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Bibliographical synopsis on the main traits of life of *Trachurus murphyi* in the South Pacific Ocean

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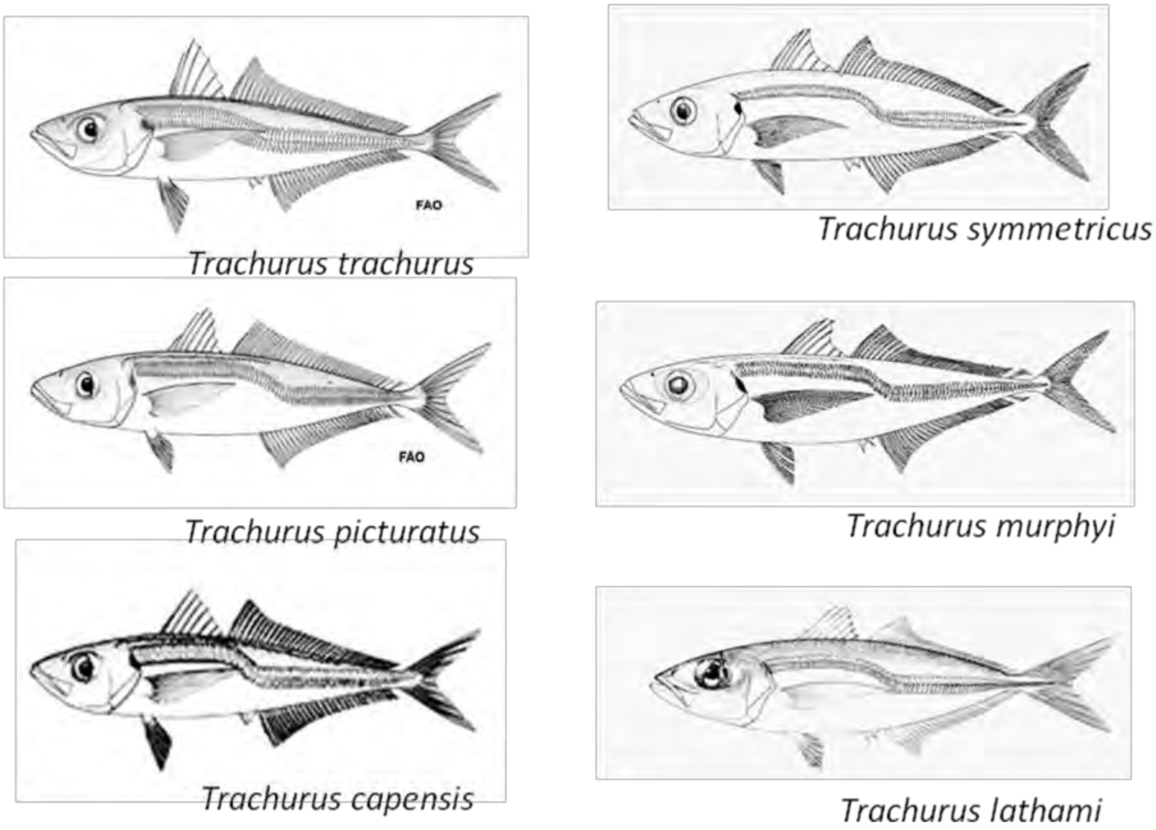
Introduction

The *Trachurus murphyi* (Nichols, 1920), or Chilean Jack Mackerel (CJM) is one of the most extended exploited stocks in the world, and an international fishery has developed on this species, reaching up to almost 5 million tons of catch. It has a great economic importance and is the principal fisheries resources of Chile, and one of the most important for other countries such as Peru and Russia.

The CJM is a typical species of the genus *Trachurus*, which gathers 16 species. All *Trachurus sp*. are physically very similar to the type species, *Trachurus trachurus* (fig. 1).



Trachurus trachurus

Trachurus symmetricus

Trachurus picturatus

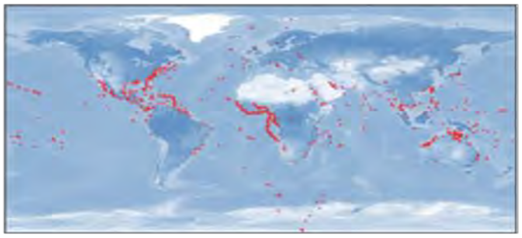
Trachurus murphyi

Trachurus capensis

Trachurus lathami

Figure 1. Drawing of six species of genus *Trachurus* (from FAO)

Biologically they are characterized by wide extensions (fig. 2) in the subtropical areas (with exception of *T. lathami, T. indicus* and *T. trecae*, which are sub-tropical and tropical); most of the species (including *T. murphyi*) have a rather long life, reaching 15-20 years old or above; sexuality is standard, with no sexual dimorphism, and fish are mature at length 20-30 cm (2-4 years old); spawning is pelagic; fish display daily cycle movements, present at up to 300 m deep by day (in most of the species they are demersal feeders on benthic fauna during this period of the day) and closer to the surface by night (eating on micronekton); the diet is mostly made of crustacean (especially Euphausiids), fish larvae, cephalopods; most of the species are related to the continental shelf and rarely observed in the open ocean.



