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Preferred habitat of Jack mackerel and chub mackerel in Peruvian National waters

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Observations on the preferred habitat of Jack mackerel (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*) in Peruvian national waters during 2018 and early 2019

by

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SUMMARY

The environmental factors affecting the distribution and abundance of Jack mackerel (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*) and their habitat characterization in the northern part of the Peruvian Current system, off Perú, is examined through the analyses of catch, effort, acoustic records and other data collected during 2018 and 2019 by the Peruvian industrial fleet that fishes for these and other pelagic species in Peruvian national waters. In so doing, this paper builds on important past contributions made by the Peruvian delegation towards the better understanding of the effects of changing environmental conditions on the Jack mackerel stock and fisheries and its habitat preferences off Peru. Sea thermal conditions in Peruvian waters during 2018 and 2019 have favored an increased Jack mackerel availability. Especially off southern Peru, associated with the presence of a front of warmer oceanic and colder coastal waters. Chub mackerel had a more northern ward distribution, associated with the presence of equatorial and subtropical waters. Summer (January-March) 2019 environmental conditions off Peru were characterized by relatively high positive thermal anomalies in the south, but with a narrow coastal strip of colder conditions. The proximity of the thermal front between the warmer oceanic waters and the colder coastal waters provided favorable environmental conditions for Jack mackerel and chub mackerel to concentrate in larger shoals, which made them more easily available to the fishing fleet. These 'favorable' environmental conditions dissipated with the onset of autumn (April-June), which partly explains the dispersion of these species during the acoustic stock assessment survey carried out by the IMARPE between May and June 2019. Fortnightly catch and fish distribution data for 2018-2019 from the industrial pelagic fleet was used to estimate monthly abundance indices of Jack mackerel and chub mackerel using a geostatistical method. The highest monthly abundance index of Jack mackerel was estimated for February 2019, with 537 495 tons, and the lowest for September 2018, with only 201 tons. The highest monthly abundance index of chub mackerel was estimated for February 2019, with 609 161 tons and the lowest was for January 2019 with 5 699 tons. Various aspects of the distribution and habitat of selected species was analyzed using acoustic data from the same fishing fleet and two main groupings were observed. One where anchoveta (*Engraulis ringens*) and red squat lobster (*Pleuroncodes monodon*) predominated, and the other one where the predominating species were Jack mackerel, chub mackerel and Panama lightfish (*Vinciguerria lucetia*). The highest abundance of Jack mackerel was observed where the acoustic density of macrozooplankton was also high, suggesting that monitoring changes in the relative abundance of macrozooplankton might contribute to explain the changes of availability of Jack mackerel in Peruvian waters. Interactions between top predators and the fishing vessels were also examined. The need to take a broad spatial and ontogenetic approach at the appropriate resolution when looking into the definition and characterization of the habitat of the Jack mackerel and other species is emphasized.

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1. Introduction and background

Detailed catch, effort, acoustic records and other data collected during 2018 and 2019 by the Peruvian industrial fleet that fishes for anchoveta (*Engraulis ringens*), Jack mackerel (*Trachurus murphyi*), chub mackerel (*Scomber japonicus*) and other pelagic species in Peruvian national waters was analyzed during a workshop organized by the Sociedad Nacional de Pesquería (SNP) and the Instituto Humboldt de Investigación Marina y Acuícola (IHMA), with the participation of the Instituto del Mar del Perú (IMARPE) and other invited participants, in Lima, Perú, 1-5 October 2019.

One of the objectives of this workshop was to contribute to this report, being presented by the Peruvian delegation to the 7th meeting of the Scientific Committee (SC07) for analyses and discussions to be held as part of the activities of the Habitat Monitoring Working Group (HMWG) of the Scientific Committee. The full report of this IHMA-SNP Workshop on the Chilean Jack mackerel and other species' habitat of the Peruvian Current in the Humboldt System, held in Lima, Peru, 1-5 July 2019, is attached herewith as Annex 1. A summary of the main findings and results of this Workshop, together with other relevant notes and observations are provided below as Peru's contribution to the forthcoming discussions at the SC07 and its HMWG, on the habitat characterization of Jack mackerel and other fishery resources, and on the environmental factors affecting their distribution and abundance. And, in doing so, this paper builds on important past contributions made by the Peruvian delegation towards the better understanding of the effects of changing environmental conditions on the Jack mackerel stock and fisheries and its habitat preferences off Peru, and on the wider SE Pacific.

In this respect, it is noted that the Peruvian delegation has made important contributions to the consideration of the various fisheries-related environmental aspects and the preferred habitat of Jack mackerel since the first meetings of the South Pacific Regional Fisheries Management Organization (SPRFMO) Scientific Committee (SC). Through the observations and results of the investigations reported by IMARPE-PRODUCE (2012, 2012a, 2013, 2014), Espino (2013), Flores *et al*. (2013), Dioses (2013), Segura and Aliaga (2013), Gerlotto & Dioses (2013), among others, important steps were taken to characterize the Jack mackerel habitat in the northern part of the Peruvian Current system, off Peru, and to highlight some of its similarities and differences with the Jack mackerel habitat, or habitats, further south, off central-southern Chile; and to explain that partly, the depletion of the Jack mackerel stock or stocks and the collapse of the Jack mackerel fisheries in the South Pacific was associated with a downward regime change. This led to the incorporation as of October 2012 (ref.: Annex SWG-03 of SPRFMO-SWG 2012) of the concept of regime change in the Joint Jack Mackerel (JJM) model being used for the assessment of the Jack mackerel stocks by the SPRFMO Science Working Group first, in 2102, and by the SC since 2013.

The initial Peru contributions to the work of the SC on matters related to environmental-fishery resources interactions and the Jack mackerel habitat characterization were mainly made through IMARPE's work and inputs. Although it is noteworthy that in recent years the private sector, through the work of the SNP and the IHMA lately, has also been providing valuable inputs, data and information aimed at fostering further SC research work in relation to the environmental-fishery resources interactions and the habitat characterization of Jack mackerel, including Peru's active role within the SC's HMWG.

In fact, relevant progress has been made in Peru during the last two years regarding the use of commercial fishing vessels as platforms of opportunity for marine habitat and other environment-fishery related studies (Melvin *et al.* 2016). Selected pelagic industrial fishing vessels that regularly fish for anchoveta, Jack mackerel and chub mackerel have the capability and are recording acoustic data with digitally calibrated echosounders (120 kHz ES60, ES70 and ES80). The data collected by these vessels is routinely analyzed by the fishing companies to be then shared with the SNP and IMARPE during workshops, usually carried out soon after the end of every main fishing season. The data that is extracted mainly consists of NASC values by fish schools, NASC values from macrozooplankton layers, and profiles of the depth of the minimum oxygen zone (MOZ), that are recorded along all tracks during fishing trips.

Peruvian scientific vessels and a selected number of commercial fishing vessels are already equipped with echosounders of the new generation (scientific EK80 and digital ES80). But the use of broad band systems is challenging, not only due to the need to use high performance computers, but also the need to acquire newer and expanded analytic capabilities, both in IMARPE and the industry. To tackle some of these needs, a first cooperative workshop between IMARPE and industry with support from the University of Aberdeen was organized recently, to develop classification algorithms combining the use of Echoview and R, and some interesting results have been achieved, such as the automated creation of virtual echograms for the red squat lobster, which is a key component of the coastal system of the Peruvian current.

It is noted that an increasing number of Peruvian commercial fishing vessels are collecting data on interactions with top predators, such as seabirds and marine mammals, which could contribute to characterize the habitat of Jack mackerel and other pelagic species also from the high trophic level perspective. Some promising preliminary results have been obtained so far, regarding the possible links between the distribution of certain species of fish and the above mentioned top predators.

Some papers have been published during the last few years regarding the habitat characterization of different species in the Peruvian Current, including analyses of interdecadal changes in the distribution patterns of some species, such as anchoveta and red squat lobster (Santivanez *et al.* 2017; Castillo *et al.* 2018). There was also a paper on how the fisheries drive the population level of certain top predators' species (Barbraud *et al.* 2017; Gerlotto 2017). Also, a paper was published on the methods being used for calibrating echosounders and removing noise and interferences from echograms (Vasquez and Gutierrez 2017). There are other ongoing research activities, such as on the relationship of ocean vorticity with the Jack mackerel distribution and abundance, and on the acoustic measurement of prey and its relationship to MOZ during fishing trips. Also, an update of IMARPE's protocol for acoustic analyses is being prepared for its use by the fishing companies.

Also, IMARPE and industry representatives participated in the ICES MesoMeth Workshop (ICES 2019) carried out in Galway, Ireland, 27-28 April 2019. And a report on mesopelagic population studies made around the world will soon be published by ICES, and a section of this report devoted to the progresses made in Peru. Several Peruvian colleagues are co-authors of this ICES report.

The use of fishers' acoustic data as a source of environmental information has been considered in the SPRFMO since 2009, after an initiative leaded by the International Council for the Exploration of the Sea (ICES) and its Fisheries Acoustics Science and Technology

Working Group (WGFAST). In 2014 a Task Group on "Fishing vessels as scientific platforms" was created by SPRFMO for a duration of 3 years. It produced reports on calibration procedures for acoustic equipment aboard fishing vessels and on Jack mackerel standard target strength (TS) measurements. The Task Group recommended creation a Working Group to deal with the theme of Habitat Monitoring, and during a workshop held in Chile in May 2018, a specific proposal was prepared and presented to the SC, which then proceed to the creation of the Habitat Monitoring Working Group (HMWG) in September 2018, assigning the habitat of the Jack mackerel as its first study case.

2. On the habitat characterization

An apparently subtle, but very important aspect to consider in these habitat characterization exercises, has to do with the level of detail and spatial and temporal resolution of the observations and data on the environmental, population, biological and fishery characteristics and parameters that are used. Which could determine whether the characterization of a single general habitat (possibly with broader tolerance boundaries and more flexible food, space and climatic preferences) is made for the whole Jack mackerel in the south Pacific. Or whether the analyzes are done in more detail and at higher resolution, with which we would be better placed to identify possible local adaptations and distinguish differences in food, space and climatic preferences, and thus determine if there are two or more habitats, possibly with subtle differences and little or no connectivity between them, corresponding to two or more Jack mackerel sub-units in different parts of the south Pacific (e.g., in the northern part of Peru, central-southern Peru, northern Chile, south-central Chile, in the middle of the south Pacific along the Jack mackerel belt, in the western south Pacific, etc.). This also has to be analyzed from the perspective of the different life-history stages of the Jack mackerel, as there would be a need to characterize the most suitable environmental conditions and habitat characteristics for the survival and somatic development of Jack mackerel from the egg phase, through its larval and juvenile stages, to the size of recruitment and adult stages. And it is not to be assumed that the ideal food supply and environmental conditions, or habitat characteristics for each of these important stages of the life-history of Jack mackerel would be same in all the possible distribution area. On the contrary, should look into these life-history stages to determine the extent of possible habitat differences. Particularly at the early life-history stages since it is at these very early life-history stages where reproduction success and recruitment strength are determined.

It is evident that the results of these observations could condition the way in which the hypotheses about the identity and population structure of the Jack mackerel, the connectivity between possible population sub-units, and their seasonal to decadal variability are postulated. Also conditioning the way in which research activities directed to test or discard these hypotheses would be carried out and presented. It is therefore clear that ensuring that this broader view is taken is of utmost importance when looking into the definition and characterization of the habitat of the Jack mackerel and other species to be considered by the SC HMWG.

Large pelagic fish stocks may suffer huge changes in abundance. For instance, the biomass of Jack Mackerel *Trachurus murphyi* (JM) of the south Pacific varied from around 30 million tons during the 1980s-90s to less than 5 million tons in the late 2000. Moreover, the distribution area may vary in surface and location. Such populations are difficult to monitor. The first abundance estimates for Jack mackerel were achieved by the Soviet fishery in the early 1970s.

Later Peruvian and Chilean acoustic research programs were developed, followed by EU and China. More recently, data bases were enriched by acoustic information from fishing vessels. Still, there is need for more integrative research, and the concept of habitat is one possible solution for monitoring the dynamics of fish populations.

It has been observed that off Peru, the dominant groups of species by volume are the macrozooplankton and mesopelagic fish, mainly Panama lightfish *Vinciguerria lucetia*. These are important prey items for later life-history stages, including pre-recruits, recruits and adult stages of both the Jack mackerel and the chub mackerel, as well for other species including the jumbo flying squid *Dosidicus gigas*. Is then important to monitor the abundance and distribution of targeted species, and also their habitat, through its various components. This information is now more easily available due to more frequent use of fishing vessels as platforms of opportunity collecting quality data on the target species (and life-history stages) and their interactions with top predators. To ensure a more integrated approach in the efforts to define the habitats of these target species, efforts should be made to also look into the habitat characterization of earlier life-history stages as well, probably through a strengthened cooperation with scientific institutions.

3. Changes in environmental conditions and their relation to Jack mackerel and chub mackerel habitats

Jack mackerel availability in Peruvian waters was low during 2017. Fishing surveys reported a high dispersion and a predominance of fish under the legal-size limit. While during recent years chub mackerel has been more available due to the advection of oceanic waters. There was an increasing trend in the observed abundance of both species during 2018, until March 2019, when the Jack mackerel annual quota set up by the Ministerio de la Producción (PRODUCE) was completed. During this time-period both species were found in denser aggregations along the thermal fronts over the outer continental shelf and slope. And, in general, it appears that the sea thermal conditions observed during 2018 and 2019, which were generally colder than those observed during the last decade have provided the appropriate habitat conditions for Jack mackerel to form denser aggregations, specially off southern Peru, while chub mackerel was distributed to the north, where equatorial and subtropical waters predominated.

Summer of 2017 was characterized by high positive values of sea surface anomalies (SSTA) off northern Peru. During autumn 2017 the positive anomalies covered a large part of the coast, but the conditions quickly changed at the beginning of winter generating thermal anomalies below -3°C. These conditions, with high thermal anomalies do not seem to configure a suitable habitat for Jack mackerel. While, during 2018, the summer and autumn seasons were characterized by low negative SSTA, and slightly high positive values between winter and spring.

Denser concentrations and increased availability of Jack mackerel and chub mackerel were observed during 2018 (mainly during the second part of the year) in concomitance with the moderate SST anomalies observed during 2018, with more chub mackerel in the northern zone, and more Jack mackerel in the south, where it is more frequently observed). The 2019 summer was characterized by relatively high thermal anomalies in the south, but with the presence of a narrow coastal zone with colder conditions. This generated a front between ocean and coastal waters, where denser Jack mackerel and chub mackerel schools were found. These conditions dissipated by autumn 2019, which probably explains the high Jack mackerel and chub mackerel dispersion found during the acoustic stock assessment survey carried out by IMARPE between May and June 2019.

Regarding water masses, during the first months of 2017, there was a strong presence of equatorial waters associated with the development of a coastal El Niño event, which caused intense rainfalls in a vast zone of the country, but especially in the northern part. Such conditions do not configure a suitable habitat for Jack mackerel, but it does for chub mackerel, which has been more available in recent years due to the warmer waters from the north and northwest.

It should also be kept in mind that the seasonality of Jack mackerel and chub mackerel catches is strongly influenced by the timing and duration of the anchovy fishing seasons, given that a large part of the fleet that is authorized to fish for Jack mackerel and chub mackerel is also authorized to fish for anchoveta. And, whenever the anchoveta fishing seasons are extend and overlap with the open fishing season for Jack mackerel and chub mackerel, this part of the fleet usually opts for the anchoveta, reducing its time devoted to the Jack mackerel and chub mackerel fishery.

4. Distribution and abundance of Jack mackerel

Figure 1 shows the distribution of fishing sets made for Jack mackerel between January 2018 and March 2019. The fishing quota issued for Jack mackerel by PRODUCE for the industry during 2019 was 89 thousand tons, and the quota was completed by March. The fishing sets have been classified by geographical regions (8) and by fortnights, with the purpose of calculating the average catch (tons/mn^2), the centers of gravity (latitude, longitude) and inertia (mn^2) in every region/fortnight.

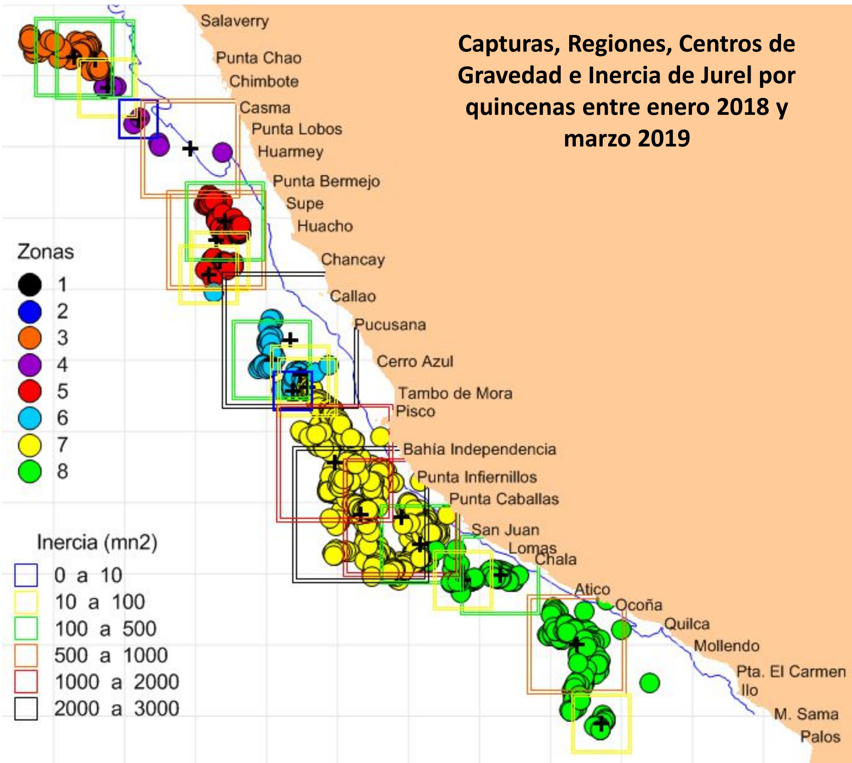

Figure 1.- Distribution of fishing sets for Jack mackerel made between January 2018 and March 2019. The fishing sets have been classified in 8 regions by fortnights. The centers of gravity (indicated by black crosses) and the inertia in every region and fortnight were estimated with the purpose of estimating an abundance index of Jack mackerel. The blue line indicates the contour of the outer border of the continental shelf (at a depth of 182 m)

It has been observed that the fishing sets made for Jack mackerel occurred beyond the outer continental shelf and slope, at 10 to 120 nm distance from the coast, and between latitudes 8°30'S (Salaverry) and 18°20'S (Sama). Total of 1,088 fishing sets have been made, with catches ranging from 5 to 680 tons. The average catch was 105.53 tons, and the total estimated catch of Jack mackerel between January 2018 and March 2019 was 114,602 tons.

Obviating the fortnights where there were no fishing operations, the largest Jack mackerel catches occurred during the first fortnight of March 2019, with 31,204 tons, and the smaller catch was reported during the second fortnight of December 2018, with just 160 tons. The average monthly catch was 8,185 tons.

Using geostatistical methods, the higher abundance index of Jack mackerel was estimated for February 2019 with 537,495 tons, followed by March 2019 with 100,143 tons. The lowest abundance index was estimated for September 2018, with just 201 tons. The ratio between catches and abundance index was 16%, meaning that, on average, the amount fished has been one sixth of the estimated index of the available abundance.

The largest calculated inertia for Jack mackerel, as a proxy of its distribution area in the zones where the fleet operated, was 5,189 mn^2 during March 2019; and the smaller inertia was just 8 mn^2 during August 2018.

5. Distribution and abundance of chub mackerel

Figure 2 shows the distribution of fishing sets made for chub mackerel between January 2018 and March 2019. The fishing quota issued for chub mackerel by PRODUCE during 2019 was 135 thousand tons, and by March 2019 the total catch was 28 thousand tons (20% of the quota), with 107 thousand tons still remaining. As done for Jack mackerel, the fishing sets for

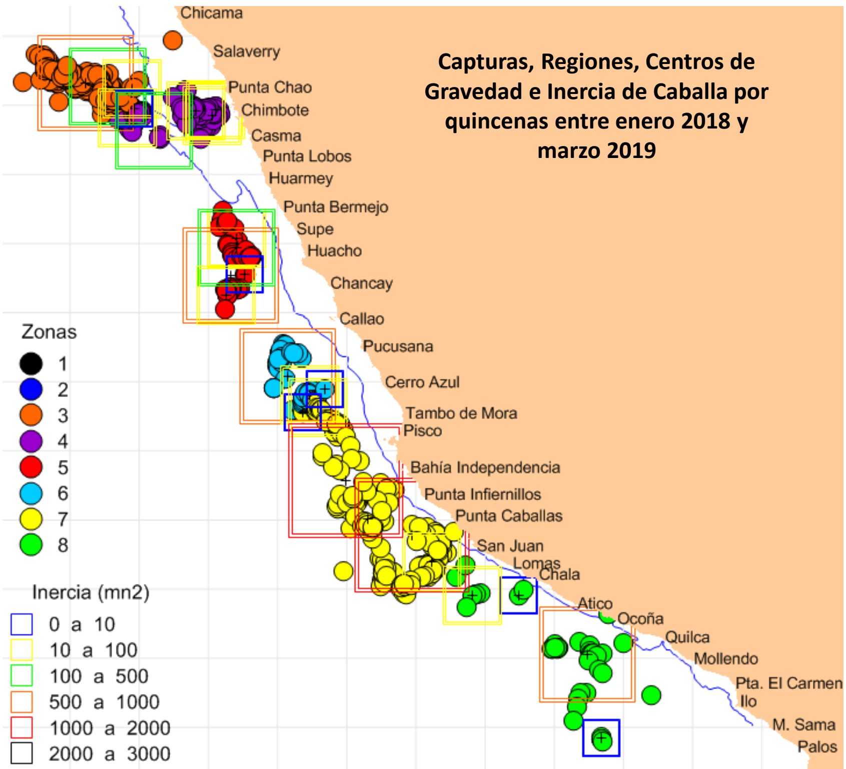

Figure 2.- Distribution of fishing sets for chub mackerel made between January 2018 and March 2019. The fishing sets have been classified in 8 regions by fortnights. The centers of gravity (indicated by black crosses) and the inertia in every region and fortnight were estimated with the purpose of estimating an abundance index of chub mackerel. The blue line indicates the contour of the outer border of the continental shelf (at a depth of 182 m)

chub mackerel have been classified by geographical regions (8) and by fortnights, with the purpose of calculating the average catch (tons/mn^2), the centers of gravity center (latitude, longitude) and inertia (mn^2) in every region/fortnight.

Except for the area off from Chimbote, it has been observed that all the fishing sets made for chub mackerel occurred beyond the outer continental shelf and slope, at 10 to 120 nm distance from the coast, and between latitudes 8°30’S (Salaverry) and 18°20’S (Sama). Until March 2019, the sets made were 718, with caches ranging from 3 to 500 tons. The average catch was 82.19 tons, and the total catch estimated catch of chub mackerel between January 2018 and March 2019 was 58,697 tons.

Obviating the fortnights where there were no fishing operations, the largest chub mackerel catch occurred during the second fortnight of March 2019, with 13,625 tons, and the smaller catch was reported during the first fortnight of February 2018, with 280 tons. The average monthly catch was 6,522 tons.

