
63	-	-	-	-	-
64	-	-	-	-	-
65	-	0	0	-	-
Total	**2,665**	**2,476**	**1,857**	**1,506**	**1,328**

Table 4. Results of the CJM abundance estimated between 2019 and 2023.

Fork Length (cm)	Biomass 2019 (Ton)	Biomass 2020 (Ton)	Biomass 2021 (Ton)	Biomass 2022 (Ton)	Biomass 2023 (Ton)
24	-	147	-	-	-
25	-	5,061	-	-	-
26	-	21,197	24	-	341
27	581	25,923	292	-	383
28	16,669	19,518	6,676	-	1,282
29	77,662	12,887	25,190	-	1,901
30	132,930	15,390	52,076	-	1,932
31	119,217	15,681	37,127	-	1,649
32	88,792	46,409	27,103	-	5,447
33	95,347	59,368	26,757	861	13,718
34	114,895	85,414	35,032	1,130	16,816
35	108,696	101,773	48,336	6,164	22,148
36	80,647	99,187	63,628	8,945	27,942
37	52,573	106,949	90,502	13,597	38,992
38	46,749	117,644	91,174	26,306	44,798
39	34,552	106,250	91,329	35,836	44,774
40	44,811	108,572	100,983	84,703	55,918
41	15,809	80,422	77,056	116,346	53,019
42	8,549	67,073	74,597	198,641	76,299
43	11,865	66,666	64,504	178,487	96,347
44	5,683	43,988	66,621	181,036	120,434
45	6,113	46,698	60,258	175,320	134,946
46	-	36,110	45,731	105,554	92,207
47	5,281	32,426	49,682	97,155	81,964
48	5,655	26,789	29,936	84,392	64,341
49	-	17,201	25,205	75,104	51,761
50	-	19,510	24,831	53,403	60,827
51	2,296	8,550	15,071	21,015	19,335
52	-	8,623	18,515	16,877	22,373
53	-	5,293	13,914	16,441	20,741
54	2,765	3,568	11,476	13,611	15,680
55	2,935	1,887	8,435	13,583	6,631
56	-	1,995	6,038	-	6,420
57	-	3,912	833	890	3,695
58	-	3,174	3,224	937	3,246
59	-	669	1,237	987	2,051
60	-	705	1,630	-	-
61	-	741	-	-	-
62	-	1,169	-	-	-
63	-	-	-	-	-
64	-	-	-	-	-
65	-	451	419	-	-
Total	**1,081,072**	**1,424,990**	**1,295,440**	**1,527,320**	**1,210,359**

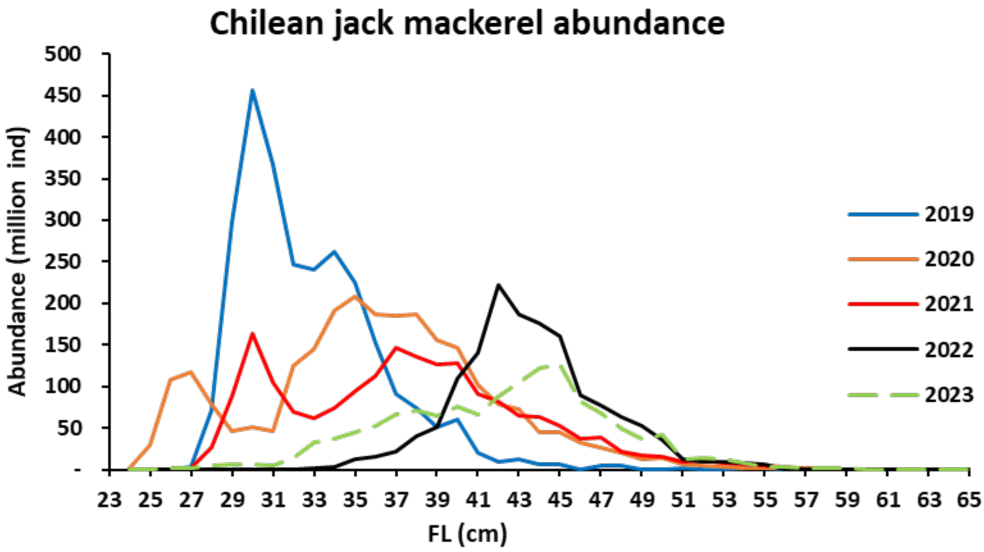

Figure 4. CJM abundance distribution by length (2019 – 2023).