World distribution of *Selar crumenophthalmus* *(from Fish Base)*

Figure 2. Distribution and extension of the major species of genus Trachurus in the world

Apart the shared general characteristics, *T. murphyi* presents also several particular features that differ from the average biology of the genus. For instance it has by far the widest extension, and in some extreme occasions it seems that this species was covering the whole subtropical area of the Southern hemisphere and was observed in the South Pacific (from the South America's coastline to New Zealand and Australia), but also the South Atlantic (observed in Argentina and South Africa) and even the Indian Ocean along the east coast of South Africa (Nakamura et al., 1986). Contrarily to the other species (with exception of *T. symmetricus* which presents a rather similar biology), it can be found both over the continental shelf and in the open ocean; the continental shelf is not indispensable for this fish, and interestingly although the vertical daily migration exists, it is not used for feeding on the shelf (at least for the part of the stock living offshore), but in most of the cases for resting (Bertrand et al, 2004). We may also note that there is a significant proportion of very large-very old adults along the coast of South America, the largest individuals reaching 80 cm (even up to 1 m for *T. murphyi* according to fisheries observations in the early 20th century in Peru (?) see chapter 4-A); this characteristics is shared by *T. symmetricus* and *T. capensis* where fish as long as 81 cm were found. A particular characteristic of the South Pacific environment explains probably most of the differences between *Trachurus murphyi* and the other

Trachurus, i.e. the existence of the El Niño Southern Oscillations (ENSO), which induce huge variations in the environmental conditions to which the fish must adapt.

Curiously, rather few scientific researches have been published on the CJM before the 2000s, and we numbered less than 100 publications in international journals in the bibliography, among which more than half of them are older than 30 years and purely descriptive. This is probably due to the fact that until the late 90s, only 3 countries were exploiting the CJM and the works produced were principally published as grey literature or in national series in Chile, Peru and the Soviet Union (until 1992) (e.g. final report of scientific projects; series from the Instituto de Fomento Pesquero, Chile; Informe del Instituto del Mar del Peru; etc.). Moreover, the difficulties to study a species distributed in such a wide area made the research extremely expansive and therefore rather infrequent. This has changed when the CJM fishery suffered two changes: the interest of several countries from outside of the south Pacific, e.g. China, E.U., Cuba, etc. in exploiting this resource and a strong decrease of the abundance beginning in the late 90, where the catch dropped from several million tons to around 500 000 tons since 2010. In 2006 was created the South Pacific Region Fisheries Management Organization (SPRFMO), committed, among other tasks, to produce scientific analyses and recommendations for the management and assessment of the CJM. Since this period, a growing scientific interest on the CJM has appeared and an important body of works has been published, but again mostly in grey literature and communications to the SPRFMO Scientific Working Group (since 2013, Scientific Committee).

A good synthetic not on the CJM was given by SPRFMO in a document published in July, 2008 (SWG-JMSG-02). We cite extensively the six points that this synthesis presented as results/questions.

- *There is clear evidence that jack mackerel abundance and distribution patterns, and therefore probably stock structure, are strongly influenced by oceanographic and environmental factors. These factors affect jack mackerel abundance and distribution patterns over different spatial and time scales, from within-year influences on migration and spawning patterns, to large-scale decadal shifts in distribution and abundance.*
- *During suitable oceanographic conditions, stocks of Chilean jack mackerel are clearly capable of undergoing rapid and substantial expansions, such as the substantial increase in abundance, and apparent increase in distributional range of jack mackerel across the south Pacific, between the mid-1980s and mid-1990s.*
- *Key issues to try and understand in relation to such expansions include whether these result from simultaneous increases in different stocks in response to large-scale and/or long-term climatic changes and oceanographic events, or whether these primarily result from substantial expansion of one major stock (such as the southeast Pacific Ocean stock), with subsequent separation of the increased biomass into separate stocks in different ocean regions (such as a southwest Pacific Ocean stock previously proposed by some authors).*

> - *Under the latter scenario, the question then arises as to whether such stocks become self-sustaining, or whether they slowly decline, unless sustained by further influx of jack mackerel from the east. In either case the question also arises as to presence and level of any mixing with the original parent stocks to the east.*
> - *It is important to use a wide variety of data and techniques to evaluate linkage / separation between jack mackerel in different regions, in order to develop scientifically objective and robust definitions of stock structure. Different techniques or data can provide different results, and integration of a number of methods is required. The approach taken by the HOMSIR project provides a good example of an effective multi-disciplinary research programme.*
> - *The strong influence of environmental factors on every aspect of jack mackerel distribution indicates that environmental or oceanographic factors are likely to play a strong role in determining the boundaries between stocks. Potential stock structure hypotheses based on other data should be tested against oceanographic information wherever possible, to ascertain whether oceanographic evidence supports or refutes the proposed stock boundaries.*