Using geostatistical methods, the higher abundance index of chub mackerel was estimated for February 2019 with 609,161 tons followed by March 2019 with 101,872 tons. The lowest abundance index was estimated for January 2019, with 5,699 tons. The ratio between catches and abundance index was 14%, meaning that, on average the amount fished has also been one sixth of the estimated index of available abundance.

The largest calculated inertia for chub mackerel, as a proxy of its distribution area in the zones where the fleet operated, was 4,007 mn^2 during March 2019; and the smaller inertia was just 2 mn^2 during August 2018.

6. Species interaction

The Nautical Acoustic Scattering Coefficient (NASC, m^2/mn^2) distribution values have been analyzed using variograms as exploratory tools. The main activity was the study of the potential interactions between the main pelagic stocks in Peruvian waters: jack mackerel, anchoveta, chub mackerel, vinciguerria and red squat lobster (*Pleuroncodes monodon*). The occurrence of Jumbo flying squid was not sufficient to include it in this analysis.

The variograms obtained for the 5 species show particular similarities and affinities; it is the case for Jack mackerel and vinciguerria, whose models for 2019 could be overlapped (Figure 3).

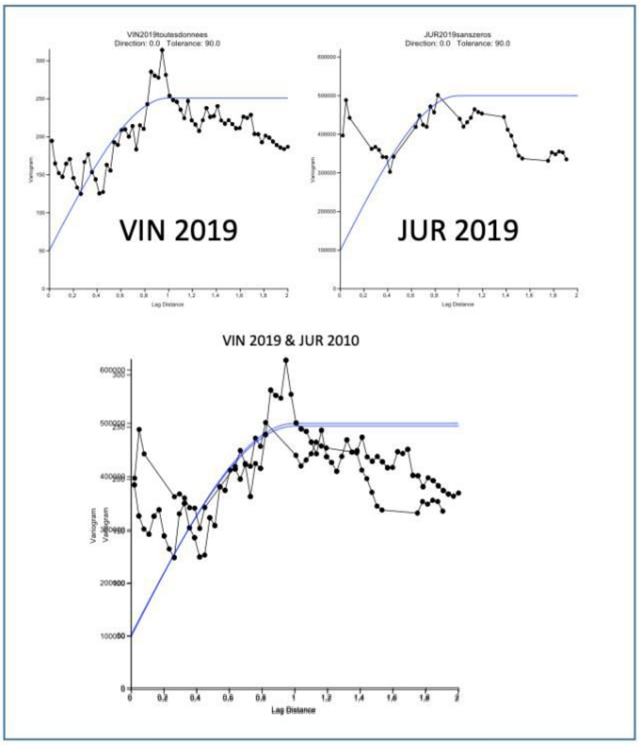

Figure 3.- Comparison of variograms for Jack mackerel 2019 (“JUR 2019”) and vinciguerria 2019 (“VIN 2019”)

Other affinities concern Jack mackerel and chub mackerel between 2018 and 2019; also, anchovy and red squat lobster correspond similarly in 2019 (Figure 4).

The results are limited and preliminary. Nevertheless, it seems that we could already conclude that two main groups exist between these species: the anchoveta-red squat lobster and the Jack mackerel-Chub mackerel-vinciguerria. This is not surprising, as these groups are often encountered in the same water masses. With a larger data base this analysis could be repeated in order to evaluate the level of familiarity between the species and how it could change over time. This conclusion about the affinities of species is speculative, and should require adding other types of data (e.g. oceanography).

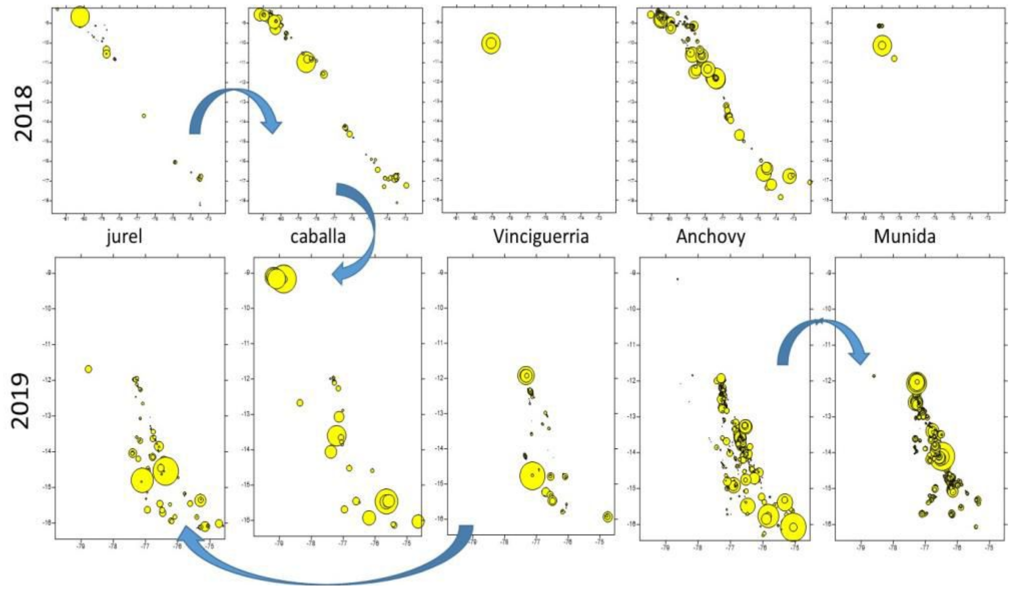

Figure 4.- Distribution of acoustic density in 2018 and 2019 for the 5 main species. The blue arrows show the groups whose variograms present some similarities (jurel=JM; caballa=CM; múnida=red squat lobster).

It was attempted to determine whether the presence of other species, and particularly species directly observable from the fishing vessels (e.g. top predators), might be indicative of Jack mackerel or chub mackerel habitat, either because the species shares a common attraction to certain features of habitat (e.g. physical tolerance range, prey type), and/or the other species are attracted to the fishing operation. If associations between jack mackerel and other species is robust and independent of fishing, it may be possible to create indicators of the likely presence of the fish through observation of surface phenomena.

The majority of sightings were of marine birds; however, when examined at the species level, southern fur seals and dusky dolphin were the most numerous sightings (Figure 5).

Sightings were not spread evenly over calendar time. When the data were examined by season, the vast majority of sightings occurred in the austral summer months (January, February, March), with data from 2018 and 2019 combined (left graph in Figure 6). However, fishing effort was also not evenly distributed. When effort (proxied by miles traveled fleet-

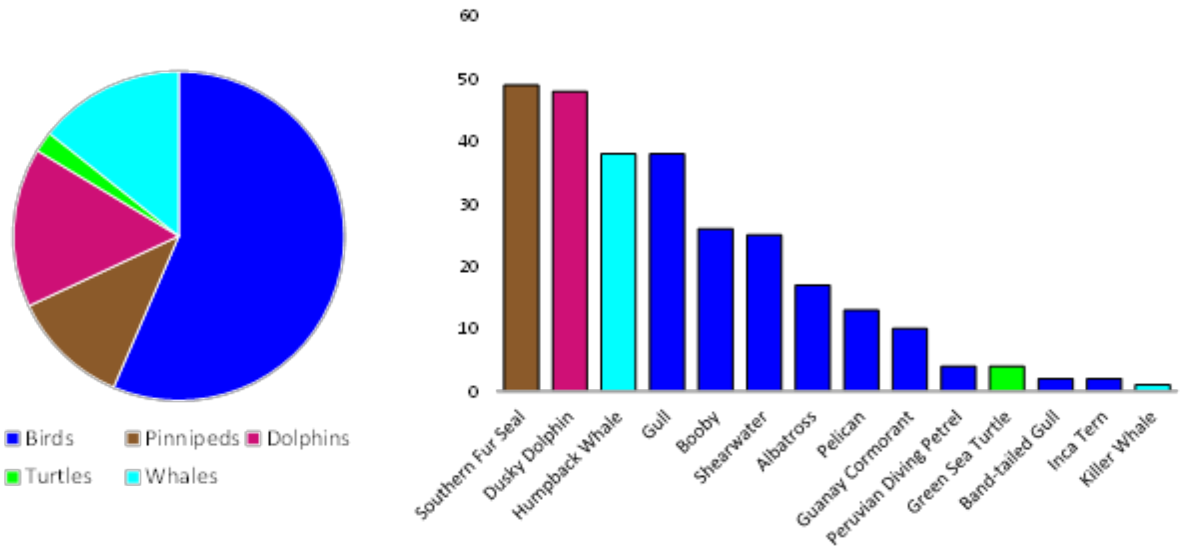

Figure 5.- Sightings of non-fishing species by group of species (left) and by species (right)

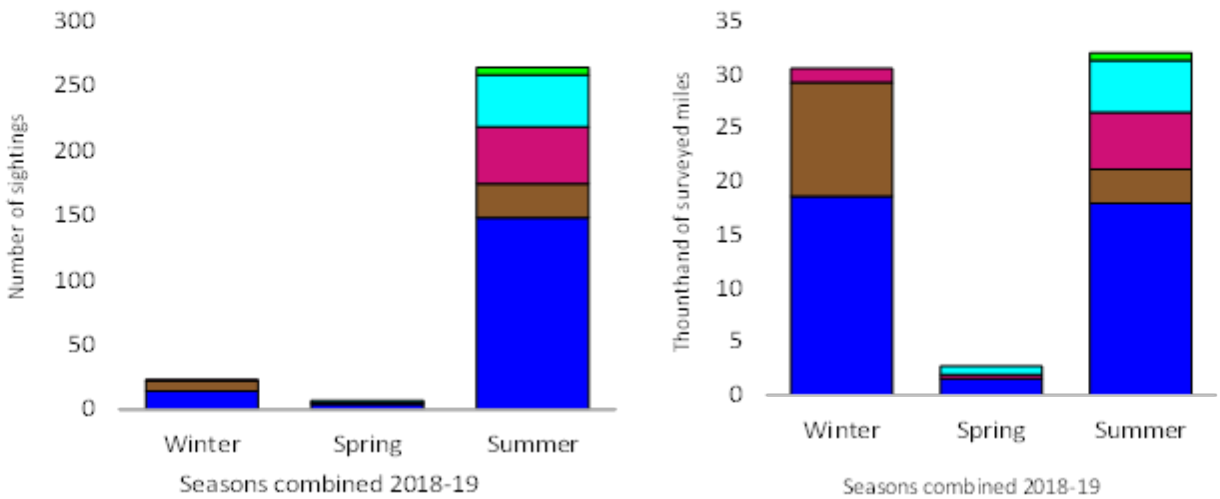

Figure 6.- Number of sightings by seasons (left) and by travelled nautical miles (right)

wide) is accounted for (right graph in figure 6), sightings rate was approximately equal in summer and winter (represented in the dataset only by August).

Other patterns to note include the presence of whales predominantly in the summer, the almost equivalent sightings rate of birds in summer and winter (see right graph in the figure 6 above), and the increased rate of sightings of pinnipeds in the winter versus the summer, with the opposite pattern for dolphin.

Further consideration of birds by species, using those taxa for which there were ten or more sightings (gull, booby, shearwater, albatross, pelican, guanay cormorant) indicated these species could be seen anywhere within the fishery. Collectively, these data do not suggest that, at least within the physical bounds of the Peruvian jack mackerel fishery, these taxa are strongly assorting according to simple habitat characteristics.

7. Conclusions and recommendations

Three key results were detailed during the workshop and are referred to here, followed by additional relevant notes and observations derived from the workshop itself, or from follow-up or parallel analyses. The three key results from the workshop relate to: (1) the evolution of the distribution of Jack mackerel, chub mackerel and other species in the Peruvian Current in the Humboldt System during 2018-2019; (2) the description of new methods and models for the analysis of the available fisheries data on distribution and abundance; and, (3) a definition for the Jack mackerel habitat, or at least of part of it.

Clear differences in the oceanographic conditions and in the spatial distribution of Jack mackerel and chub mackerel were observed in Peruvian waters during the two years, 2018-2019, that were analyzed; and the possible relationship of the observed changes in the distribution of these species with the observed oceanographic conditions were considered and discussed, although no conclusions were reached on the significance and causal mechanism of these interactions, suggesting that more detailed data and in-depth studies are needed, including through retrospective analyzes.

New available methods and models for the analysis of georeferenced information and data on fish distribution, concentration, abundance, etc., and the related environmental conditions are potentially very useful tools, although some methodological and technical improvements may be required in order to fully and effectively benefit from their practical use. The workshop referred to herewith is the first workshop convened in the context of the SPRFMO to look into the Jack mackerel habitat. And therefore, there is no intention to advance here a definition of habitat. Nonetheless, some results obtained shows that the available data could provide inputs for some models and contribute to appropriate definitions of habitat for Jack mackerel and chub mackerel.

Therefore, as discussed during the workshop, it is suggested that further workshops and/or other alternatives aiming at improving knowledge on the habitat should focus on the following aspects:

- Revision of the existing models, in order to reduce the errors and improve their fitness;
- Considering the use of new models that could improve or replace the existing ones;
- Incorporating the routine use of non-conventional information such as on top predators, geostatistics, oceanography, etc.
- Performing retrospective analysis
- Building a wider data base that includes the information gathered during previous years. This will require a special attention to the fishing vessels acoustic data quality and technical improvement, as well as exploring other sources of data of potential interest.

Furthermore, as stated above, it should not be assumed that for Jack mackerel, or for other target species, the habitat characterization would be the same throughout all its range and/or throughout all its life-history stages. Particular attention should be given to the habitat of early life-history stages since it is at these very early stages where reproduction success and recruitment strength are usually determined. Therefore, taking a broader spatial and ontogenetic approach through observations and data at the appropriate resolution is of utmost importance when looking into the definition and characterization of the habitat of the Jack mackerel and other species to be considered by the SC HMWG.

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Annex 1 – Workshop Report

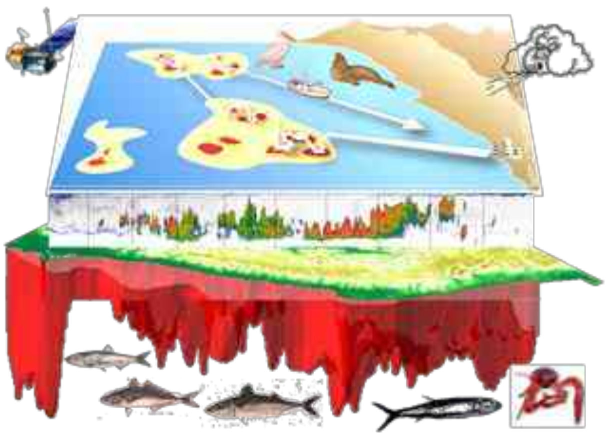
Can also downloaded from the following link: https://drive.google.com/file/d/10fAZ7iYpuk2wNuIv7bFWFsApGtHVF8ga/view?usp=sharing

SOCIEDAD NACIONAL DE PESQUERÍA – COMITÉ DE INVESTIGACIÓNJ CIENTÍFICA
INSTITUTO HUMBOLDT DE INVESTIGACIÓN MARINA Y ACUÍCOLA

Seventh SNP Workshop on the Chilean Jack Mackerel and other species' habitat of the Peruvian Current in the Humboldt System

Lima, Peru, July 1 to 5th 2019

REPORT



INDEX

Abstract

In relation to the environmental conditions, it was observed that the availability of Chilean Jack Mackerel (*Trachurus murphyi*)(CJM) during 2017 was reduced, whilst Chub Mackerel (*Scomber japonicus*)(CM) has been denser during recent years. It is considered that, in general, the colder thermal conditions during the last two years (2018-19) have fostered a larger CJM availability, especially in the southern zone, while CM has had a tendency to be distributed northward these last two years. This is due to the predominant presence of equatorial and subtropical waters there, which are considered to be an optimal habitat for CM.

2019 had a summer characterized by relatively high thermal anomalies in the south, but with a narrow coastal band exhibing normal conditions. It generated a thermal front between oceanic and coastal waters where both CJM and CM were concentrated. These conditions in autumn already had dissipated, which probably explains the relatively high dispersion of these species found during the acoustic survey made by IMARPE (carried out between May and June 2019).

Regarding sizes structures, it was observed that the mode for CJM during 2018 was about 28 cm, with secondary modes in 23, 35 and 43 cm. In 2019 there were observed two main modes: one in 26 cm and other in 34 cm, with a secondary mode in 34 cm. The variation in the main mode is 6 cm from one year to the next (2018-19), which indicates not only the fish growth in size but the inflow of individuals of larger size in the fishing zones.

In the case of CM during 2018 it presented a main mode in 26 cm, with secondary modes in 34 and 38 cm. In 2019 there were observed two main modes in 15 and 33 cm, with a secondary mode in 19 cm. Between 2018 and 2019 there was an increment of 7 cm in the main mode, which represents a size fish growth and the possible inflow of individuals of larger size considering the dominance of oceanic waters in the northern zone during the first months of 2019.

Regarding catches and abundances it was observed during the fishing season of 2018 that the fishing effort at the beginning was set near Chimbote (8°S), prevailing CM catches, to then move far south near Ilo (18°S) and finally taking place in near Huacho and Callao (11-12°S). In 2019 the fishing efforts was different and took place between Pisco and San Juan (14-16°S).

The largest month catch of CJM took place during March 2019 with 31,024 tons; the smaller month catch was reported during December 2018, with 160 tons. The month average catch from January 2018 to April 2019 was 8,185 tons.

The bigger month abundance of CJM was estimated for February 2019, with 537,495 tons, following March 2019 with 100,143 tons. The smaller estimated moth abundance was September 2018, with only 201 tons. The ratio between catch and abundance along the analyzed months was about 16% meaning it that the average catch was one sixth of the available abundance.

The largest month catch for CM was observed during March 2018 with 13,625 tons. The smaller moth catch was reported in February 2018 with 280 tons. The monthly averaged catch was about 6,522 tons.

The bigger month abundance for CM was estimated for February 2019, with 609,161 tons followed by March 2019 with 101,872 tons. The smaller month abundance was estimated in January 2019 with 5,699 tons. The mean ratio catch-abundance was about 14% meaning that the amount fished was a sixth part of the available abundance.

Regarding interactions between all studied species the next aspects were highlighted:

- Analyzing the available data it can be concluded that two main groups exist between species: the anchovy (*Emgraulis ringens*) and red squat lobster (*Pleuroncodes monodon*) group; and the CJM-CM and vinciguerria (*Vinciguerria lucetia*) group.
- A larger abundance of CJM was observed regarding the acoustic density of macrozooplankton. Then the variations of the relative abundance of macrozooplankton might contribute to explain the changes of availability of CJM in the Peruvian Current.
- The majority of sightings aboard fishing vessels were marine birds; however, when examined at the species level, southern fur seals and dusky dolphin were the most numerous sightings. Sightings were not spread evenly over calendar time. When the data were examined by season, the vast majority of sightings occurred in the summer months (January, February, March), with data from 2018 and 2019 combined.
- Other patterns to note include: the presence of whales predominantly in summer; the almost equivalent sightings rate of birds in summer and winter; and the increased rate of sightings of pinnipeds in winter versus summer, with the opposite pattern for dolphin.
- Further consideration of birds by species, using those taxa for which there were ten or more sightings (gull, booby, shearwater, albatross, pelican, guanay cormorant) indicated that these species could be seen anywhere within the fishery. Collectively, these data do not suggest that, at least within the physical bounds of the CJM Peruvian fishery, these taxa are strongly assorting according to simple habitat characteristics.

Finally it is highlighted the fact that for first time has been used data on interactions between top predators and fishing vessels based upon information collected by fishermen.

1. **Introduction**

The Scientific Committee of the National Fisheries Society (SNP), in cooperation with the Humboldt Institute of Marine and Aquaculture Research (IHMA), organized the Seventh SNP Workshop on the habitat conditions of the Chilean Jack Mackerel (*Trachurus murphyi*) (CJM) and other species of the Peruvian Current in the Humboldt System, which took place in Lima, Peru, from July 1st to 5th 2019. This activity was a contribution to the national & international effort to research and diagnose the current population status of CJM, one of the most important fisheries of the South Pacific, as well as to identify aspects of its habitat and from other species related to it. Previous workshops were conducted between 2011 and 2016.

At the other hand, the Scientific Committee of the South Pacific Regional Fisheries Management Organization (SC-SPRFMO), during its last meeting in Puerto Varas (Chile, September 2018) founded a Habitat Monitoring Working Group (HMWG), whose mission is to revise all the multidisciplinary information that is relevant to build geographically explicit indicators of the CJM and other species habitat. These indicators are expected to be used for fisheries management purposes, then the workshop was an opportunity to join efforts for common objectives.

In the frame of what it has been described, the workshop seeked to generate analysis that constitutes a contribution to the Peruvian report that must be submitted for the next SC-SPRFMO meeting to be held during October 2019. The workshop was also an opportunity to analyze the progress on the current knowledge on the CJM and other species' habitat, also in terms of the current methods being used for these purposes using fishing vessels as data collectors. Finally it is highlighted the fact that for first time has been used data on interactions between top predators and fishing vessels based upon information collected by fishermen.

2. **Specific objectives**

    1. To gather all available information on set by set catches, biometrical, biological, satellite and acoustic data regarding CJM and other species during 2018 and 2019 (up to April 2019).
    2. To update the knowledge about environmental variables observed via satellite to characterize the distribution of CJM and others.
    3. To perform calculations of geostatistics abundance for CJM and CM.
    4. To perform calculations of acoustic abundance of macrozooplankton.
    5. To perform an acoustic characterization of CJM's habitat in relation to the abundance of its preys and the existence of physical structures such as internal waves and Oxygen Minimum Zone (OMZ), fronts and convergence-divergence processes.
    6. To perform an analysis of the habitat from the perspective of the distribution of sighting of top predators in the zones were the CJM fishing fleet operated.

3. Report on the Chilean Jack Mackerel (CJM) and other species' habitat using fishing vessels and satellite oceanography data

3.1. Sea Surface Temperature (SST) between 2017 and 2019

The figure 1 shows the SST for 2017 (top panel), 2018 (mid panel) and 2019 (lower panel) with indication of the fishing sets for CJM (indicated by black crosses) and CM (indicated by black circles). Also it is presented from left to right the SST images for February 15th, May 15th, August 15th and November 15th for every year, being the purpose to show the seasonal thermal variations occurred within the last two years and its possible relation with the distribution and relative abundance of CJM and CM.