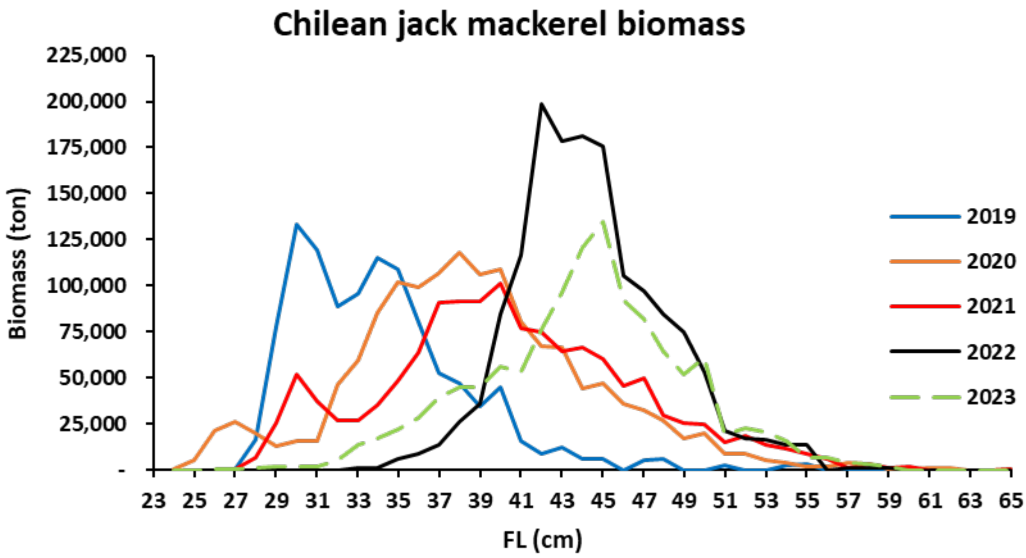

Figure 5. CJM Biomass distribution by length (2019 - 2023).

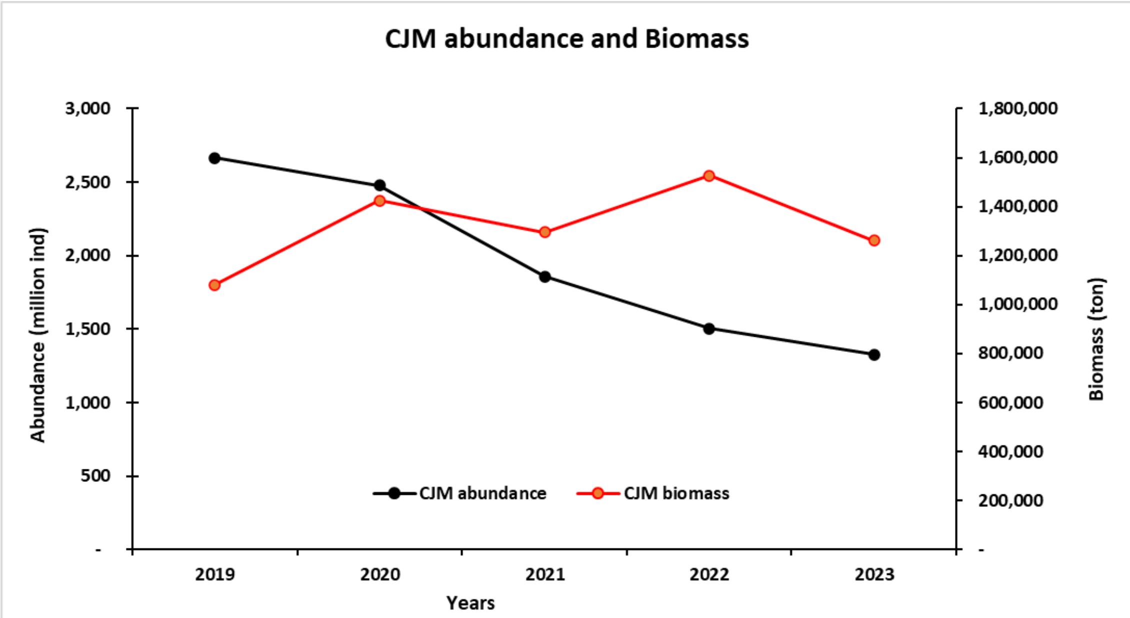

Figure 6. Comparison between CJM abundance and biomass estimates from 2019 to 2023.