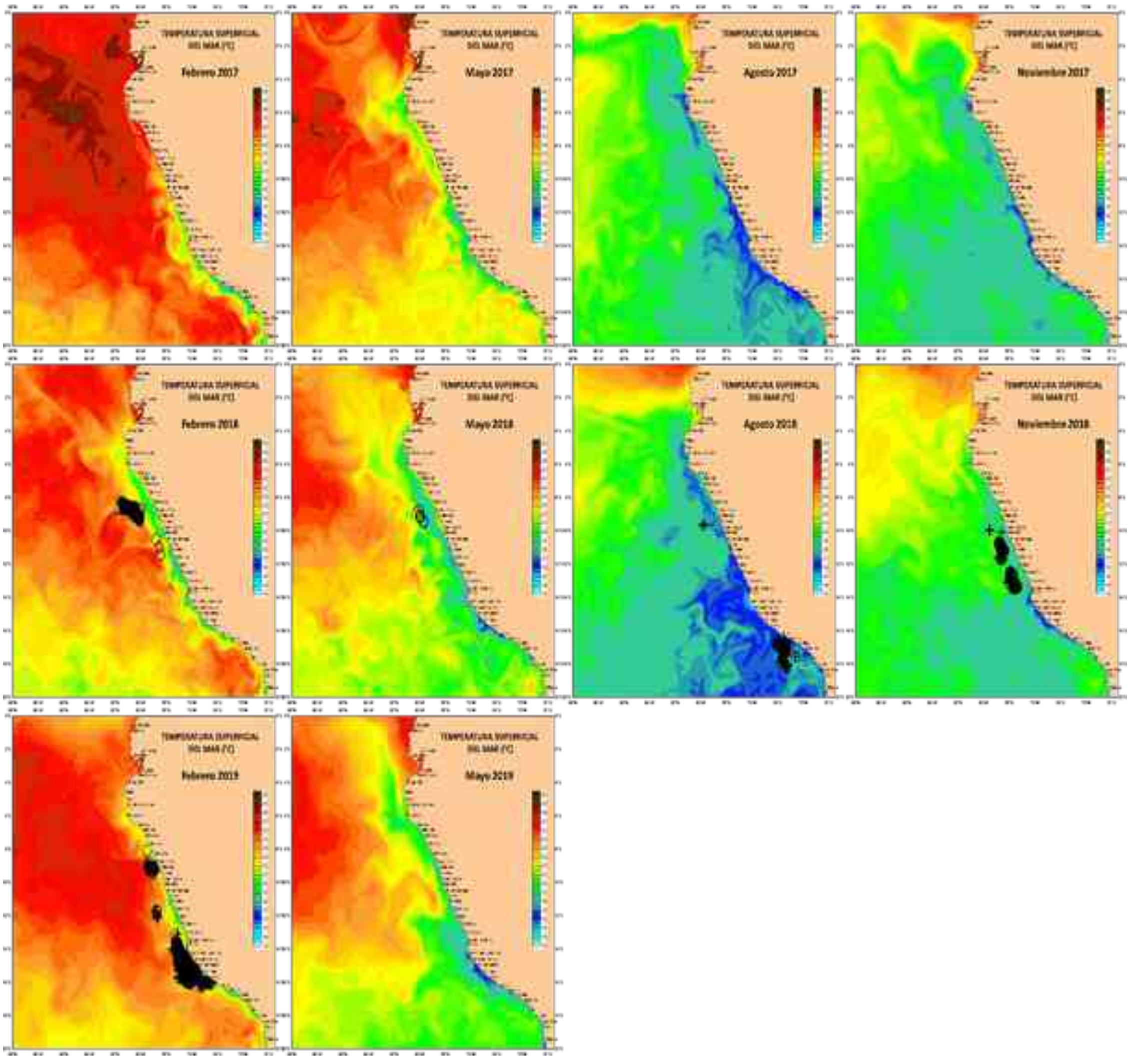


Figure 1. Sea Surface Temperature (SST) in Celsius degrees for 2017 (top panel), 2018 (mid panel) and 2019 (lower panel). From left to right the images correspond to seasons (summer, autumn, winter and spring seasons respectively). Fishing sets made by CJM and CM are indicated in black crosses and circles, respectively.

The CJM availability during 2017 was minimum, fishing surveys reported a high dispersion and sizes below authorized limits. CM has been instead available during recent years due to the advection of oceanic waters. There was an increasing trend of the abundance of both species during 2018 until March 2019 when the CJM annual quota issued by the Peruvian government was completed. During this lapse both species were found in denser aggregations along the thermal fronts outside the limit of the continental shelf.

It is considered that the thermal conditions were colder during the last two years compared to the last decade. It propitiated a better habitat for CJM to form denser aggregations especially in the southern zone, while CM has had a tendency to being distributed northward due to the dominance there of equatorial and subtropical waters, which configure a better habitat for it.

3.2. **Sea Surface Temperature Anomaly (SSTA)**

In figure 2 it is shown the SSTA by years 2017 (upper panel), 2018 (mid panel 2018) and 2019 (lower panel), with indication of the fishing sets made for CJM and CM (indicated by black crosses and circles respectively). It is also presented the images by seasons: from left to right the SSTA on February 15th, May 15th, August 15th and November 15th (summer, autumn, winter and spring respectively) being the purpose to observe the changes occurred within the last two years and its possible linkage to the CJM and CM distribution and abundance.

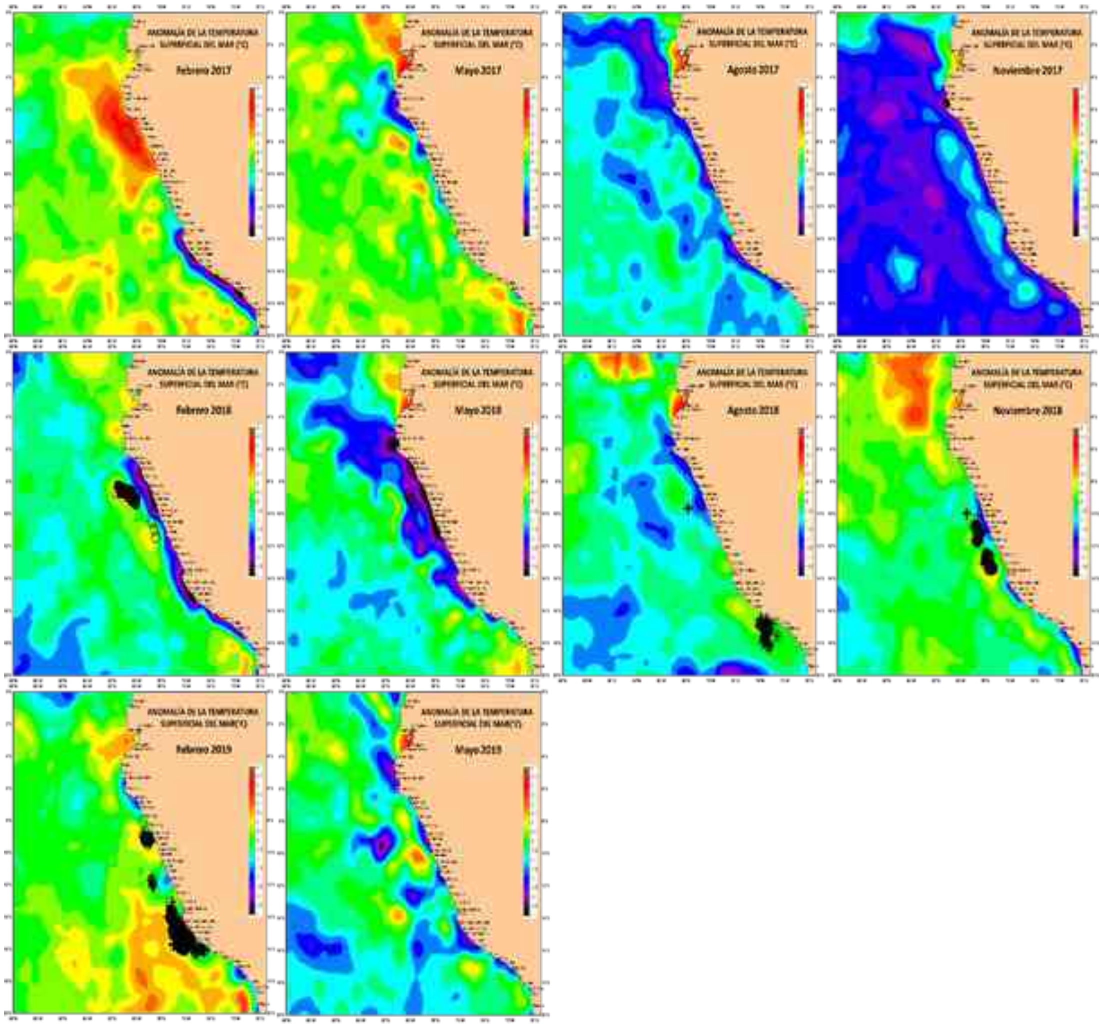


Figure 2. Sea Surface Temperature Anomaly (SSTA) in Celsius degrees for 2017 (top panel), 2018 (mid panel) and 2019 (lower panel). From left to right the images correspond to seasons (summer, autumn, winter and spring seasons respectively). Fishing sets made by CJM and CM are indicated in black crosses and circles, respectively.

The summer during 2017 was characterized by high values of SSTA in the northern zone. During autumn that year the positive anomalies covered a large part of the coast, but the conditions quickly changed at the beginning of winter generating thermal anomalies below -3°C. These conditions of large anomalies do not seem to configure a suitable habitat for CJM. Instead during 2018 there were summer and autumn seasons with slightly negative anomalies, and slightly positive ones between winter and spring. During

2018, with moderated anomalies it was observed a denser availability of CJM and CM (more CM in the northern zone, and more CJM in the south, as it is usual to be observed). The 2019 summer was characterized by relatively high thermal anomalies in the south zone, but with a narrow coast zone with normal conditions. This generated a front between ocean and coastal waters were they were found the denser CJM and CM fish schools. These conditions dissipated by autumn, which probably explains the high CJM and CM dispersion found during the Acoustic Survey made by IMARPE (between May and June 2019).

3.3. Sea Surface Salinity (SSS)

The figure 3 shows the SSM for 2017 (upper panel), 2018 (middle panel) and 2019 (lower panel), with locations of catches of CJM and CM indicated by black crosses and circles, respectively. Also in the figure 3 it is presented, from left to right the seasonal variations among February 15th, May 15th, August 15th and November 15th in every year (corresponding to summer, autumn, winter and spring respectively) with the purpose of appreciating the changes that have occurred in the last two years regarding water masses and the distribution and abundance of the studied species.

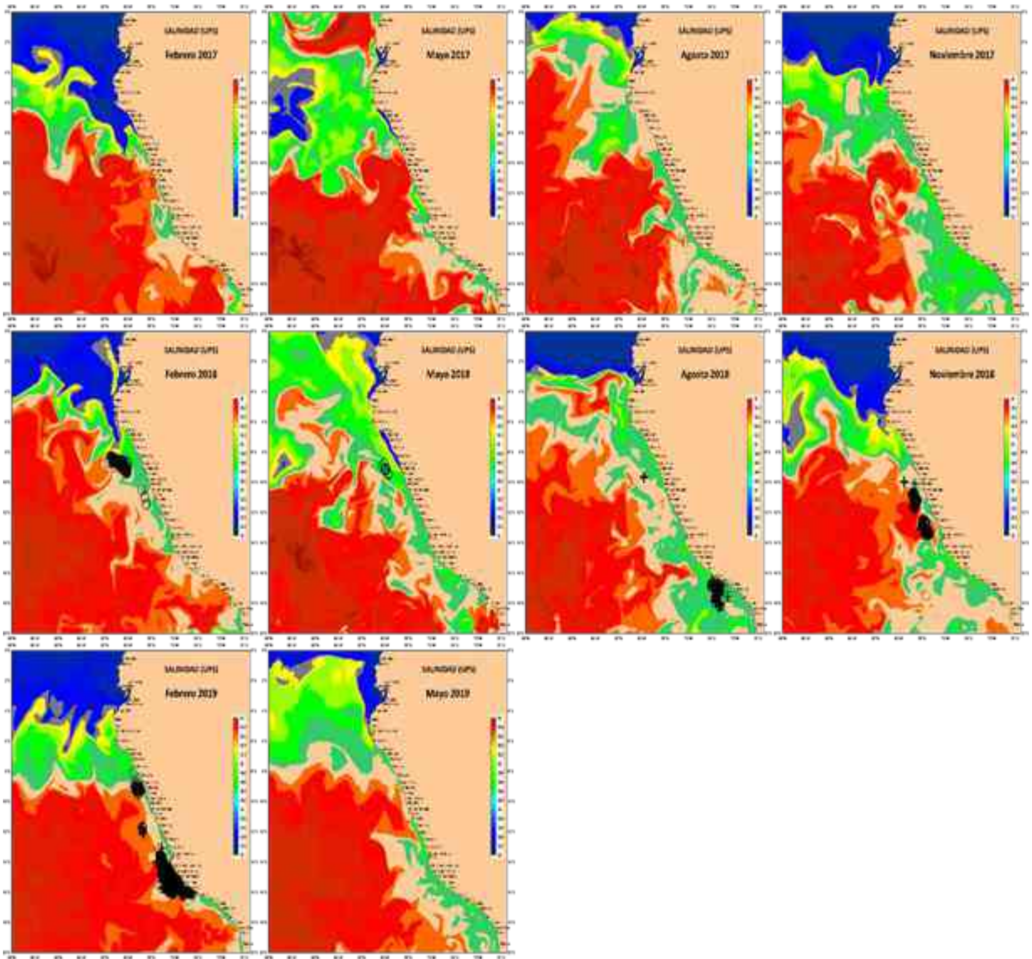


Figure 3. Sea Surface Salinity (SSS) in psu for 2017 (top panel), 2018 (mid panel) and 2019 (lower panel). From left to right the images correspond to seasons (summer, autumn, winter and spring seasons respectively). Fishing sets made by CJM and CM are indicated in black crosses and circles, respectively.

During the first months of 2017, there was a strong presence of equatorial waters caused by the development of a coastal El Niño event which caused strong rainfalls in a vast zone of the territory but especially in the northern area. Such conditions do not configure a suitable habitat for CJM but for CM, so being more available in recent years due to the warm waters from the north and northwest.

At the same time it must be commented that the seasonality of the CJM and CM catches is strongly influenced by the development of the anchovy fishing seasons, given that part of the fleet is authorized to catch those three species. In other words, when the anchovy fishing seasons extend over time it determines the duration of the fleet operation on CJM and CM, which evidently impacts on the performance of this fishery.

3.4. Sea Surface Chlorophyll (SSC)

In figure 4 it is shown the SSC by years 2017 (upper panel), 2018 (mid panel 2018) and 2019 (lower panel), with indication of the fishing sets made for CJM and CM (indicated by black crosses and circles respectively). It is also presented the SSC images by seasons: from left to right the SSTA on February 15th, May 15th and November 15th (summer, autumn and spring respectively) being the purpose to observe the changes occurred within the last two years and its possible linkage to the CJM and CM distribution and abundance.

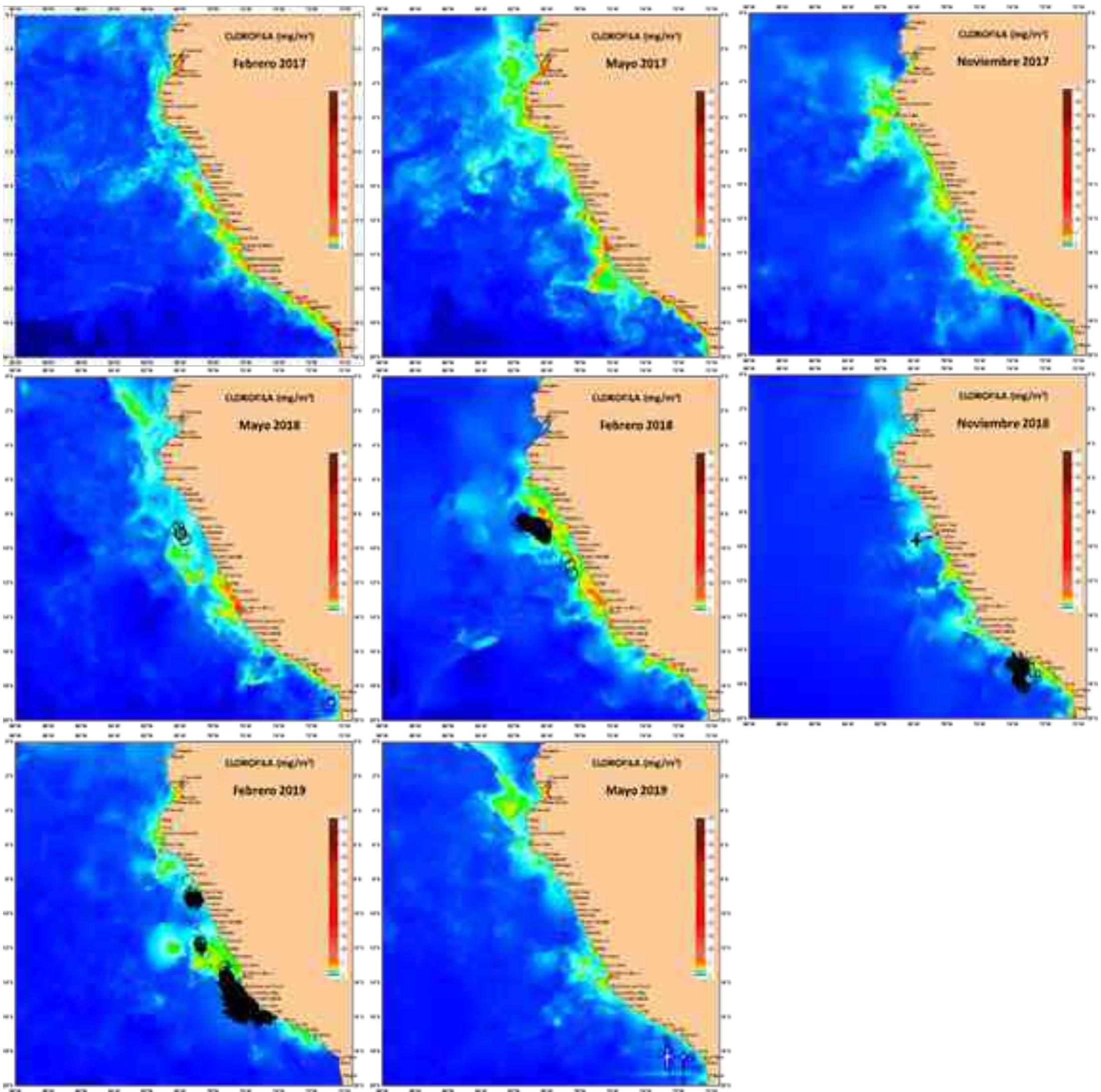


Figure 4. Sea Surface Chlorophyll (SSC) in ug/l for 2017 (top panel), 2018 (mid panel) and 2019 (lower panel). From left to right the images correspond to seasons (summer, autumn, winter and spring seasons respectively). Fishing sets made by CJM and CM are indicated in black crosses and circles, respectively.

In despite of the warm conditions observed during the first six months in 2017, it was observed for summer and autumn high SSC concentrations along the northern and central zones. Nevertheless this was not meant in a larger abundance of fish like anchovy, which had a difficult year regarding its availability to fishing. It is just in the next year (2018), with lower SST, when it is observed an increase of the availability of CJM and CM during summer and spring, although as before noticed, the fishing operations were limited when the fleet had to complete its quota in the anchovy fishery

3.5. Modeling of the CJM potential habitat and distribution

It is a challenge to identify and model the factors that potentially influence or determine the CJM habitat. The used approach during the workshop was to identify the candidate factors based in the experience of the participants in the group, so that that knowledge was used as an exercise modeled to quantify the habitat of CJM in the Peruvian current the past two years.

The perspectives to identify the potential factors included spatial distributions on the horizontal and vertical domains, the temporal changes in the abundance and distribution of CJM as a response to episodic events such as El Niño. The used data included the volume and area covered by fishing vessels. After a discussion the group decided that to guarantee that all the relevant variables were included, a complete list of the candidate variables candidates in the exercise of modelling had to be identified. The alternative approach that was rejected consisted in beginning the analysis with a limited number of variables to evaluate its suitability for the model.

The data included years 2018 and 2019. The number of fishing sets was 1850. The response variable was the standardized catch according the capacity of every vessel (in m^3). The candidate covariables were:

- Depth of the thermocline (m) as a proxy of the depth of the oxycline
- Distance to the nearest altimetry front
- Distance to the border of the continental shelf
- Concentration of chlorophyll (as a proxy of the presence of euphasiids) and acoustic density of zooplankton when available
- Latitude
- Longitude
- Hour of the day
- Ratio between adult/juvenile fish percentage observed in catches
- SST
- SSTA
- SSC
- Sea Level Anomaly (SLA)

Then the candidate covariables consisted in environmental, biological and space-time variables. The depth of the thermocline, as an indicator of depth of the oxycline, was included as a primary environmental covariable. To include the role of the geostrophic eddies as potential sources of retention of prey there were used two variables: the distance (m) to the border of the nearest altimetry front and the proportion of major and minor axis to the nearest eddy. The distance to the nearest eddy was used as a proxy of the gradient between cyclonic and anticyclone eddies in the proximities of the fishing sets. The ratio to the nearest eddy was used as a metric of the altimetry of the eddy, which indicates the potential amplitude of the gradient.

There were two environmental variables used to measure the influence of preys in the CJM habitat. First, the ecological zone defined by Ballon[1] (2011) was included as a nominal variable. And second, the nearest distance (m) from every fishing set relative to the location of the

[1] Ballón M., A. Bertrand, A. Lebourges-Dhaussy, M. Gutiérrez, P. Ayón, D. Grados, F. Gerlotto. (2011). Is there enough zooplankton to feed forage fish populations off Peru? An acoustic (positive) answer. Progress in Oceanography 91 (2011) 360–381

continental shelf (defined as 200 m depth) was used to quantify the proximity to possible preys such as copepods and euphasiids.

To track the influence of the SST in the CJM habitat, the location of the fishing sets in relation to the isotherm of 16°C was included as a candidate variable. An environmental covariable was the time and location of every fishing set. The metric for El Niño Southern Oscillation (ENSO) was the SSTA in the El Niño Region 1+2, which was classified as La Niña, Neutral or El Niño.

The number of candidate biological variables is more restricted. To quantify the presence of CJM in catches, the percentage of the adult/juvenile ratio was included. An alternative index to indicate the availability of preys was the concentration of chlorophyll. Finally, the space-time variables were the latitude, longitude and time.

The structure of the generated model is the following:

The relationships between catches of CJM and the factors that define its habitat were quantified using Generalized Additive Model (GAM) and mixed (GAMM). The response variable was the standardized logarhytmically transformed catch with potential covariables which included environmental, biological and space-time variables as previously described. For he GAM model it was used the identity function.

The execution of the model was made for (1) all data; and (2) for adults and juveniles.

It was intended to find: (1) the link between catch, temperature, salinity and chlorophyll; (2) the role of the oxycline (Bertrand et al 2008[2]); and (3) the definition of ecological zones regarding nutrients and euphasiids (Ballón et al 2011[3]).

Also, it was calculated an Index of Aggregation (IA) and a vertical Center of Mass:

$$IA = \frac{\int S_v(z)^2 dz}{\left(\int S_v(z) dz\right)^2}, m^{-1}$$

$$CM = \frac{\int z S_v(z) dz}{\int S_v(z) dz}, CM$$

Where Z is the depth of the sampled layer (m), and Sv is acoustic mean strength of the backscattered volume (dB/m).

Therefore the entire Peruvian marine zone was grilled by Marsden squares Marsden of 60x60 minutes. Inside every polygon IA and CM were calculated using all the acoustic information. IA is higher when higher are the densities of fish into smaller areas. CM indicates the central position of CJM in the water column. Figure 5.

[2] Bertrand A, Gerlotto F, Bertrand S, Gutiérrez M, Alza L, Chipollini A, et al. (2008). Schooling behaviour and environmental forcing in relation to anchoveta distribution: An analysis across multiple spatial scales. Progress in Oceanography. 2008;79:264–77.

[3] Ballón M., A. Bertrand, A. Lebourges-Dhaussy, M. Gutiérrez, P. Ayón, D. Grados, F. Gerlotto. (2011). Is there enough zooplankton to feed forage fish populations off Peru?An acoustic (positive) answer.Progress in Oceanography 91 (2011) 360–381.

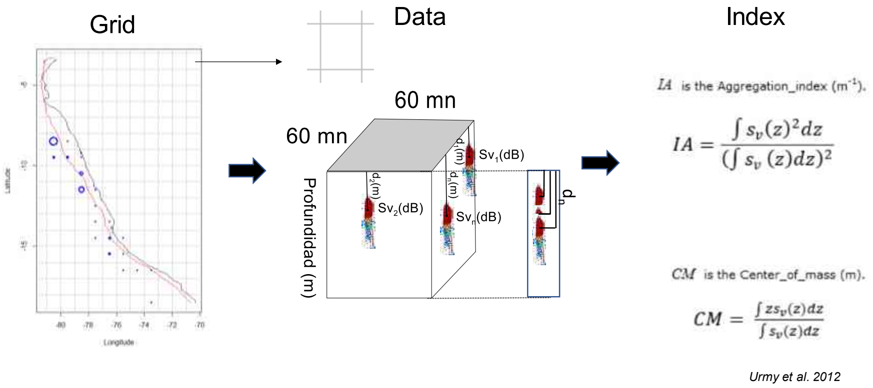


Figure 5. Process to calculate the index of vertical distribution of CJM.

In figure 6 it is shown that in diverse areas CJM was found closer to surface and forming disperse shoals (IA near to 1). At the other hand, in the south CJM was found deeper (15-30 m) forming denser aggregations (IA near to 0).

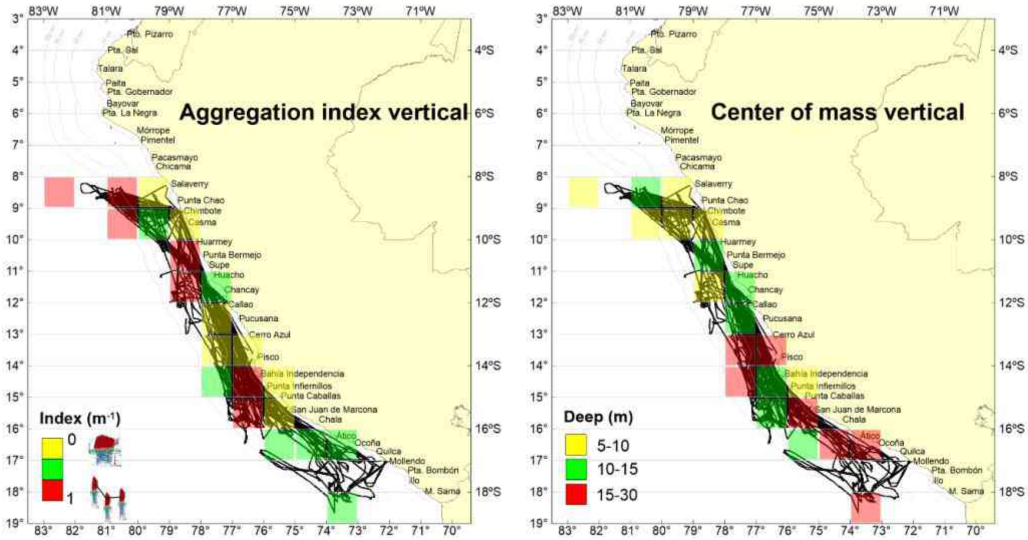


Figure 6. Left: tracking of fishing vessels (black line) and IA (index of vertical aggregation). Right: vertical center of mass for CJM

Table 1 presents the GAM model developed for the catches of CJM based on the sea level anomaly (SSA) and latitude (LAT), the distance from the coast (DC), the sea surface temperature anomaly (SSTA), the sea surface salinity (SSS), the distance to the nearest eddy (db_eddie) and the time of the day. In the table they are shown the related coefficients and probability statistics that are related (with R=0.213 and 24% of explained variance).

Table 1. GAM model used to explore the variables that best represent the CJM catches

```
Formula:
log(Pesca.declarada.JUREL) ~ s(ssa) + s(lat) + s(dc) + s(atsm) +
    s(ssm) + s(db_eddie) + s(hora)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.18666    0.03391   123.5   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
              edf Ref.df      F  p-value
s(ssa)      3.413  4.320  2.626 0.029746 *
s(lat)      7.422  8.352  3.605 0.000523 ***
s(dc)       2.364  2.992  1.397 0.225867
s(atsm)     2.822  3.519  9.442 1.23e-06 ***
s(ssm)      1.000  1.000 15.771 7.85e-05 ***
s(db_eddie) 7.849  8.565  2.152 0.016160 *
s(hora)     1.000  1.000 10.171 0.001487 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.213   Deviance explained =   24%
GCV = 0.8863  Scale est. = 0.85425    n = 743
```

Figure 7 shows the graphic result of the GAM model for CJM. The SSA (cm) shows a weak positive trend for larger catches when the anomaly is higher. The latitude shows a uniform distribution of values between 13 and 16°S, but the trend seems to be negative in zones located northward, meaning it that CJM has been distributed mainly in the south zone (unless in the areas where the fleet operated). The distance from the coast (dc) shows a weak declining trend in catches when fishing sets have been effectuated further from the coastline. The thermal anomaly (atsm) shows a slightly positive trend towards larger catches when anomalies are up to 2°C. The salinity of sea Surface (ssm) shows a negative trend when the salinity increases, given that the smaller catches have occurred in those zones. Finally the distance to the nearest eddy shows a multimodal structure without a clear trend regarding the catches.

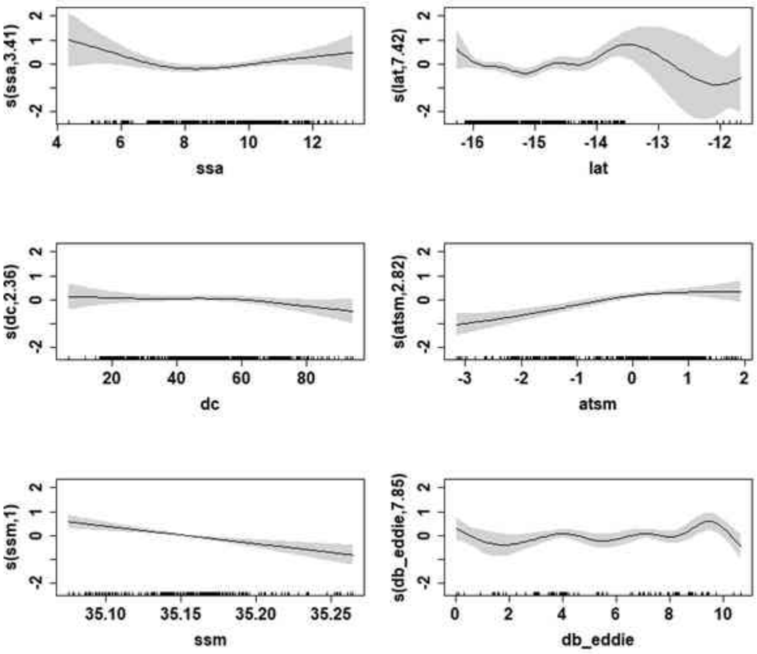


Figure 7. Results of the GAM models for CJM

Table 2 presents the GAM model developed for the CM catches following the same methods described for CJM.

Table 2. GAM model used to explore the variables that best represent the CM catches.

```
Family: gaussian
Link function: identity

Formula:
log(Pesca.declarada.CABALLA) ~ s(ssa) + s(lat) + s(dc) + s(atsm) +
    s(ssm) + s(db_eddie)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.60578    0.04871   53.49   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
              edf Ref.df     F  p-value
s(ssa)      1.000  1.000 1.685 0.194785
s(lat)      5.707  6.740 4.166 0.000304 ***
s(dc)       3.531  4.442 7.029 1.16e-05 ***
s(atsm)     6.527  7.647 9.872 1.92e-12 ***
s(ssm)      3.586  4.468 1.115 0.292388
s(db_eddie) 1.000  1.000 3.629 0.057234 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.274   Deviance explained = 29.7%
GCV = 1.6234  Scale est. = 1.5685    n = 661
```

In the figure 8 they are shown the results of GAM models for CM catches. For SSA it is observed a structure with several modes without trend. The latitude (lat) does not show a clear trend either; instead there were few catches between latitudes 10 to 13°S. The distance to coast (dc) shows a negative trend of catches when they are made at larger distances from the coast. The thermal anomaly shows a slight positive trend to have better when higher are the anomalies (with a maximum threshold of 2°C). Finally the salinity (ssm) and time of day do not present trends.

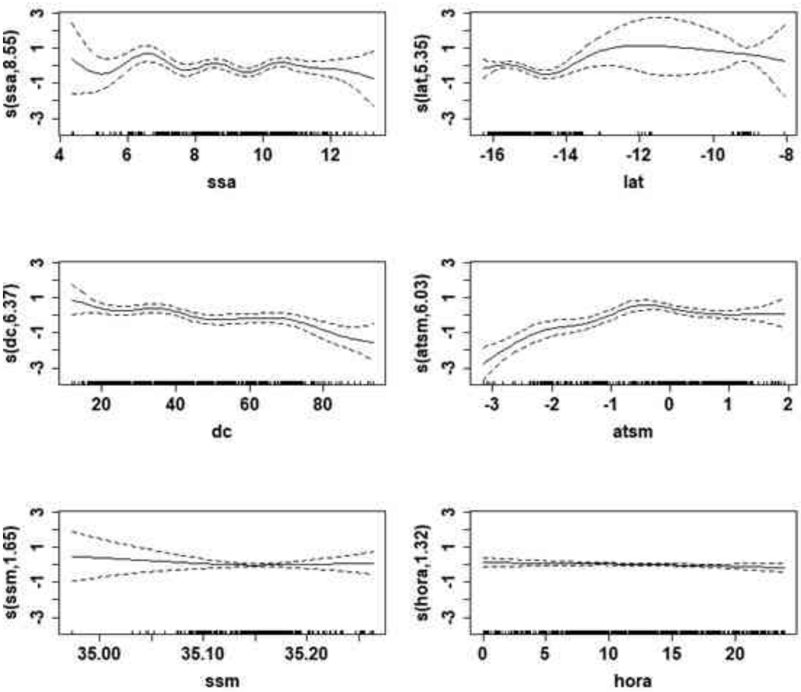


Figure 8. Results of GAM models for CM

3.6. Changes on the acoustic distribution of CJM

In figure 9 they are shown the acoustic detections of CJM made by the fleet. The spring-summer 2018 fishing season was characterized for presenting catches mostly performed in the northern Peru. On the contrary, for the same season during 2019 it is observed that CJM is distributed in the center zone of the studied area, similar to it was noticed during autumn-winter 2018. Besides it was observed a rapid migration towards the end of 2018 from the northern to the central and southern zones during the beginning of 2019. This demonstrates the ability of CJM to move from one place to another on a relatively short period of time. The higher densities of CJM during 2018 were recorded between 8 and 16°S, and during the first months of 2019 were observed in 14°S.

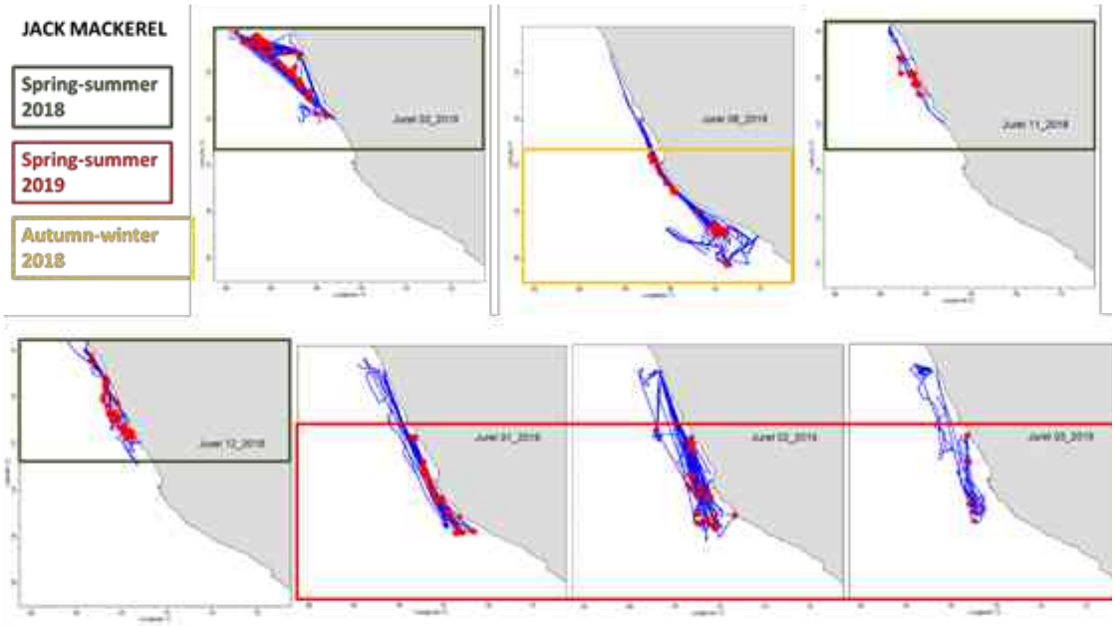


Figure 9. Seasonal distribution of CJM detections during 2018-2019. Green squares highlight the distribution between spring and summer 2018; the red squares indicate the distribution between spring 2018 and summer 2019. The yellow square indicates the distribution between autumn and winter 2018.

3.7. Potential Habitat Model for CJM

Valdez et. al (2015[4]) produced a 2D deterministic and probabilistic model (MHPJ) to describe CJM potential habitat using satellite oceanography data and positional variables (seven parameters in total). Catches has been found to be better correlated when the probabilities in the model were higher than 0.6 (in a range from 0 to 1). A refinement to the model was introduced by loading fish schools detections and catches into the model. Nevertheless the model is strongly influenced by chlorophyll so that quality of results depends on the availability of clear satellite images.

During the workshop the MHPJ was run every 2 weeks from January to March 2019 (2 runs each month). The result is shown on figure 10; over the results they were plotted the catches in order to visualize the asertivity of the model.

---

[4] Valdez C., S. Peraltilla, M. Gutiérrez, E. Méndez, A. Aliaga, A. Zuzunaga, D. López, U. Munaylla & F. Gerlotto. (2015). Modelling Jack mackerel (*Trachurus murphyi*) potential habitat off Peru validated throughout industry vessels catch and acoustic data. Proceedings of the RIO Acoustics 2015 IEEE/OES Acoustics in Underwater Geosciecnes Symposium, Rio de Janeiro, July 2015.

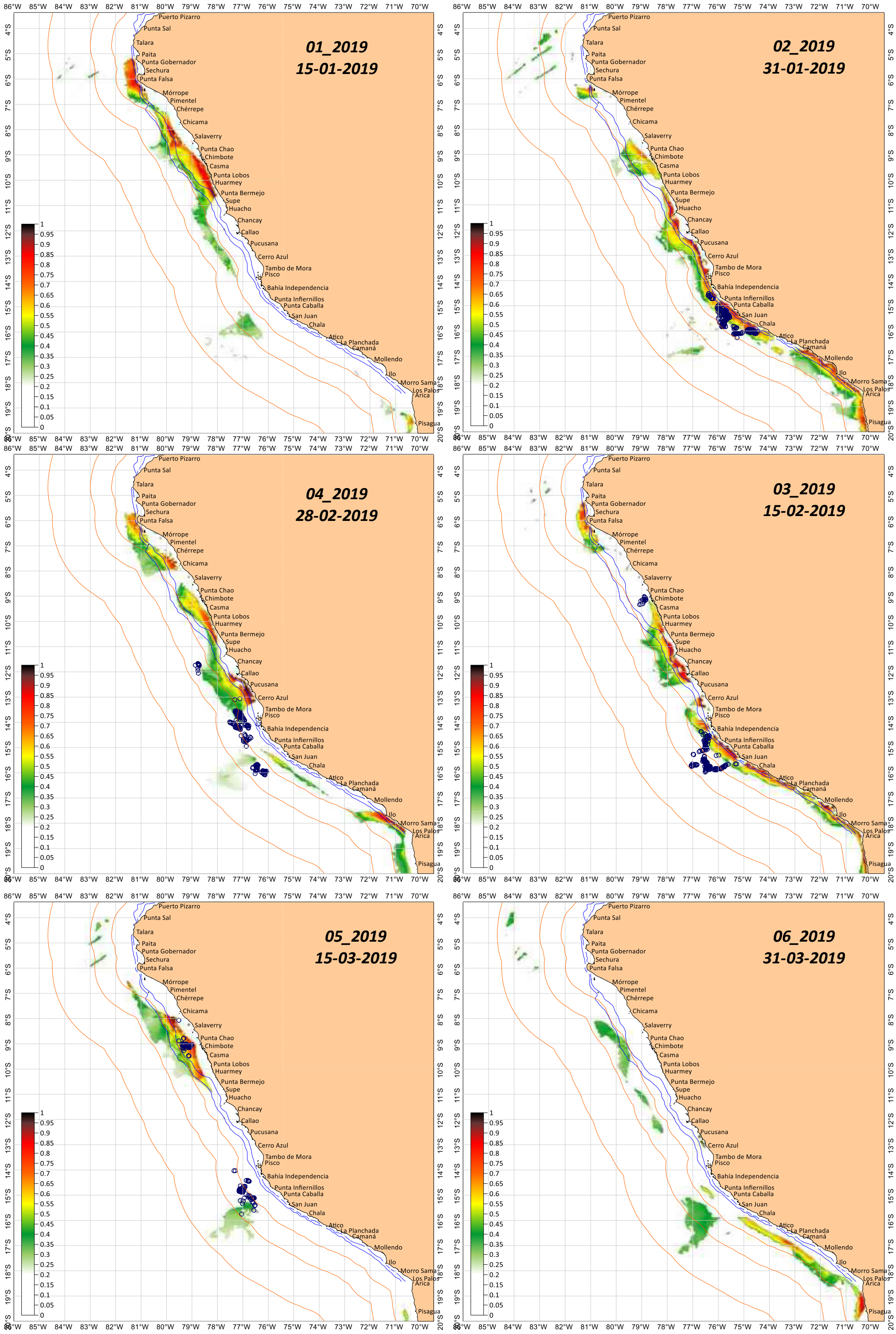


Figure 10. MHPJ runs fortnightly between January and March 2019. The black dots indicate the catches effectuated by the fleet. The distances from the coast are represented by orange lines (50, 100, 200 nm). The blue lines represent bathymetry lines in 80 and 200 m depth. The color scale indicates the probability of finding CJM (with values from 0 to 1).

For the second fortnight of 2019 it was observed that the fishing sets in the south zone match appropriately the model. During the third fortnight the fishing effort is made further the coast while the model remains to describe a possible habitat near the coast. For the fourth fortnight the catches matches the results of the model in the Pisco area. For the fifth fortnight it is observed that catches match a high probability area close to Chimbote while in the southern zone there were catches near the Independencia bay (14°S) with a slight difference compared to the model. During the last fortnight, when the quota was completed and the fishing season terminated it was observed an overall decrease in the probability of finding a suitable habitat for CJM.

Finally, in figure 11 it is shown a comparison between the distribution of CJM obtained during an acoustic survey made by IMARPE during summer 2019 and the distribution estimated with the MHPJ, considering that the model is run instantaneously whilst the survey was performed throughout 40 days. They are highlighted in the figure with colored circles the zones of the model that match the acoustic detections of CJM made by IMARPE.

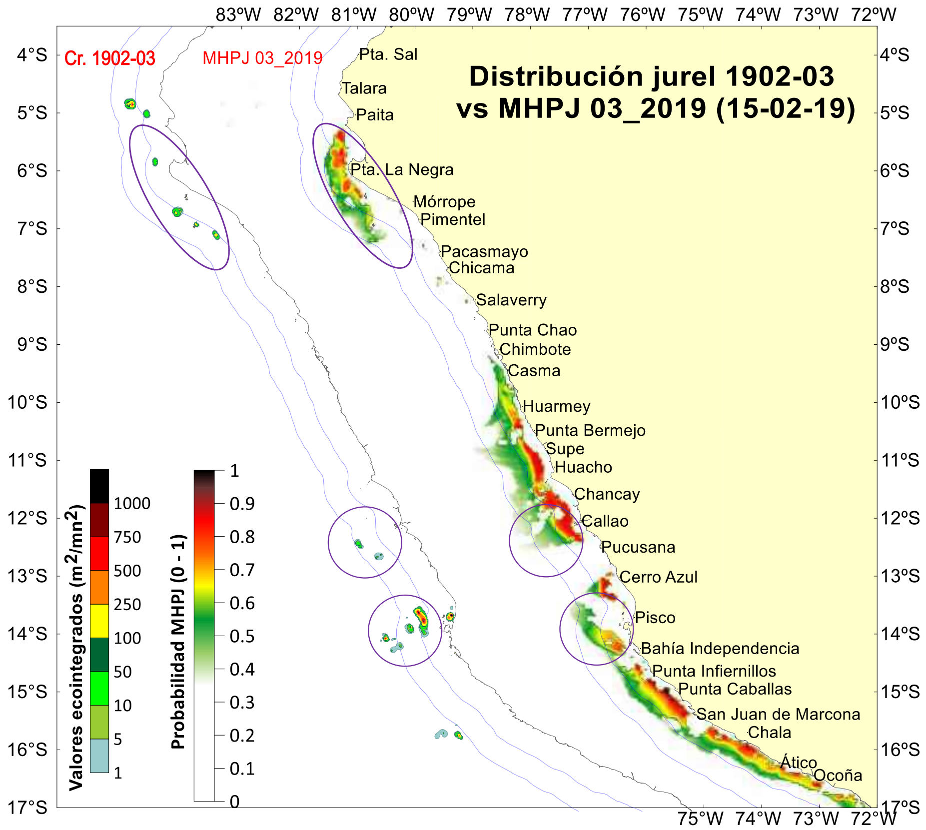


Figure 11. Comparison of results of the potential habitat CJM model (MHPJ) with the acoustic detections made during the acoustic survey made by IMARPE during summer 2019.

4. Report on the Chilean Jack Mackerel and other species' abundance regarding macrozooplankton and ocean dynamics using acoustic and geostatistics techniques

4.1. Size structures of CJM and CM

4.1.1. CJM sizes structures

It is presented on figure 12 the size structures of CJM obtained from the biometric sampling of catches effectuated aboard fishing vessels during 2018 and 2019. In the case of 2019 it is included the structure of sizes obtained by IMARPE during a CJM acoustic survey performed between May and June. In 2018 it was observed a main mode of 28 cm and secondary modes of 23, 35 and 43 cm. In 2019 it is observed two main modes, one in 26 and other in 34 cm with secondary mode in 31 cm. The variation on the main mode is about 6 cm in a year, which indicated not only the growth in size but the influx of individuals of larger size to the fishing zones. In the case of 2019, the smaller sizes of CJM observed by IMARPE were not found by the fishery

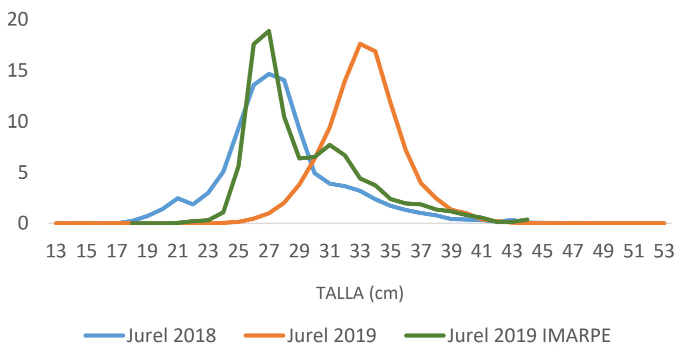


Figure 12. Size structure of CJM for 2018 and 2019 according to the sampling made aboard the fishing fleet.