Figure 7 shows the comparison between the results obtained by the CJM hydroacoustic evaluation cruise (systematic sampling) carried out by the Instituto de Fomento Pesquero (IFOP) between 2017 and 2022 (Córdova *et al*., 2022), with the results obtained by the hydroacoustic evaluation carried out with acoustic data recorded by fishing vessels (random sampling) for the same years.

To make the results obtained in the present study by means of random sampling comparable with those obtained in the formal evaluation of CJM in the central-southern zone of Chile by means of systematic sampling, only the data recorded by the vessels of the fleet were analysed. in the months of June and July, the time of year in which the CJM hydroacoustic evaluation cruise is usually carried out in Chile.

The results show that, in the years in which there are estimates using both types of sampling, there is a notable closeness in the results obtained (Figure 7).

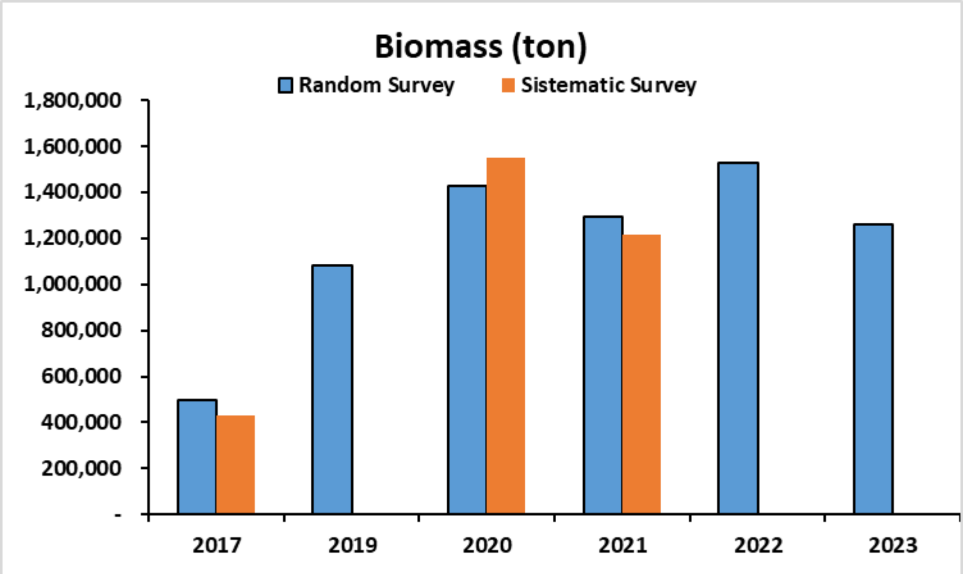

Figure 7. Comparison between CJM biomass obtained by random survey with systematic survey since 2017 to 2023 (In 2023 the month was april). (Font systematic sampling: Córdova *et al.*, 2022).

Concluding remarks

- A reduction in the westward distribution of CJM was observed between 2018 and 2023, locating near the coast, then a slight increase in its latitudinal distribution began between 2021 and 2022, to finally present a new latitudinal contraction during 2023.

- Between January and April of 2023, the average density of CJM was stable, presenting its maximum values in March and February, respectively. It is observed that January shows the highest density compared to previous years

- In April of 2023, the CJM abundance and biomass estimated was lower than 2022, with an abundance of 1,328 million of CJM and a biomass of 1,210,359 tons (CV= 17.95%), which represents a decrease in 11.82% and 20.75% in abundance and biomass, respectively, but its online with the values estimated the last years. The decrease in the CJM abundance and biomass can be explained because the spatial distribution area of CJM during 2023 was lower too.

- Considering the size structure of CJM since 2019 to 2023, it is observed that the estimation of abundance (in millions of individuals) has had an increase in the time towards larger specimens, which has had consequently the sustained decrease in the abundance in the last five years.

- A comparison was made between the results obtained by the CJM hydroacoustic evaluation cruise (systematic sampling) from 2017 to 2023 and the hydroacoustic evaluation carried out with acoustic data recorded by fishing vessels (random sampling) for the same years. The results show that, in the years in which there are estimates using both types of sampling, there is a notable closeness in the results obtained.

- Finally, to continue with the series, we expect to update the information of this working paper adding results for the months of June and July 2023.

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