4.1.2. CM sizes structures

In the case of CM it is shown in figure 13 that during 2018 there was a main mode in 26 cm, with secondary modes in 34 and 38 cm. During 2019 they were observed two main modes in 15 and 33 cm, with a secondary mode in 19 cm. Between 2018-19 has been an increase of the main mode of 7 cm, which represents both the increase of the size in the population and the possible influx of individuals of larger size considering the observed presence of oceanic waters masses during summer 2019. It is interesting to notice that the smaller sizes of CM (with the indicated modes in 15 and 19 cm) were found during an acoustic survey made by IMARPE during May and June of 2019; those modes were not observed by fishing vessels.

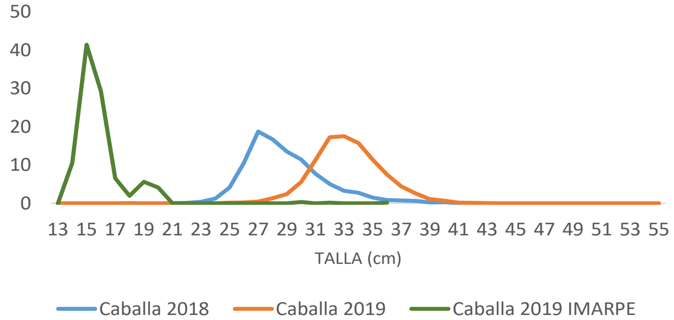


Figure 13. CM size structure during 2018 and 2019, according to the biometrical sampling made on board of the fleet.

4.2. **Estimation of the CJM and CM abundance**

Since the first workshop on CJM in 2011 there have been used two methods for the estimation of the abundance of fish. One of them is acoustic, which means that a number of vessels that participate in the fishery deploy digital systems (echosounders) operating at 120 kHz of frequency to collect data files to be analyzed during the workshops. In this case it has been processed a sample of the acoustic data from 21 fishing vessels that collectively performed 79 fishing trips during 2018 and 2019. However this amount of data is considered insufficient to perform an acoustic abundance calculation for CJM and CM. Instead the acoustic information has been used to estimate the relative abundance of macrozooplankton in a large part of the surveyed zone made by the fishing fleet. Furthermore the acoustic data has been useful to also collect information on other species such as anchovy, red squat lobster in areas were the fleet operated.

Another used method was geostatistics. Therefore the fishing sets data obtained during 2018 and 2019 was regionalized in 8 zones both for CJM and CM, being the purpose to perform separated calculations of the abundance of fish. This is based in the estimation of gravity centers and inertias associated to each region. The information was also grouped by fortnights (29 fortnights, from January 2018 to March 2019) and used the mean catch by zone and fortnight as a proxy of the density of fish (tons/mn^2). In this way the multiplication of the mean catches by the inertia let to obtain the abundance in tons. These estimations of abundance are assumed to be proportional to the biomass of CJM and CM only in the areas where the fleet operated.

The methodological details for both types of analysis are described in SNP[5] (2015).

4.2.1. **CJM abundance**

Figure 14 shows the distribution of fishing sets made for CJM between January 2018 and March 2019. The fishing quota issued for CJM by the Ministry of Production (PRODUCE) during 2019 consisted in 89 thousand tons; the quota was completed by March. The fishing sets have been classified by geographical regions (8) and by fortnights, with the purpose to calculate the averaged catch (tons/mn2), the gravity center (latitude, longitude) and inertia (mn2) in every region/fortnight.

The fishing sets made for CJM have been observed to occur outside the limit of the continental shelf, from 10 to 120 n.mi. off the coast, and between latitudes 8°30’S (Salaverry) and 18°20’S (Sama). They have been made 1,088 fishing sets with catches in a range from 5 to 680 tons. The average catch was 105.53 tons, and the total catch was 114,602 tons of CJM between January 2018 and March 2019.

Obviating the fortnights where there were no fishing operations, the larger CJM catch occurred during the first fortnight of March 2019 with 31,204 tons, and the smaller catch was reported during the second fortnight of December 2018 with just 160 tons. The average month catch was 8,185 tons.

[5] SNP.(2015). Informe del VI Taller de Evaluación del Estado del Recurso jurel Trachurus murphyi. Comité de Investigación Científica de la Sociedad Nacional de Pesquería. Lima, 109 pp.

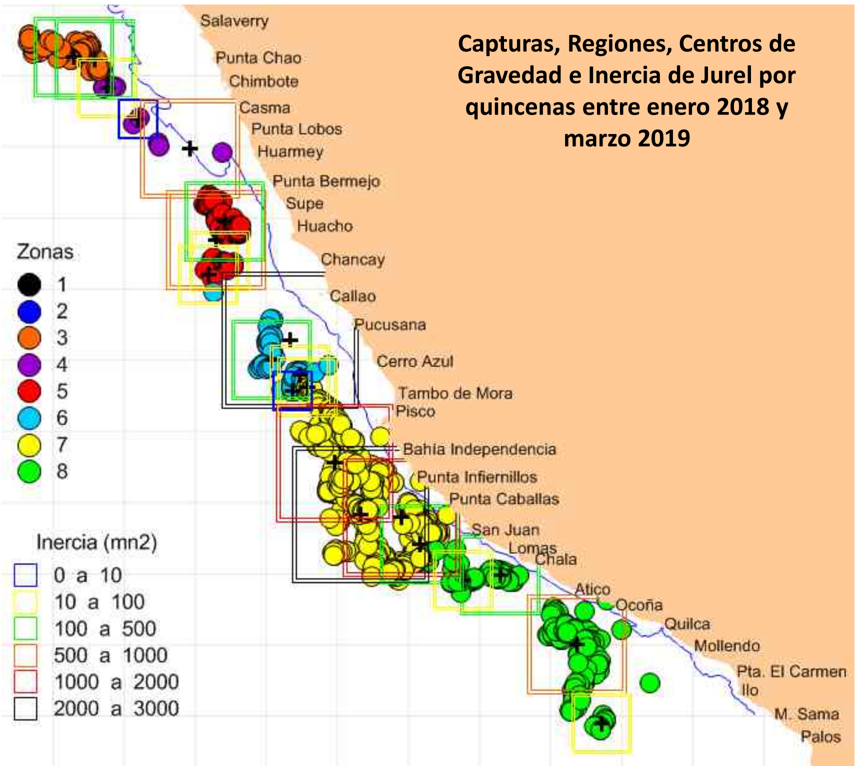


Figure 14. Distribution of fishing sets made for CJM between January 2018 and March 2019. The fishing sets have been classified in 8 regions by fortnights. They have been calculated the gravity centers (indicated by black crosses) and the inertia in every region and fortnight with the purpose of calculating the abundance of fish.

In the table 3 and figure 15 they are observed the catches and abundances estimated for CJM using the geostatistics method (tons) and also the ratio or proportion of both amounts between January 2018 and March 2019. It must be precised that the lack of estimations in January and February 2018, and from April to July of the same year is due to the fact that the fishing vessels were participating in the second fishing season of 2017 and the first one of 2018 for anchovy fishing.

The higher abundance of CJM was estimated for February 2019 with 537,495 tons followed by March 2019 with 100,143 tons. The smaller abundance was estimated for September 2018 with just 201 tons. The ratio between catches and abundance was 16%, meaning that on average the amount fished has been one sixth of available abundance.

The largest calculated inertia for CJM, as a proxy of its distribution area in the zones where the fleet operated, was 5,189 mn^2 during March 2019; and the smaller inertia was just 8 mn^2 during August 2018. The averaged area of distribution has been calculated in 876 mn^2 along the studied period of time.

Table 3. Abundance and Catch (tons) of CJM between January 2018 and March 2019, with indication of the ratio (percentage) between catch and abundance.

Month	Abundance (t)	Catch (t)	Ratio (%)
January 2018	0	0	
February	0	0	
March	51,726	4,057	7.84
April	0	0	
May	0	0	
June	0	0	
July	0	0	
August	61,861	13,181	21.31
September	201	50	24.90
October	91,166	12,581	13.80
November	43,739	7,077	16.18
December	1,411	160	11.34
January 2019	51,157	11,142	21.78
Februrary	537,495	52,672	9.80
March	100,143	13,682	13.66

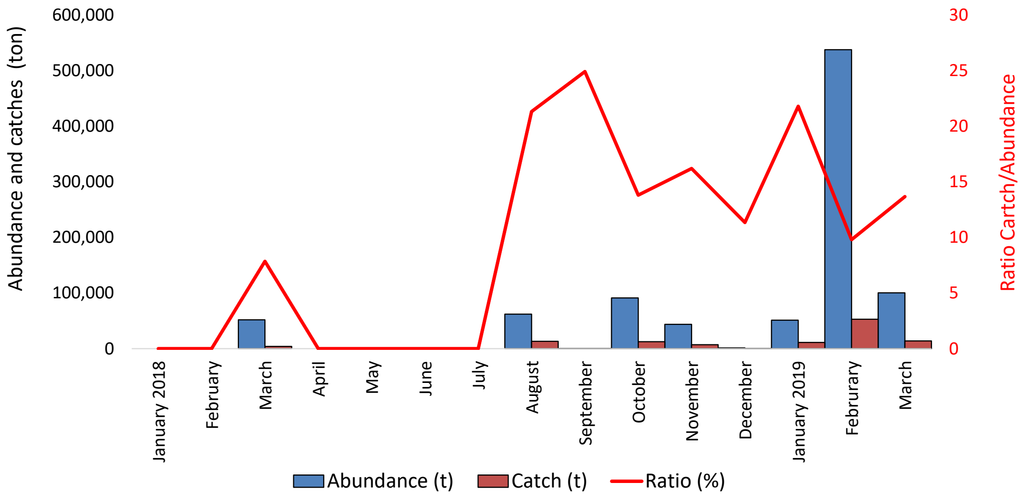


Figure 15. Abundance and catch (tons) of CJM between January 2018 and March 2019 with indication of the ratio (percentage) between catch and abundance.

4.2.2. CM Abundance

Figure 16 shows the distribution of fishing sets made for CM between January 2018 and March 2019. The fishing quota issued for CM by the Ministry of Production (PRODUCE) during 2019 consisted in 135 thousand tons; the fished quota by March 2019 was 28 thousand tons (20%), with a remaining amount of 107 thousand tons. The fishing sets have been classified by geographical regions (8) and by fortnights, with the purpose to calculate the averaged catch (tons/mn2), the gravity center (latitude, longitude) and inertia (mn2) in every region/fortnight.

The fishing sets made for CM but in Chimbote have been observed to occur outside the limit of the continental shelf, from 10 to 120 n.mi. off the coast, and between latitudes 8°30'S (Salaverry) and 18°20'S (Sama). Until March 2019 they have been made 718 sets with caches in a range from 3 to 500 tons. The average catch was 82.19 tons, and the total catch was 58,697 tons of CM between January 2018 and March 2019.

Obviating the fortnights where there were no fishing operations, the larger CM catch occurred during the second fortnight of March 2019 with 13,625 tons, and the smaller catch was reported during the first fortnight of February 2018 with 280 tons. The average month catch was 6,522 tons.

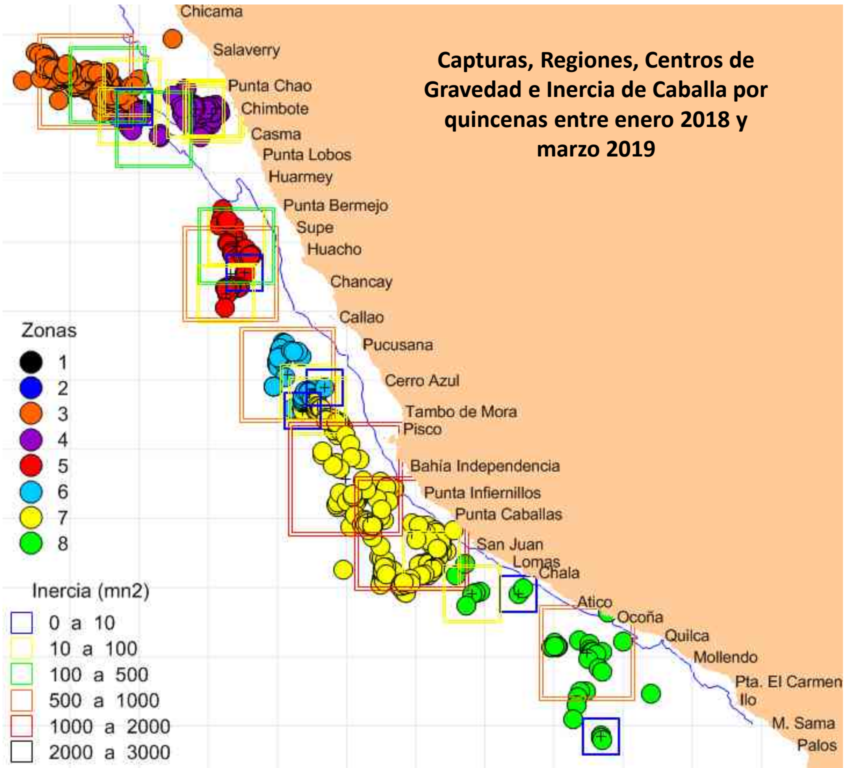


Figure 16. Distribution of fishing sets made for CM between January 2018 and March 2019. The fishing sets have been classified in 8 regions by fortnights. They have been calculated the gravity centers (indicated by black crosses) and the inertia in every region and fortnight with the purpose of calculating the abundance of fish.

In the table 4 and figure 17 they are observed the catches and abundances estimated for CM using the geostatistics method (tons) and also the ratio or proportion of both amounts between January 2018 and March 2019. It must be precised that the lack of estimations in January and February 2018, and from April to July of the same year is due to the fact that the fishing vessels were participating in the second fishing season of 2017 and the first one of 2018 for anchovy fishing.

The higher abundance of CM was estimated for February 2019 with 609,161 tons followed by March 2019 with 101,872 tons. The smaller abundance was estimated for January 2019 with 5,699 tons. The ratio between catches and abundance was 14%, meaning that on average the amount fished has been one sixth of available abundance.

The largest calculated inertia for CM, as a proxy of its distribution area in the zones where the fleet operated, was 4,007 mn^2 during March 2019; and the smaller inertia was just 2 mn^2 during August 2018. The averaged area of distribution has been calculated in 710 mn^2 along the studied period of time.

Table 4. Abundance and Catch (tons) of CM between January 2018 and March 2019, with indication of the ratio (percentage) between catch and abundance.

Month	Abundance (t)	Catch (t)	Ratio (%)
January 2018	0	0	
February	8,607	280	3.25
March	43,880	16,991	38.72
April	11,001	745	6.77
May	0	0	
June	0	0	
July	0	0	
August	105,760	3,475	3.29
September	0	0	
October	48,115	3,209	6.67
November	61,690	6,121	9.92
December	0	0	
January 2019	5,699	2,830	49.66
Februrary	609,161	17,681	2.90
March	101,872	7,365	7.23

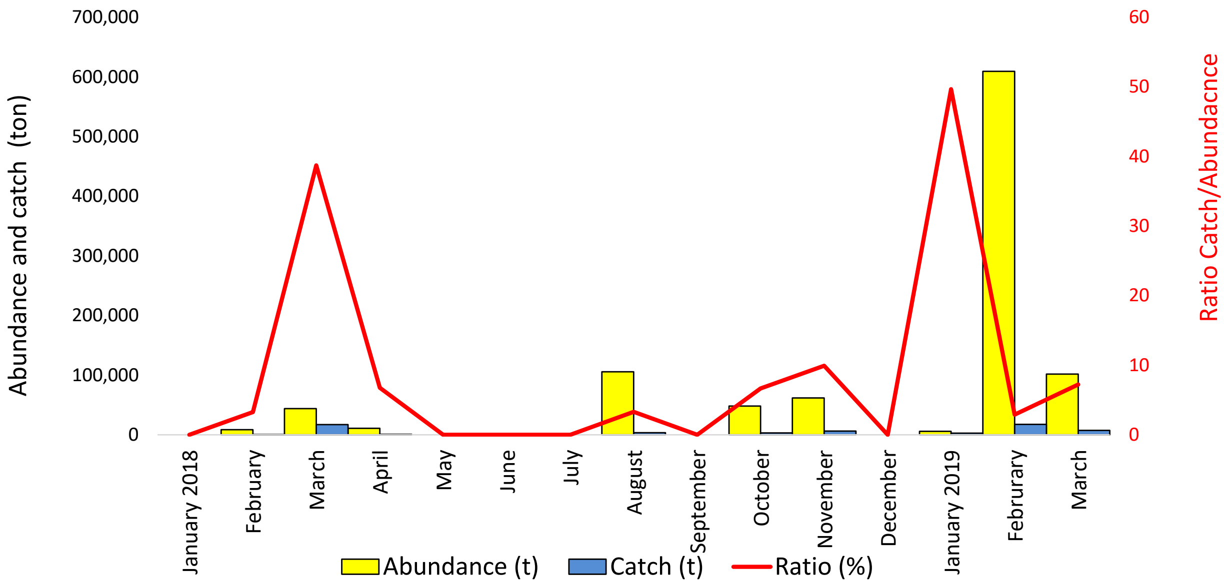


Figure 17. Abundance and catch (tons) of CM between January 2018 and March 2019 with indication of the ratio (percentage) between catch and abundance.

4.3. Interactions between species in Peruvian waters.

This section concerns the analysis of Nautical Acoustic Scattering Coefficient (NASC, m2/mn2) distribution (acoustic density) using variograms as exploratory tools. The main activity was the study of the potential interactions between the main pelagic stocks in Peruvian waters: Chilean Jack Mackerel (CJM), anchovy, chub mackerel (CM), vinciguerria and red squat lobster. Jumbo squid did not present enough data to be included in this analysis. The question to which it was intended to answer was the following: are there any relationships between the 5 major species (CJM, CM, Vinciguerria, Anchovy, red squat lobster), that could help to define the CJM habitat?

The major hypotheses behind this question are the following: (i) Aggregation structures are evolving in order to adapt to changing environmental conditions: they can provide indicators; (ii) Habitat of a given species is in part shared by others which have a rather similar biology (e.g. CJM and CM): these “others” can give information on the CJM habitat.

Apart these hypotheses, in a first attempt we added a methodological one: the data are not affected by time, so that by adding data over one year does not affect the spatial structure when considering short distances models. Indeed acoustic data is gathered by years, with a large temporal drift. In these conditions the large spatial scales cannot be studied, as the fish may have migrated during the observation period. But as long as we consider small scales (compared to the whole area), it is unlikely that these large movements have any effect on the results.

The spatial distribution of data is presented in figure 18.

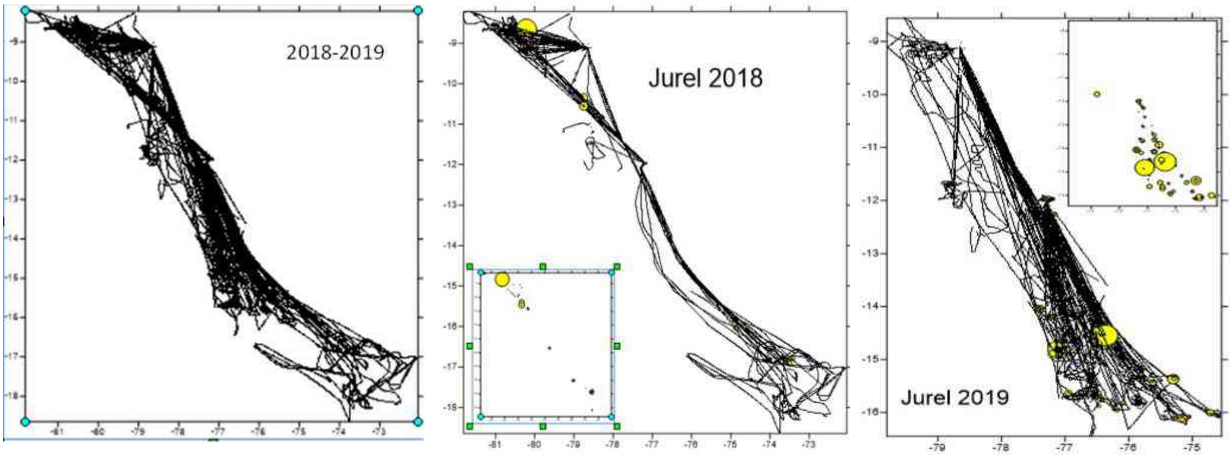


Figure 18. Spatial distribution of data 2018-2019 (left). The distribution of CJM in 2018 is shown in the central panel, and the one for 2019 is shown to right. The two panels shows also the spatial distribution and the NASC values (yellow circles proportional to the abundance). This last information is presented alone in the smaller map in each panel.

The variograms obtained for the 5 species show particular similarities and affinities; it is the case for CJM and vinciguerria, which models for 2019 could be overlapped (figure 19).

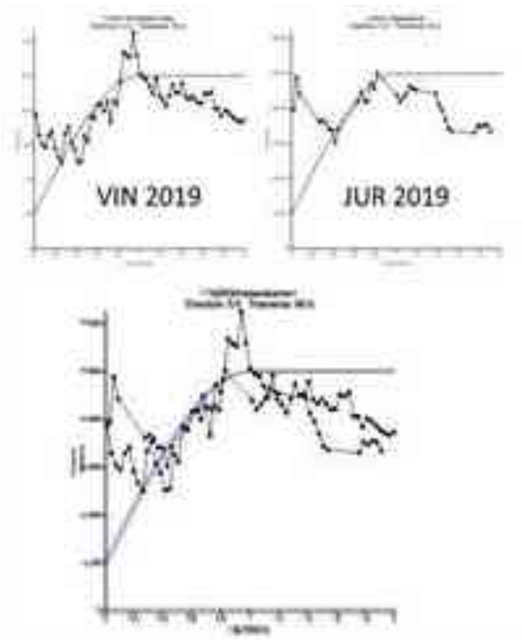


Figure 19. Comparison of variograms for JM 2019 and vinciguerria 2019

Other affinities concern CJM and CM between 2018 and 2019; also anchovy and red squat lobster correspond similarly in 2019 (figure 20).

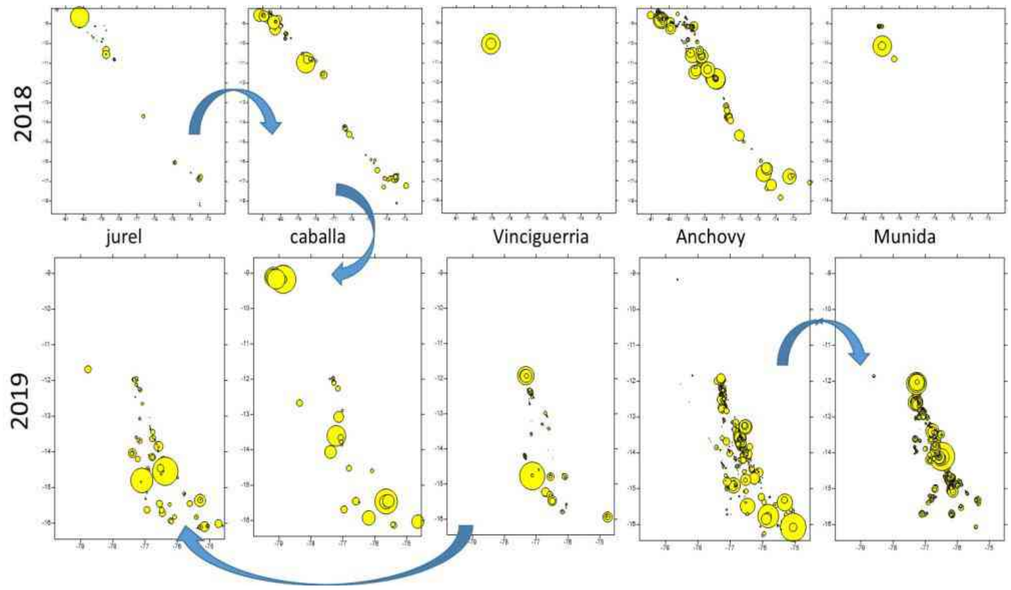


Figure 20. Distribution of acoustic density in 2018 and 2019 for the 5 main species. The blue arrows show the groups whose variograms present some similarities (jurel=CJM; caballa=CM; múnida=red squat lobster).

The results are limited and preliminary. Nevertheless it seems that we could already conclude that two main groups exist between these species: the anchovy-red squat lobster and the CJM-CM-vinciguerria. This is not surprising, as these groups are often encountered in the same water masses. With a larger data base this analysis could be repeated in order to evaluate the level of familiarity between the species and how it could change over time. This conclusion about the affinities of species is speculative, and should require adding other types of data (e.g. oceanography).

No other conclusions can be extracted from this series of calculations and analyses. Nevertheless it seems that the methodology of using variograms to describe the spatial structure, and especially the spatial dimensions of the aggregations could produce interesting results over the years. This was also the case for some analyses using variograms presented during the former SNP workshops (discrimination between CJM and CM, changes in school dimensions, migrations, etc.).

A general recommendation for the Habitat Monitoring Working Group (HMWG) is to gather all these preliminary studies, evaluate their potential in answering questions relevant to the HMWG and generalize their use on a more complete set of data, for an eventual decision on their application.

4.4. Additive Generalized Model (GAM) of the CJM abundance

During 2018, the non-parametric regression model (GAM) presented an adjustment of 48.6%; in Figure 21A it is shown higher abundances from 14:00 to 22:00 hours. In this period, CJM was distributed in the central-northern zone, between 8° to 11°S and from 14° to 18°S in the south (Figure 21B); it must be noticed that during 2018 CJM was distributed until 140 m depth, and presenting the denser abundance between 20 and 80 m (Figure 21C). According to satellite data, during 2018 the Cold Coastal Waters (CCW) extended in a range from coast up to 30 to 70 n.mi.; mixed waters of CCW with Surface Subtropical Waters (SSW) and Surface Tropical Waters (STW) was observed in the zones where CJM distributed.

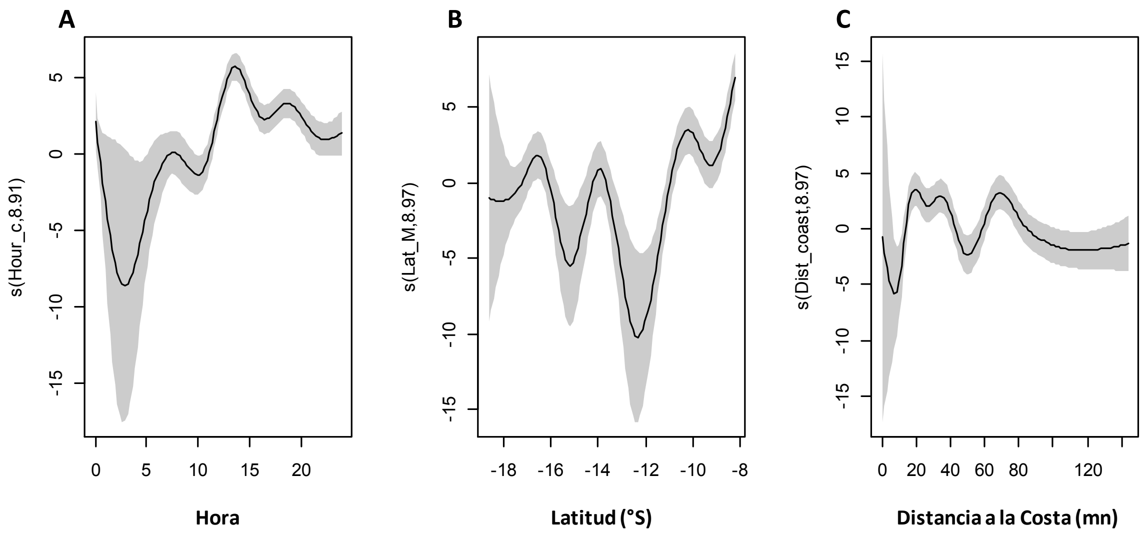


Figure 21. Generalized Additive Model (GAM) for CJM abundance during 2018 in relation to Hour (A) Latitude (B) y distance to the coast (C)

In 2019 the model presented a lower adjustment than in 2018 (25.7%). In the 22A figure it is shown an increasing trend according to the diel cycle; it must be noticed that the fleet operated in summer until completing the fishing quota during March. During that period of time CJM was distributed along the central-south zone, from 12 to 17°S (Figure 22B), showing the denser aggregations between 20 and 70 n.mi. (Figure 22C). During summer-autumn the SSW with salinities over 35.1 psu were distributed near the coast zone (<10 n.mi.) in the central-north zone. However, in the central-south zone these waters were observed out of 40 n.mi. being the denser zones for CJM located in mixed waters between CCW and SSW.

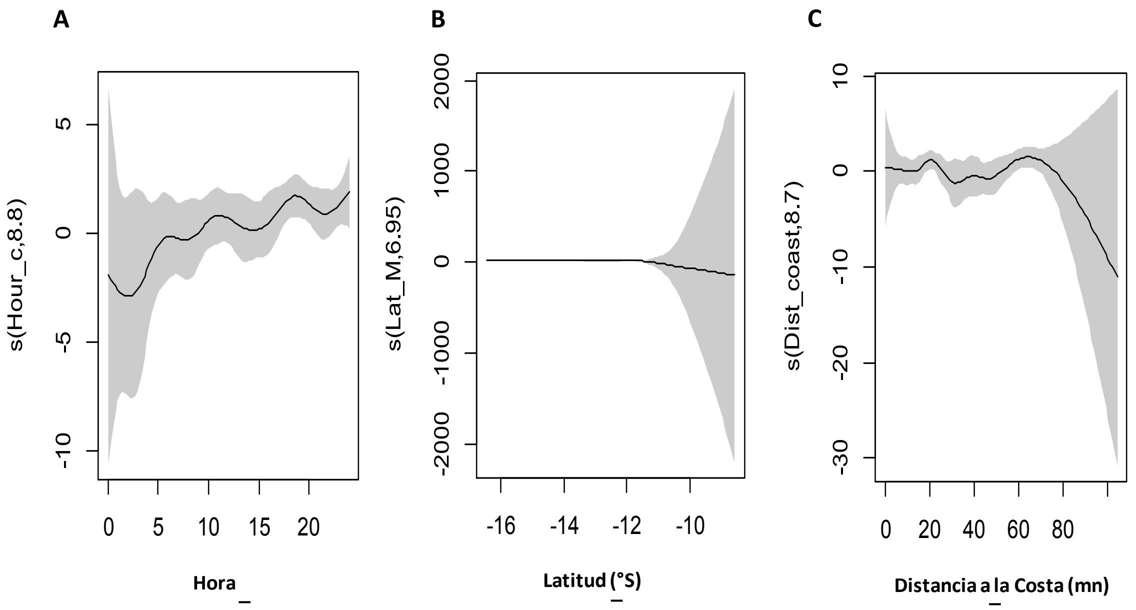


Figure 22. Generalized Additive Model (GAM) for the CJM abundance during 2019 in relation to the Hour (A), Latitude (B), and Distance to the Coast (C).

4.5. **Generalized Additive Model (GAM) for CM abundance**

During 2019, the model of non-parametric regression (GAM) presented an adjustment of 29.1%. In the figure 23A it is not observed a trend for CM regarding the time of the day. Similar to CJM, CM was distributed in the central-north zone from 8° to 11°S (figure 23B) and in the south from 14° to 18°S. CM was distributed up to 140 n.mi. from the coast, with the denser aggregations out of 20 n.mi. (figure 23C).

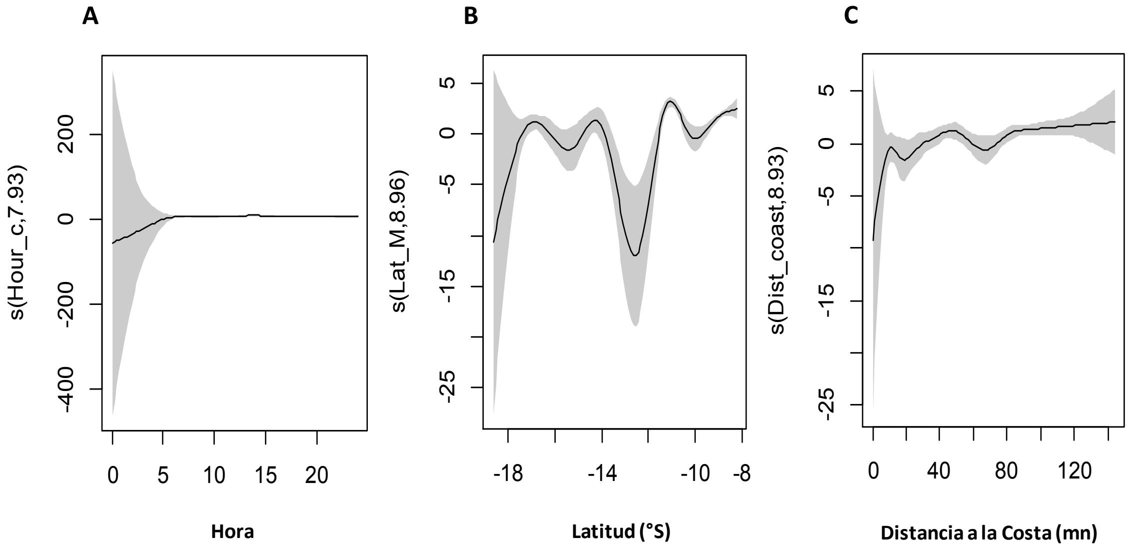


Figure 23. Generalized Additive Model (GAM) for the CM abundance during 2019 in relation to the Hour (A), Latitude (B), and Distance to the Coast (C).

During 2019 the model showed a larger adjustment than for 2018 (40.1%). Figure 24a does not show a trend of the CM abundance according to the time period. In 2019 CM was distributed in the central area from 8 to 10°S. In the southern area it was distributed between 12 to 16°S (Figure 24b); and up to 80 n.mi. from the coast (figure 24c).

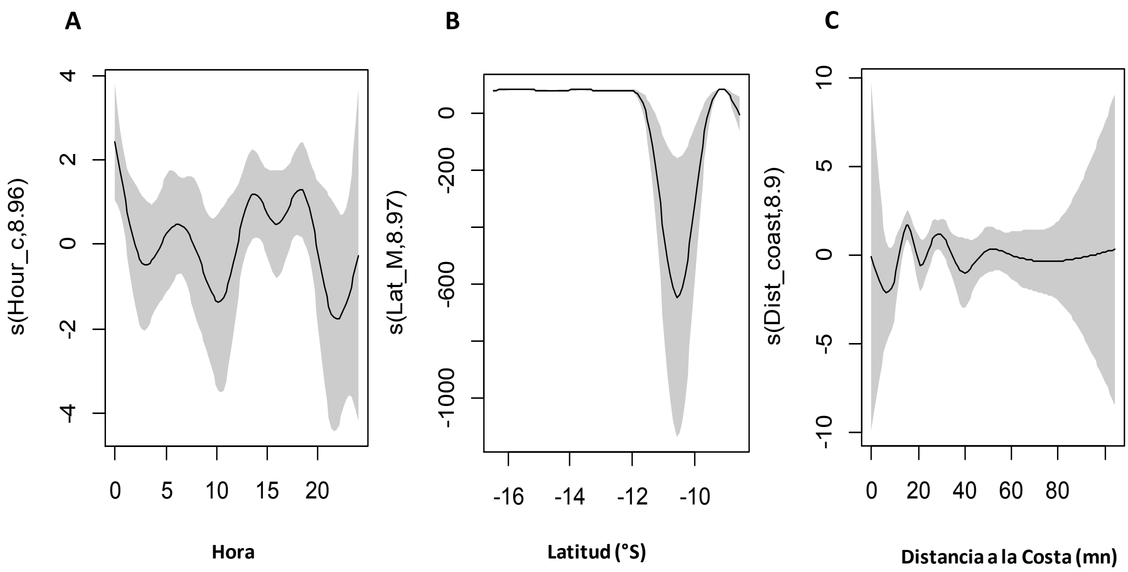


Figure 24. Generalized Additive Model (GAM) for the CM abundance during 2019 in relation to the Hour (A), Latitude (B), and Distance to the Coast (C).

3.6 Relative abundance of macrozooplankton and its relation to CJM

The figure 25 corresponds to summer 2018, on it is observed the acoustic distribution of macrozooplankton (NASC, m^2/mn^2) between Salaverry (8°S) and Callao (12°S), and the black crosses represent the locations of fishing sets to highlight the relatively low zooplankton density.

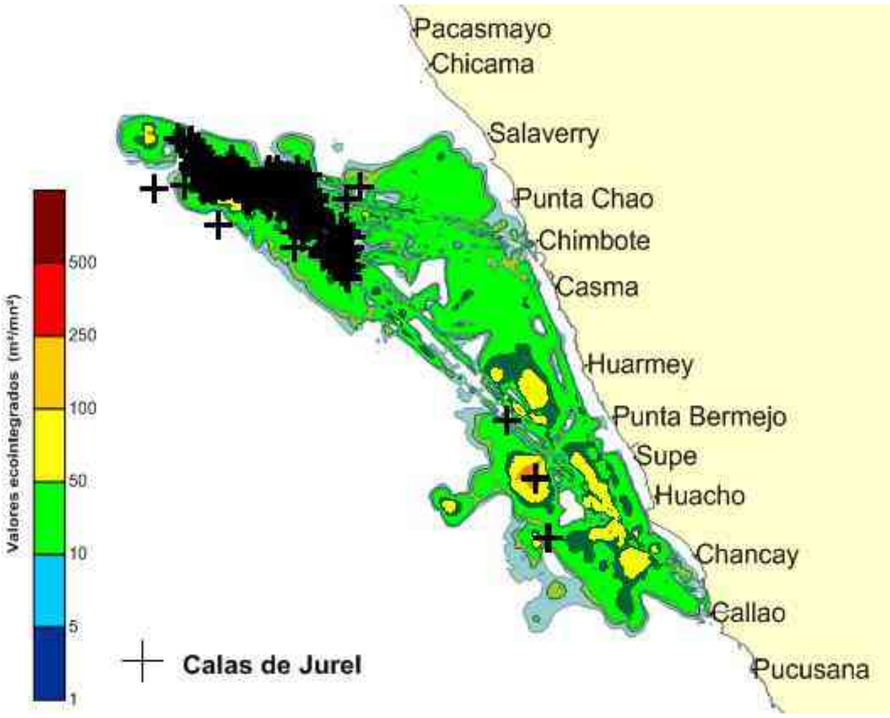


Figure 25. Distribution and relative acoustic abundance (NASC, m^2/mn^2) of macrozooplankton with indication (black crosses) of fishing sets made for CJM during summer 2018.

In the figure 26 it is observed the same kind of information on acoustic density of macrozooplankton during autumn 2018. The fishing sets location are again performed in areas with low density of preys in the area from Punta Chao to Casma.

Figure 26. Distribution and relative acoustic abundance (NASC, m^2/mn^2) of macrozooplankton with indication (black crosses) of fishing sets made for CJM during autumn 2018.

In the figure 27 it is shown the acoustic distribution of macrozooplankton between Casma and Ocoña during spring 2018. This time the fishing sets are observed in the south matching areas of higher prey density compared to summer and autumn of 2018.

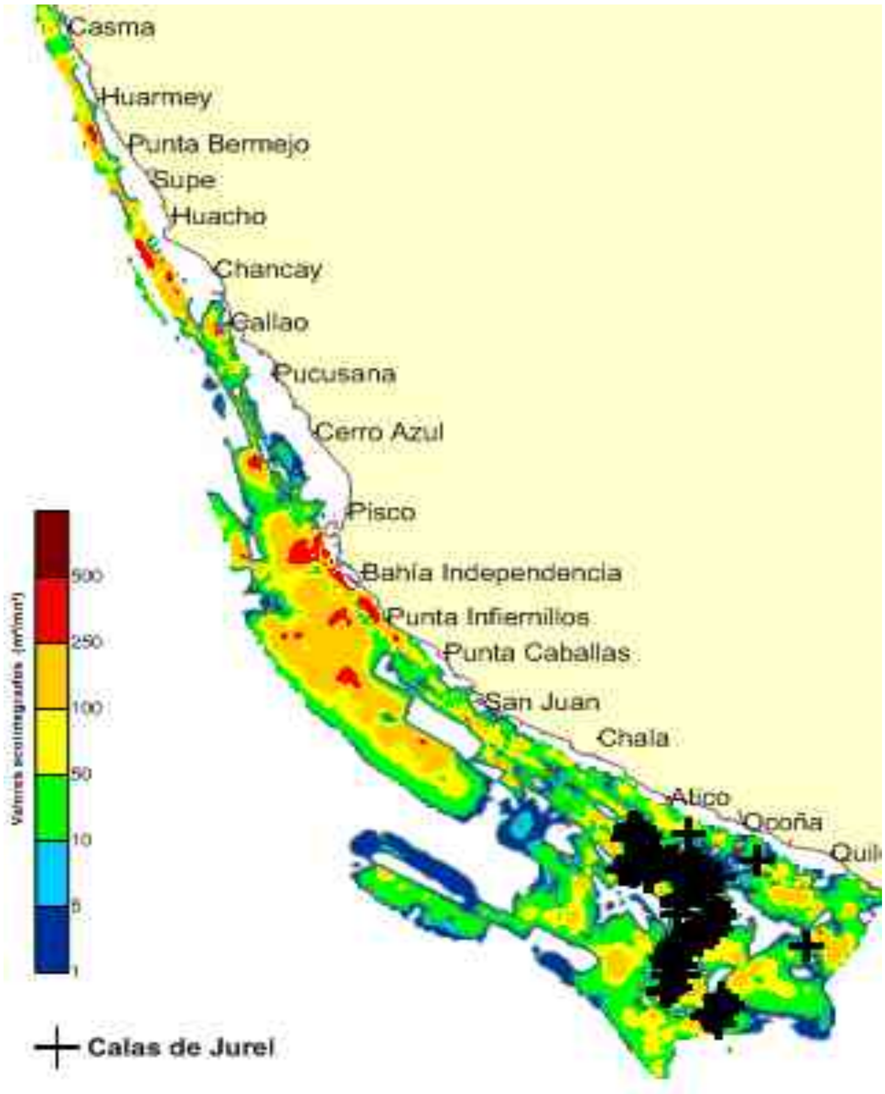


Figure 27. Distribution and relative acoustic abundance (NASC, m^2/mn^2) of macrozooplankton with indication (black crosses) of fishing sets made for CJM during spring 2018.

In figure 28 it is shown the acoustic density of macrozooplankton during summer 2019 from Punta Chao to Ocoña. It is again observed that CJM fishing sets took place in areas of higher density of prey. These observations contribute to sustain the hypothesis about the link between macrozooplankton abundance and availability of CJM in the Peruvian coast.

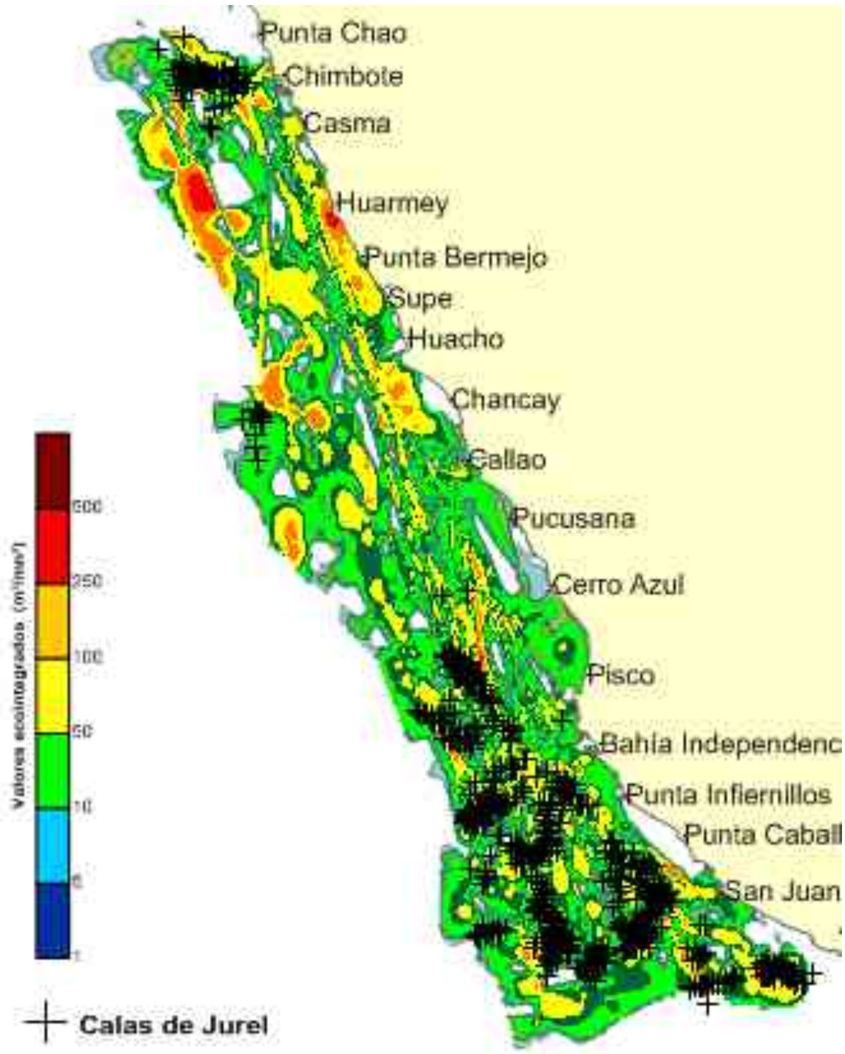


Figure 28. Distribution and relative acoustic abundance (NASC, m^2/mn^2) of macrozooplankton with indication (black crosses) of fishing sets made for CJM during summer 2019.

5. Report on the identification of indexes using fishing and vessel monitoring system data

5.1. Catches

5.1.1. VMS and area of Operations

The Vessel Monitoring System (VMS) data available during the workshop represented 569,327 records. The effective duration of CJM and CM fishing operations during 2018 lasted 7 months, plus 3 months during 2019. In the figure 29 it is shown the month spatial dynamics of the fishing fleet, where the central zone was the main fishing zone during 2018, and the southern zone one during 2019. From this information were obtained operational parameters such as the total trip length (figure 30a) and their duration (figure 30b).

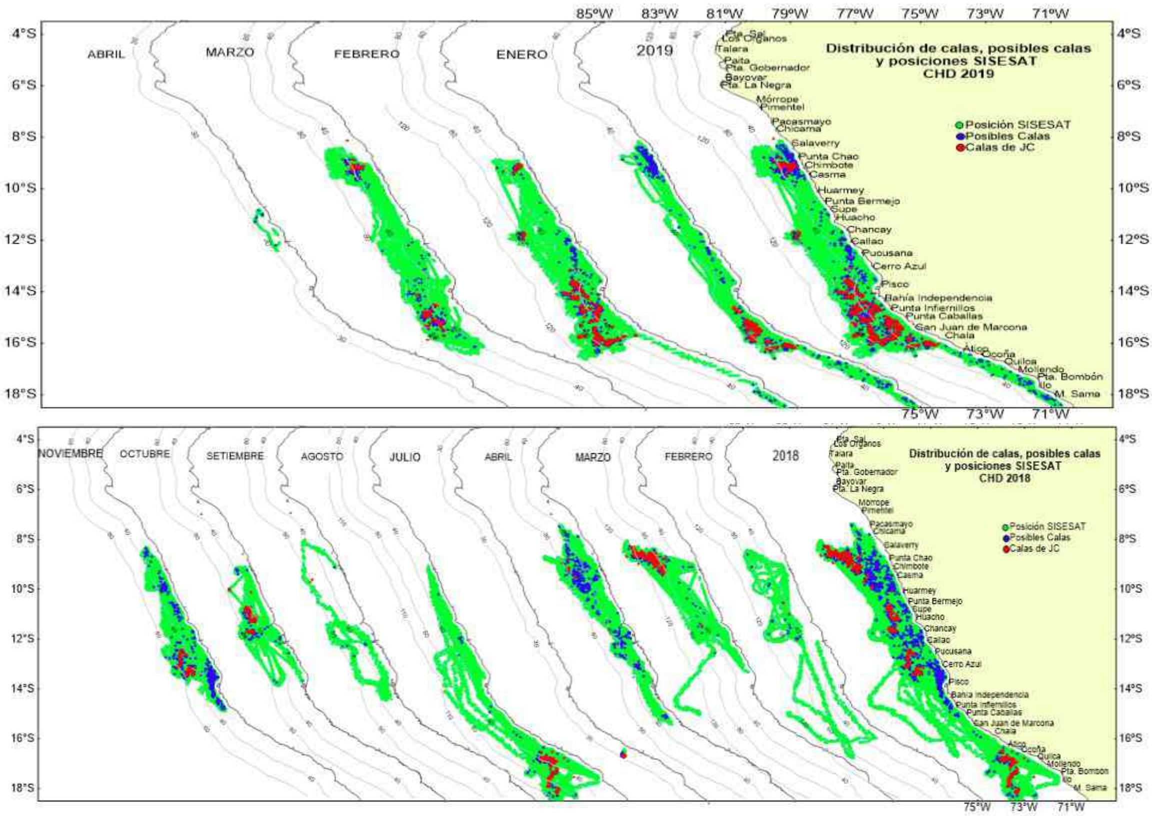


Figure 29. Month spatial dynamics of the CJM and CM fishing fleet during 2018 and 2019. Green dots represent VMS records location, red dots are reported fishing sets, and blue dots indicate low speed VMS records.

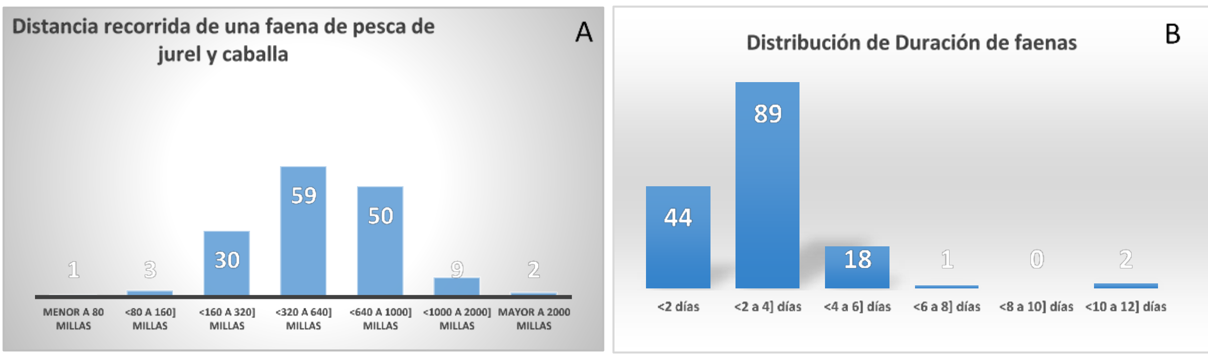


Figure 30a. Spatial dynamics of the CJM and CM fishing fleet during 2018 and 2019. Figure 30b. Distribution of fishing trips according to their duration during 2018 and 2019.

In the figure 31a it is shown the distribution of fishing sets made by fishing trip (from 2 to 10 sets), and the figure 31b shows the distribution of fishing sets according to distance from the coast (from 20 to 100 n.mi.).

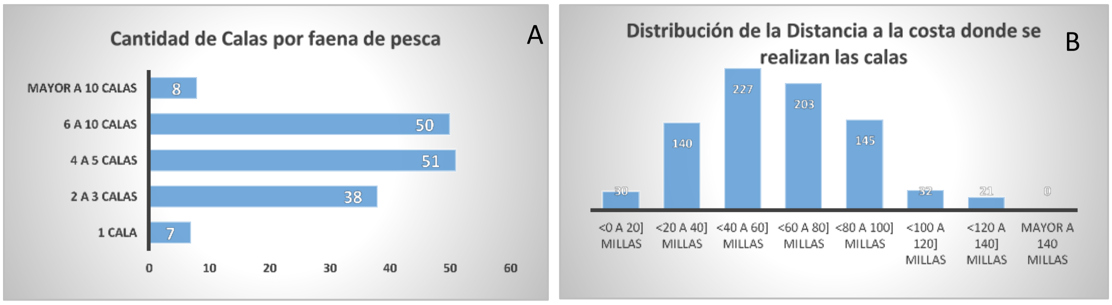


Figure 31a. Number of fishing sets made by fishing trip. Figure 31b. Fishing sets made by distance from the coast during 2018 and 2019.

5.2. Spatial Distribution of fishing sets made on CJM and CM

In the figure 32 there are presented the fishing sets made for CJM (indicated by blue triangles) and CM (indicated by orange circles). The grey dots represent the fishing sets where both species were caught.

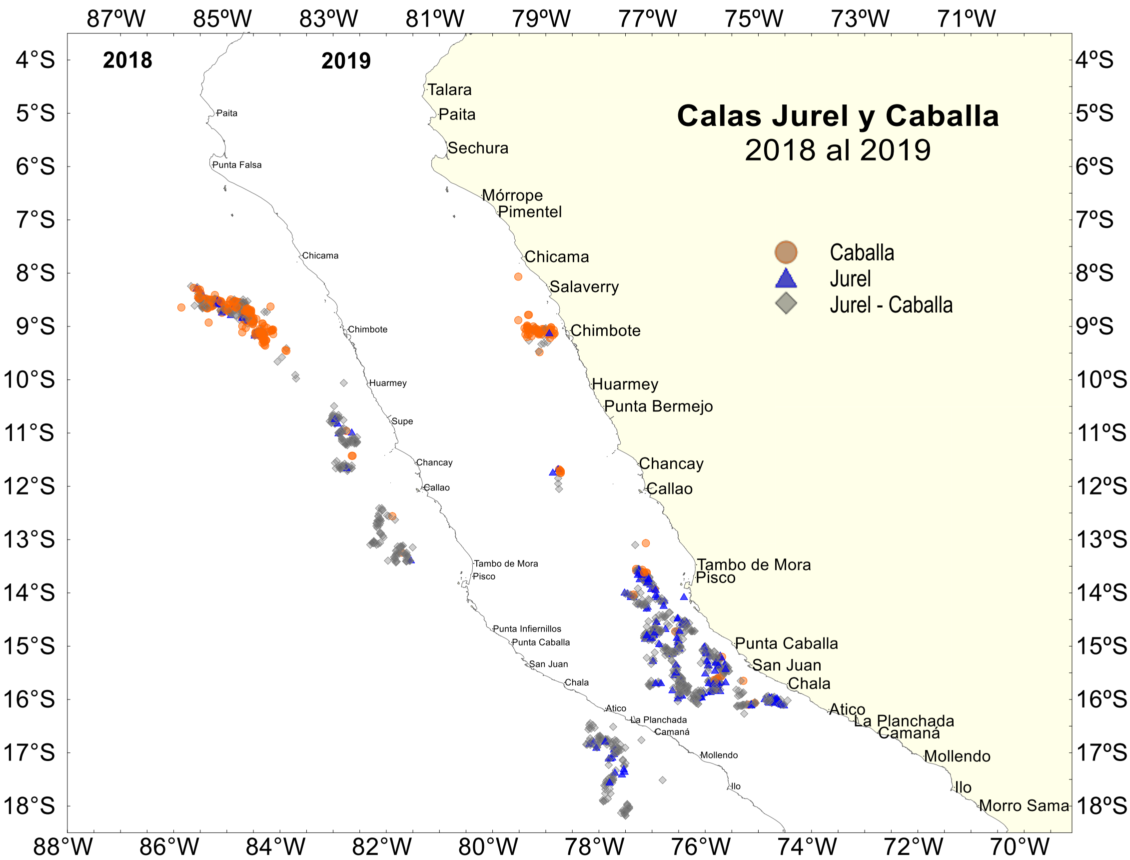


Figure 32. Distribution of fishing sets made on CJM (blue triangles) and CM (orange circles). Grey dots indicate the location of those fishing sets where the two species were caught during 2018 and 2019.

With information consolidated from the VMS and reported fishing sets it has been built the table 5 which summarizes the number of fishing sets made by dates. A total number of 1594 fishing sets are accounted for 2018 and 2019 (until March), with an average of 277 tons per ship/trip during 2018 and 316 tons for 2019.

Table 5 – Consolidated data from VMS and fishing reports during 2018 and 2019. (Mes=month; EP=number of fishing vessels; N° de faenas= number of fishing sets; TM Jurel=CJM catch in tons; % Des Jurel=CJM % en catches; TM Caballa= CM catch in tons; % Des Caballa= CM % in catches; Tm Total= Total catch in tons.

MES	EP	N° de faenas	TM Jurel	% Des Jurel	TM Caballa	% Des Caballa	Tm Total
Ene-18	-	-	-	-	-	-	-
Feb-18	2	2	6	2%	304	98%	309
Mar-18	21	63	896	6%	13,931	94%	14,827
Abr-18	5	6	156	15%	859	85%	1,015
May-18	-	-	-	-	-	-	-
Jun-18	-	-	-	-	-	-	-
Jul-18	-	-	-	-	-	-	-
Ago-18	18	32	7,270	77%	2,202	23%	9,472
Set-18	1	1	46	100%	-	-	46
Oct-18	13	30	9,993	90%	1,104	10%	11,096
Nov-18	15	27	6,903	86%	1,087	14%	7,989
Dic-18	1	1	-	-	150	100%	150
Ene-19	29	48	15,715	83%	3,115	17%	18,830
Feb-19	34	109	29,947	82%	6,704	18%	36,650
Mar-19	25	53	6,687	61%	4,322	39%	11,009
TOTAL	**47**	**372**	**77,618**		**33,777**		**111,395**

Figure 33 shows landings by month during 2018 and 2019 (until March). 2019 surpasses the catches obtained during 2018. The combined catch of CJM and CM shown the largest month landings during January and February 2019.

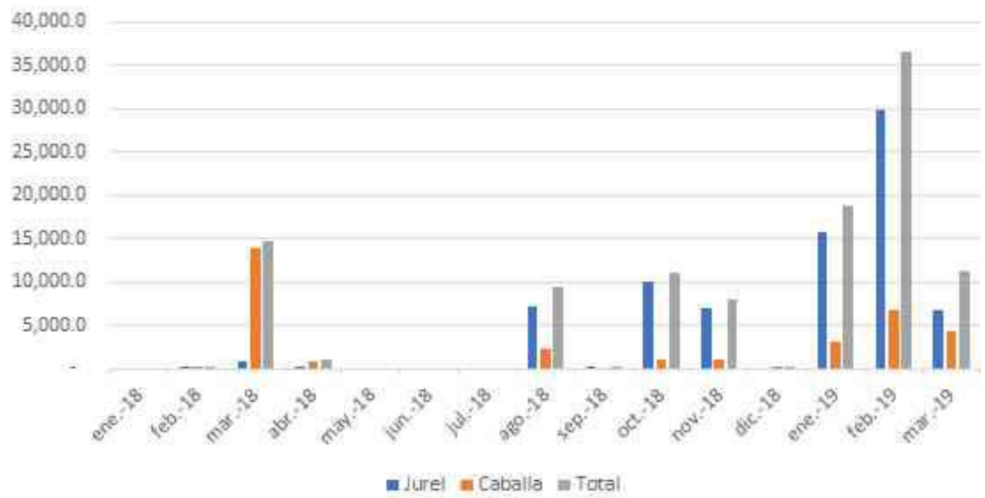


Figure 33. Landings con CJM (Jurel) and CM (Caballa) during January 2018 to March 2019.

5.3. **Catch per unit effort (CPUE) for CJM**

The catch per unit effort (CPUE) represents in relative terms the abundance of CJM. This index allows to detect changes in the catchability and possible environmental factors that impact the performance of the fishery and the state of the population.

CPUE shows a positive logarithmic relationship between the fishing effort and landing during January 2018 to March 2019. It was used information of 372 fishing trips and 1594 fishing sets. The R-squared index calculated for both years show values of 0.62 and 0.66, with a better performance for CJM during 2019.

On figure 34 it is shown the correlation between catches and CPUE for each year. The trend for both years is positive. Furthermore the fishing effort increased in 2019 considering that it was undertaken during three months only (summer).

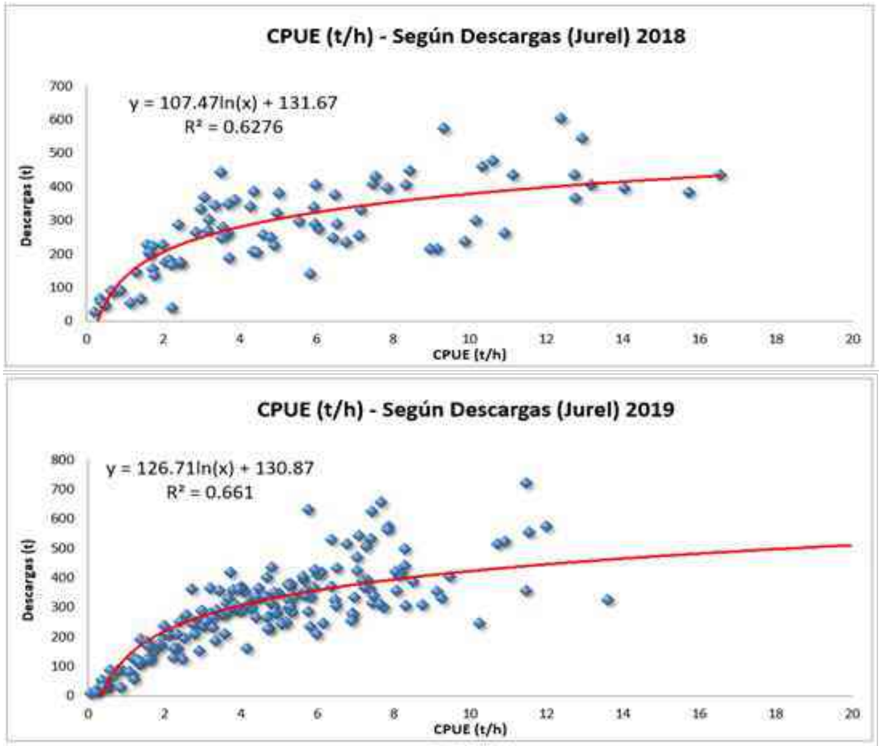


Figure 34. Correlation between catch and CPUE (tons/hour) during 2018 and 2019. The upper graphic shows the performance for CJM during 2018, and the lower graphic shows the one for 2019

6. Report on the identification of indexes using biological and interactions data collected by fishing vessels on top predators

We attempted to determine whether the presence of other species, and particularly species directly observable from the fishing vessels, might be indicative of jack mackerel (and more generally mackerel) habitat, either because the species shares an attraction to certain features of habitat (e.g. physical tolerance range, prey type), and/or the other species are attracted to the fishing operation. If associations between jack mackerel and other species is robust and independent of fishing, it may be possible to create indicators of the likely presence of the fish through observation of surface phenomena. We note that two types of indicators are possible:

- **Positive Indicators**: Sightings associated with a higher probability of the presence of target species, and/or a higher proportion of target species.
- **Negative Indicators**: Sightings associated with a higher probability of by catch species, smaller (i.e., juveniles) target individuals, smaller schools, or other less desirable aspects of the fishery.

6.1. Methods and reasoning

To undertake this exploratory analysis, we used data collected on TASA vessels fishing for jack mackerel and horse mackerel off the coast of Peru in 2018 and 2019. In total there were 14 vessels fishing during March, August, October and November in 2018, and January through March in 2019, and transiting 116,068 nautical miles. During this period, 294 sightings of non-fish on the surface were made, of which 277 (94%) were identified to species.

We note that a second much smaller dataset on releases of non-target organisms associated with the fishery (N = 21) was also available, but was not included in the analysis because the overlap in taxa was small (only pinnipeds overlapped as a taxonomic category, and only one pinniped was included in the release dataset).

Sightings included standardized information collected by ship personnel on the half hour that were, ideally, continuous over the entire trip. We divided the sightings data into two general categories, according to whether the observation was of something on the surface, or from the echosounder (that is, sub-surface). For surface observations, only data on non-fish species was used. These included the larger taxonomic categories of whales, dolphin (small cetaceans), pinnipeds, sea turtles and marine birds. For each of these categories, species level information was available for almost every observation. We constrained the observations to daylight hours (0500 – 1800; 73% of the total nonfish surface sightings dataset), as it is shown in Figure 35.

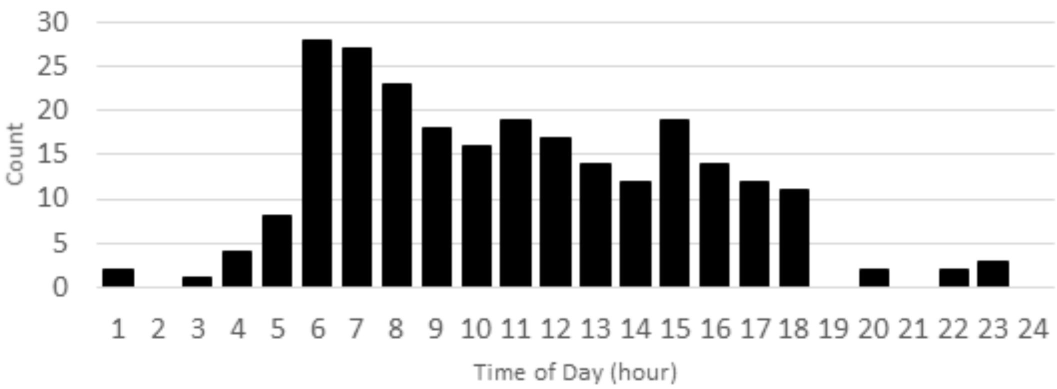


Figure 35. Diurnal distribution of non-fish surface sighting during 2018-19 jack mackerel and horse mackerel fishing trips

The observation protocol dictated that a complete set of observations be recorded in the logbook for each half hour the vessel was underway. Data were recorded in a variety of ways, including blanks and zeroes when organisms were not seen, and "X", checks and a range of numbers when organisms were seen. In addition, comments sometimes included information about estimated abundance of one or more species. Therefore, although there are observations with an abundance estimate, the majority of the observations were interpreted as presence/absence (e.g., check mark versus zero; mark versus blank). To maximize the dataset, we used all data as presence only.

Logbook information was translated into a database including a number of variables taken every 30 minutes such as vessel name, date, time, latitude, longitude, sea surface temperature and several others related to species identification and relative abundance. Because only lines when something was observed were translated, it will be necessary to return to the raw data if time-based effort is needed. Although the fleet operated in the same general area, the number of sightings was very different across the vessels, with a high of 53 and a low of none.

Vessel Code	Number of Sightings
1	53
2	43
3	30
4	26
5	23
6	20
7	18
8	16
9	12
10	4
11	3
12	3
13	2
14	0

This distribution suggests that some crew members may not be recording all of the organisms present, and may indicate the need for further training. A planned data collection app may greatly improve sampling.

The majority of sightings were of marine birds; however, when examined at the species level, southern fur seals and dusky dolphin were the most numerous sightings (Figure 36).

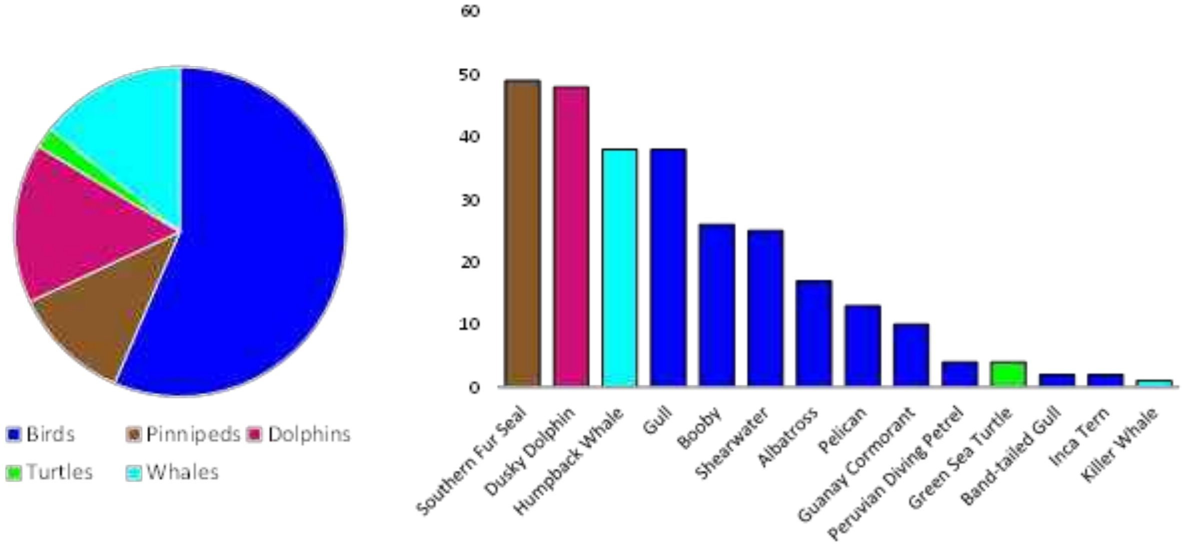


Figure 36. Sightings of non-fishing species by group of species (left) and by species (right)

Sightings were not spread evenly over calendar time. When the data were examined by season, the vast majority of sightings occurred in the summer months (January, February, March), with data from 2018 and 2019 combined (left graph in figure 37). However, fishing effort was also not evenly distributed. When effort (proxied by miles traveled fleet-wide) is accounted for (right graph in figure 37), sightings rate was approximately equal in summer and winter (represented in the dataset only by August).

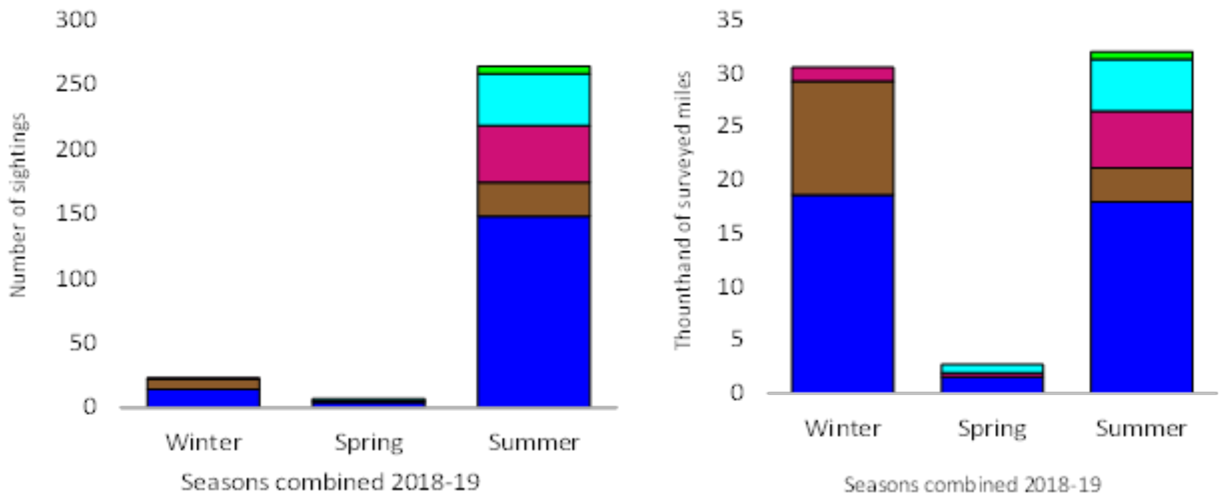


Figure 37. Number of sightings by seasons (left) and by travelled nautical miles (right)

Other patterns to note include the presence of whales predominantly in the summer, the almost equivalent sightings rate of birds in summer and winter (see right graph in the figure X above), and the increased rate of sightings of pinnipeds in the winter versus the summer, with the opposite pattern for dolphin.

6.2. Hypotheses:

To understand whether and how these organisms may provide additional information on the habitat of jack mackerel, we constructed four non-exclusive hypotheses based on a simple conceptual understanding of the system. In this concept, marine organisms arrange themselves in space according to geo-physical variables like temperature or distance to a fixed (e.g., coastline) or moving (e.g. eddy) feature; biological variables like the presence of prey or competitors; and fishery-associated variables like the presence of actively fishing vessels. In our concept of the system, organisms may assort according to any/all of these variables, and individual species may behave differently. In fact, even within a species there may be differences according to the life history and natural history of the organism.

Habitat Hypothesis: The taxon and abundance of sightings are related to fixed geographic features, including but not limited to distance from shore and distance from the shelf edge. A second form of this hypothesis predicts that taxa are more likely to be found in particular water masses, even if they are variable in space. This hypothesis assumes that organisms occupy specific marine habitats, and are more likely to be found there.

Predictions if this hypothesis is true: Some taxa will be found associated with specific geographic and/or oceanographic features.

Ecosystem Hypothesis: The taxon and abundance of sightings are related to the presence of fish (or fish schools) in the area. This hypothesis assumes that "surface" organisms aggregate in the vicinity of fish, and that there may be relationships between the taxon of fish, size of the school, length frequency distribution of the fish, or depth of the school, and the number and taxon of the sightings.

Predictions if this hypothesis is true: At least some taxa will be found in association with fish as detected on the echosounder. There may be a relationship between surface sightings and the species of fish, and/or the size of the school. Surface sightings may be present in association with the first catch, and will be present before fishing starts.

Fishing Hypothesis: The taxon and abundance of sightings are related to the fishing operation. That is, the act of fishing attracts certain organisms. Note that this hypothesis predicts that the first set would not necessarily have a higher than normal sighting rate immediately before the set, whereas subsequent sets in the immediate area would have much higher sightings rates.

Predictions if this hypothesis is true: Surface sightings will be associated with active fishing, and the sightings rate should increase as fishing intensifies (proxied by size of catch, or number of catches within a restricted space and/or time, including by multiple vessels). This hypothesis is different than the one above in that the "fish attraction" hypothesis would predict an a priori relationship between surface taxa and the presence of a school, detectable before fishing started.

Hotspot Hypothesis: The taxon and abundance of sightings are related to each other, and will be found clustered in space, without necessarily being related to other features (habitat, fish, fisheries). This hypothesis is divisible into subhypotheses:

1. Hotspots are fixed in space.
2. Hotspots are variable (ephemeral) in space.
3. Hotspots are related to oceanographic features (e.g., eddies) which move through space.

Predictions if this hypothesis is true: At least some taxa – surface and subsurface - will often be found in the same location and/or together regardless of location.

Because of the vessel-based differences in sightings, we used the dataset differently depending on question. For habitat-based questions, we used the entire dataset; for ecosystem and fishing questions we used data from the two vessels with the highest number of sightings.

6.3. Results relevant to hypotheses

Sightings occurred throughout the area of the fishery, which was centered along and just west of the shelf break (figure 38).

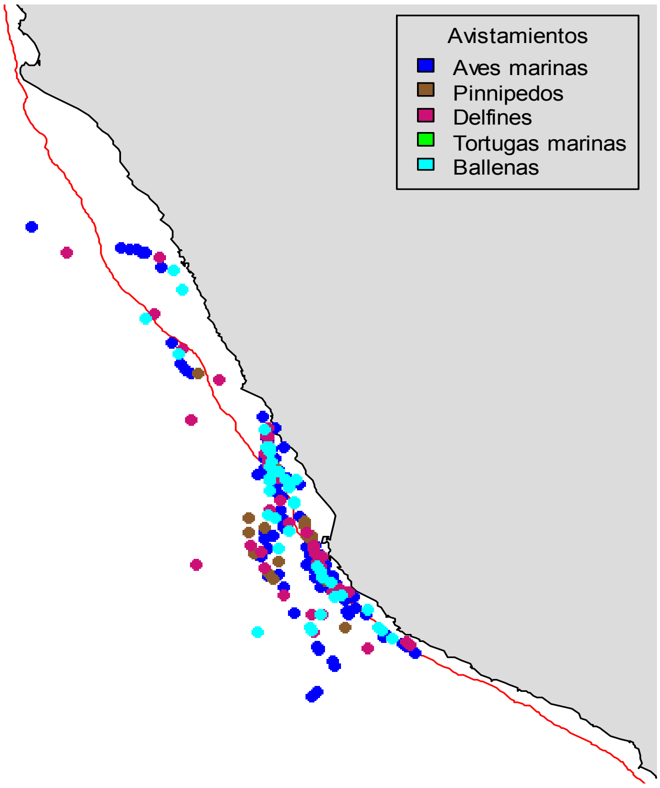


Figure 38. Total diurnal available sightings 2018-19

Measures of central tendency (Figure 39, mean and standard error) did not reveal strong taxon-specific patterns in the distribution of sightings with respect to fixed geographic features (distance from shore in miles – left graph) or oceanographic parameters (sea surface temperature, degrees centigrade – right graph). There was a weak indication that dolphin were found farther offshore.

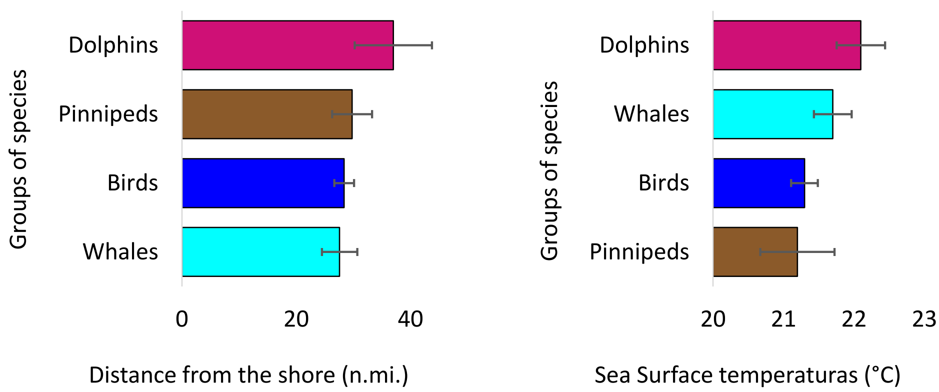


Figure 39. Mean value and standard deviation by group of species. Left is distance from shore in miles; right is sea surface temperature at the sighting from the vessel.

Further consideration of birds by species, using those taxa for which there were ten or more sightings (gull, booby, shearwater, albatross, pelican, guanay cormorant) indicated these species could be seen anywhere within the fishery. Collectively, these data do not suggest that, at least within the physical bounds of the Peruvian jack mackerel fishery, these taxa are strongly assorting according to simple habitat characteristics.

To explore potential relationships between sightings and the fishery itself, we concentrated effort on those vessels that had the highest number of sightings. With the VMS tracks (summer 2019 only; 5 trips for which the VMS and catch location data intersect) of the single best vessel examined, it appears that there is no relationship between where sightings occur and the catch locations of either jack mackerel or horse mackerel, and specifically that the majority of the sightings occur along the portion of the track when the vessel is either running out to the fishing grounds, or returning from it (Figure 40).

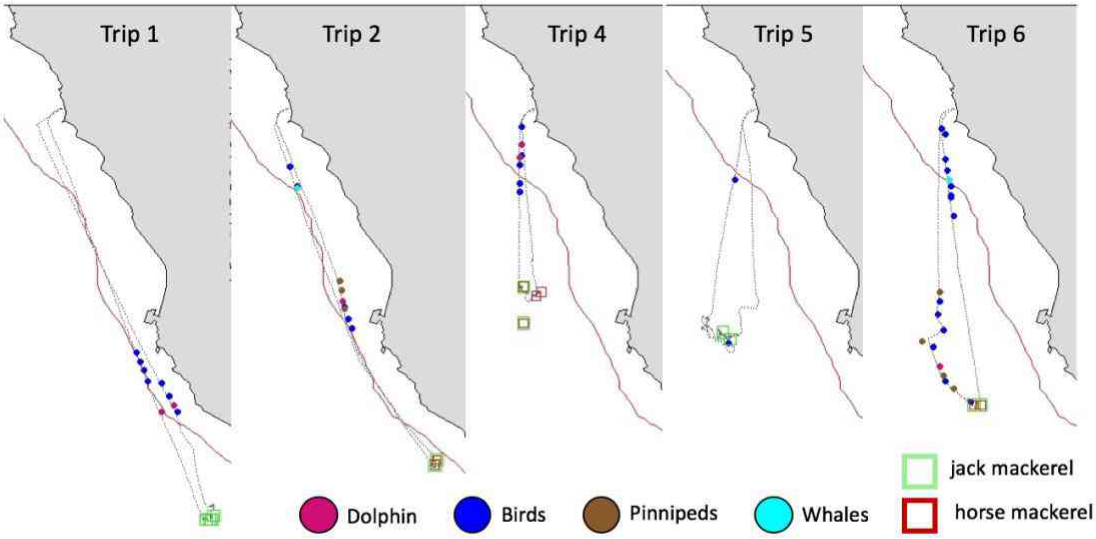


Figure 40. Selected fishing trips of vessels with largest number of sightings according to VMS data

However, when these same VMS tracks are overlaid with acoustic density from the echosounder, it appears that there is a relationship between sightings and the co-occurrence of anchovy, although this analysis is still in its infancy (Figure 41).

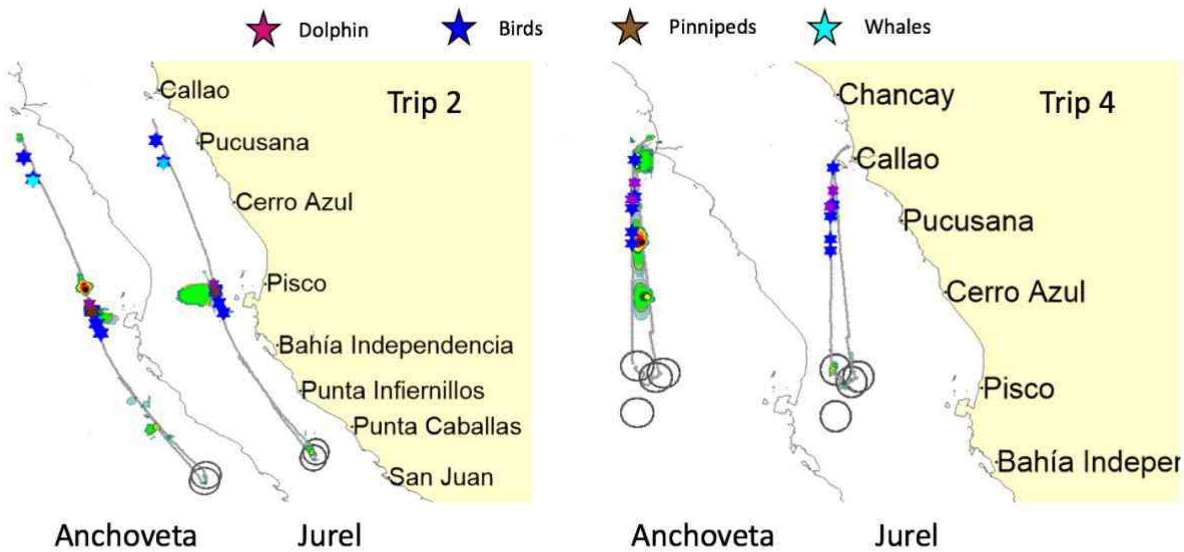


Figure 41. VMS tracks, sightings and acoustic density along selected fishing trips.

7. Conclusions and recommendations

Three key results were detailed during the workshop: (1) the evolution of the distribution of CJM and other species in the Peruvian Current in the Humboldt System during 2018-2019; (2) the description of new methods and models; (3) and a definition for the CJM Habitat.

1) Evolution of the distribution of CJM and other species in the Peruvian Current during 2018-2019. From the analysis of catch and oceanographic data the following main results were presented:

- Demographic distribution. Both CJM and CM presented a bimodal distribution, being CM smaller one and mostly juvenile (mean length 15 cm). For CJM there were observed older and bigger individuals (modes in 26 and 33 cm). In both cases the age structure was younger than in previous years. As a conclusion it must be said the new cohorts were observed in 2018 and 2019.
- Catches and abundances presented differences between 2018 and 2019, being the fish mostly distributed in the north during 2018, and mostly distributed in the south during 2019. Catches were also different regarding their distance to the coast, being the fish more available offshore during 2018 and inshore in 2019.
- Oceanographic data was analyzed in order to evaluate their effect on catches. The mean catch per fishing set was around 50 tons. The oceanic conditions where fish were caught were dominated by cold conditions in 2018, while warmer equatorial and subtropical waters characterized 2019. This could be related to differences of the characteristics of fish aggregation under different scenarios, being the fish schools deeper and aggregated in the north during 2018, and more superficial and dispersed in the south during 2019.
- It has also been observed that the development and extension of the anchovy fishing seasons condition or limit the fleet's operation on CJM and CM, given that a number of vessels participate in both fisheries. In other words, the continuity of the fishing operations on CJM and CM depends not only on the quotas granted but also on the duration of the anchovy fishing seasons, mainly in the north-central area.
- The abundance of CJM and CM has been variable throughout 2018 and 2019, with frequent changes in distribution in response to also changing oceanographic conditions. The maximum abundance of CJM has been calculated at around 500 thousand tons, and CM in 600 thousand tons; in both cases these amounts represent only the areas in which the fishing fleet has operated.
- Acoustic density data for anchovy, red squat lobster, vinciguerria and macrozooplankton was for first time available during a CJM workshop. It has been observed a similarity in the aggregation characteristics of CJM, CM and vinciguerria, but also a similarity between anchovy with the red squat lobster. It has also been preliminary noticed that the dispersed distribution of CJM and CM corresponds to a low density of macrozooplankton, while the best catches have been related to higher prey densities.

In synthesis the two analyzed years presented clear differences in the oceanographic conditions and in the spatial distribution of fish, being possible some links between these two aspects. During the workshop it was discussed about the meaning of these potential correlations, although no clear conclusion was given. Instead it was agreed that they are required deeper studies, both on future data and through retrospective analysis.

2) Description of new methods and models

- Improvements of the models. For the first time inputs from top predator observations from fishing vessels were performed. The results showed a weak correlation between the presence of top predators (marine sea birds and mammals) with “territorial data”, it is the presence of the continental shelf, or the distance to the coast. Stronger links could be observed with the "biological data" (presence of anchovies, for instance). This allowed to conclude that it exists a need to elaborate a methodology to produce numeric and conceptual models.

- The existing models on relationships between catches and ecological information gave good results allowing to explain certain changes observed for the two analyzed years. Furthermore they have been used new approaches such as the center mass centers and aggregation indexes to synthetize the distribution patterns on CJM and CM.
- Exploratory analyses made on the relationships between fish abundance and the dynamics of eddies showed a potentially utility for explaining the variability of the distribution of CJM and CM, though some methodological improvement should be required in the future.
- Exploratory analyses based on the geostatistical description of several fish populations were performed on the available acoustic data. Two aspects were achieved: on the relationships between species; and on changes of the dimensions of the aggregations. The found indexes demonstrated to be potentially useful for describing the behavioral dynamics of CJM and other species.
- Some analysis were performed based on VMS data. The proportion of "efficient" fishing sets increased from 68% during 2018 to 72% during 2019. It was detailed a list of aspects to be improved, e.g. the number of errors found regarding the hour of the day (VMS giving a "no catch" result during nighttime while the actual results gave up to 14% of the catches performed during this period). Another aspect to be improved is the confusion in classifying as CJM or CM catches that were made on anchovy.

In synthesis, the defined and applied models proved to be potentially useful, although methodological and technical research should be increased to achieve their practical use for management purposes.

3) Definition of CJM habitat.

This workshop was the first one dedicated to habitat definition, therefore it is not intended here to give already a definition of habitat. Nevertheless some results showed that the existing data is in condition to feed models able to define properly the habitat. The next workshops should try to improve the research on the following aspects:

- Revision of the existing models, in order to reduce the errors and improve their fitness;
- Considering the use of new models that could improve or replace the existing ones.
- Incorporating the routine use of non-conventional information such as top predators, geostatistics, oceanography etc.
- Performing retrospective analysis.
- Building a wider data base that includes the information gathered during previous years. This will require a special attention to the fishing vessels acoustic data quality and technical improvement, as well as exploring other sources of data of potential interest.

A general recommendation for the Habitat Monitoring Working Group (HMWG) is to gather all the preliminary studies, evaluate their potential in answering questions relevant to the HMWG and generalize their use over a more complete set of data. A set of environmental indicators and metrics must be decided to promote their use in the process of management being developed by SPRFMO.

Annex 1: List of participants

Participant	Institution	E-mail
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Group 4: Indexes using biometric and top predators data		
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Annex 2: Agenda

- Miércoles 26 a viernes 28 de junio:

  Actividades previas al taller. Consolidación de las bases de datos:

  1. Bitácora de celdas para la temporada de jurel 2018 y 2019.
  2. Bitácora de regiones para la temporada de jurel 2018 y 2019.
  3. Bitácora de regiones por celdas para la temporada de jurel 2018 y 2019.
  4. Bitácora de calas de jurel (incluyendo cualquier otra especie que se halla capturado).
  5. Bitácora de tallas para jurel y caballa.
  6. Bitácora de data SISESAT para los barcos que participaron en las temporadas 2018 y 2019 de jurel.
  7. Bitácora de datos de CTDO.
  8. Bitácora de depredadores superiores.
  9. Ficheros CSV con información oceanográfica por variables para los años 2018 y 2019.
  10. Infomación oceanográfica (GRD por variables) para los años 2018 y 2019.

- Lunes 1 de Julio de 2019: día 1 del taller

  99jConferencia SNP de sostenibilidad marina

9:00	Bienvenida a los invitados y participantes, a cargo del Dr Ulises Munaylla, Asesor Científico de la SNP
9:10	Palabras de la Presidenta de la SNP, Dra Cayetana Aljovin
9:20	Palabras del Presidente del IHMA, Sr. Ricardo Bernales
9:30	Conferencia de la Dra. Julia Parrish (U Washington). Título de la ponencia: **Monitoreo ecosistémico en el ambiente marino vía la Ciencia Ciudadana (Effective Ecosystem Monitoring in the Marine Environment via Citizen Science)**.
10:10	Conferencia del Dr. John Horne (U Washington). Título de la ponencia: **Caracterización del hábitat de peces pelágicos usando datos acústicos (Characterizing Pelagic Fish Habitat with Acoustic Data)**.
10:50	Pausa café
11:05	Conferencia del Dr. Francois Gerlotto, Presidente del Comité Científico del IHMA. Título de la ponencia: **Elementos ecológicos y comportamentales para la definición de un hábitat pelágico (Some ecological and behavioral elements for defining a pelagic habitat)**.
11:45	Rueda de preguntas
12:00	Fin de la conferencia.
14:00	Inicio del taller, revisión de la Agenda y coordinaciones previas
14:20	Exposición sobre los objetivos del taller, a cargo de Mariano Gutiérrez (IHMA).
14:30	Exposición sobre los Términos de Referencia del HMWG, a cargo de Mariano Gutiérrez (IHMA).
14:40	Exposición: **Programa de monitoreo y de conservación de la biodiversidad marina, CuidaMar**, a cargo de Rosa Vinatea (TASA).
15:00	Exposición: **Uso de las ecosondas comerciales FCV30 para el estudio de jurel y su hábitat**, a cargo de Martín Santibañez (CFG-Copeinca).
15:20	Exposición: problemas relacionados con los nuevos sistemas ES80 (Salvador Peraltilla, por consultar y confirmar).
15:40	Receso

16:00 Exposición: **Relación entre la anomalía de la superficie del mar, la vorticidad en el océano y las capturas de la flota industrial de cerco durante las temporadas de pesca del año 2011**, a cargo de Susan Montero (IHMA).
16:15 Exposición: **Relación entre la ZMO, los procesos de convergencia y su relación con la abundancia de zooplancton y peces**, a cargo de Nathaly Pereyra (CFG-Copeinca).
16:30 Exposición: **Protocolo para la estimación de la biomasa, abundancia y distribución de la anchoveta empleando ecosondas digitales de la flota pesquera**, a cargo de Diana Lozada (SNP-IHMA)
16:45 Organización del trabajo por grupos y distribución de la data.
17:00 Fin de la jornada

- Martes 2 de Julio: día 2 del taller

9:00 Inicios del trabajo por grupos
12:30 Almuerzo
14:00 Reinicio
17:00 Fin de la jornada

- Miércoles 3 de Julio: día 3 del taller

9:00 Inicios del trabajo por grupos
12:30 Almuerzo
14:00 Reinicio
17:00 Fin de la jornada

- Jueves 4 de Julio: día 4 del taller

9:00 Inicios del trabajo por grupos
12:30 Almuerzo
14:00 Exposición de resultados por grupos y sesión plenaria.
17:00 Fin de la jornada

- Viernes 5 de Julio: día 5 del taller

9:00 Resumen del día anterior
9:30 Redacción de informe resumido por grupos
12:30 Almuerzo
14:00 Consolidación de informe
16:00 Redacción de las principales conclusiones y recomendaciones
17:00 Ceremonia de clausura del taller