Among the major questions listed by SPRFMO, the principal were the **Population structure**. In order to provide sound recommendation, a correct understanding of how the population is structured is essential. In 2008, a series of hypotheses were defined during an international workshop organized by SPRFMO in Reñaca, Chile, and we cite here the part of the same document where the list was detailed:

> *"There have been a number of competing stock structure hypotheses, and up to four separate stocks have been suggested: a Chilean stock which is a straddling stock with respect to the high seas; a Peruvian stock which is also a straddling stock with the high seas; a central Pacific Ocean stock which exists solely in the high seas; and, a southwest Pacific Ocean stock which straddles the high seas and both the New Zealand and Australian EEZs. However, further collaborative research is required to confirm and/or clarify this hypothesised stock structure as a basis for effective management regimes."*

Recommendations were made to produce research in several domains.

Biology. The main characteristics of the CJM biology were explored, and many works have been performed, essentially on the reproduction (spawning areas, egg and larvae distribution, spawning areas and seasons, etc.) that allowed a rather good knowledge of this domain. Nevertheless the works have been performed by different teams on limited parts of the area (mostly the Chilean EEZ and its western extension to open sea by Chilean and Russian teams; the Peruvian EEZ by Peruvian scientists; the mid-ocean by Russian scientists) and a synthesis of these results has not been produced so far. Another important research was produced on the growth characteristics of this fish, but here too the results concerned separate areas, and it is not yet certain whether the differences observed in the growth curves are explained by differences due to the study of different parts of the same stocks (in this case, they are likely due to adaptation of the population to different hydrological characteristics) or by the existence of different populations or sub-population (depending on populations characteristics). Other works have been made on genetics, parasitism, otholiths characteristics, fish behaviour, etc.

Habitat. Due to the wide extension of the population, knowing the potential habitat of the CJM is essential, particularly in order to be able to extrapolate the scientific observations (mostly through acoustic surveys) performed in geographically limited “windows” to the whole area. This important question is new and no scientific paper has been produced that could be considered as a reference so far. Nevertheless it exists a growing body of knowledge on the interactions and reactions of the CJM to the principal hydrological parameters (temperature, salinity, oxygen, currents, etc.) which should be synthesized.

Stock assessment. A need for an adapted common model for stock assessment appeared rapidly because of the multinational aspect of the fishery. The SPRFMO developed a model from the existing ones applied on rather similar populations, in terms of dimension, distribution and fisheries, i.e. the Walleye Pollock. Nevertheless it is admitted that this model is likely to evolve into a more adapted tool, once the actual structure of the population be identified. It was also admitted that due to the strong influence of an instable environment submitted e.g. to the ENSO events, it would always remain a part of unpredictability in the dynamics of this species, and questions on the need of a constant monitoring arose.

Evolutionary strategies of the Chilean Jack Mackerel. We observed that the CJM’s biology is rather similar to those of the other species of this genus, and particularly *T. symmetricus* and *T. Trachurus*. It shares also a peculiar characteristic with at least *T. trachurus* according to the works of the EU Project HOMSIR, i.e. a low genetic diversity. This is the indication that this species has suffered in its history a series of collapses and demographic explosions, maintaining its unity. Among the adaptations to its environment and particularly to ENSOs, *T. murphyi* developed capacities to present from time to time extremely successful recruitments, and the population is then dominated by a strong generation that “rules” the dynamics –and the fishery- of the species during a decade or more. Such high recruitment appears irregularly at a rhythm of one each 5-10 years. Curiously, in general the population strategy designed through natural selection by a given species is poorly taken into account in assessment programs. Nevertheless in the particular case of the CJM, according to its spatial and dynamic characteristics, a good knowledge of this specific strategy is indispensable.

The objective of this document is to gather the most important knowledge on the jack mackerel in the areas of zoology, biology, ecology, population structure and fisheries in order to provide an up-dated synthesis.

Actually, besides the numerous production of reports and internal papers, a few syntheses were published, and particularly those of Serra (1998), Gretchina (2009), Arcos (1994), Glubokov (up-dated each year since 2006 as a SPRFMO document), Dioses (1995). The bulk of the present work will be based upon these documents.

This synthesis presents two weak points (among other): not all the documents have been taken into consideration and it is likely that some important documents should have been integrated in this report. This should be corrected in the future, by gathering a group of experts representing all the laboratories and countries working on the Chilean Jack Mackerel; the second point is that the document does not cover all the traits of life and fishery of the CJM, and particularly two important points of the biology (growth and alimentation) are not considered, as well as some important parti of the fishery (and particularly stock assessment methods). These gaps should be covered in the future.

Chapter 1

Elements of taxonomy and Morphometry of the Chilean jack mackerel

The **Chilean jack mackerel**, *Trachurus murphyi* (Nichols 1920), is a species classified under the genus *Trachurus* of the family Carangidae. The species was first described by the American ichthyologist John Treadwell Nichols in 1920 (fig. 1).

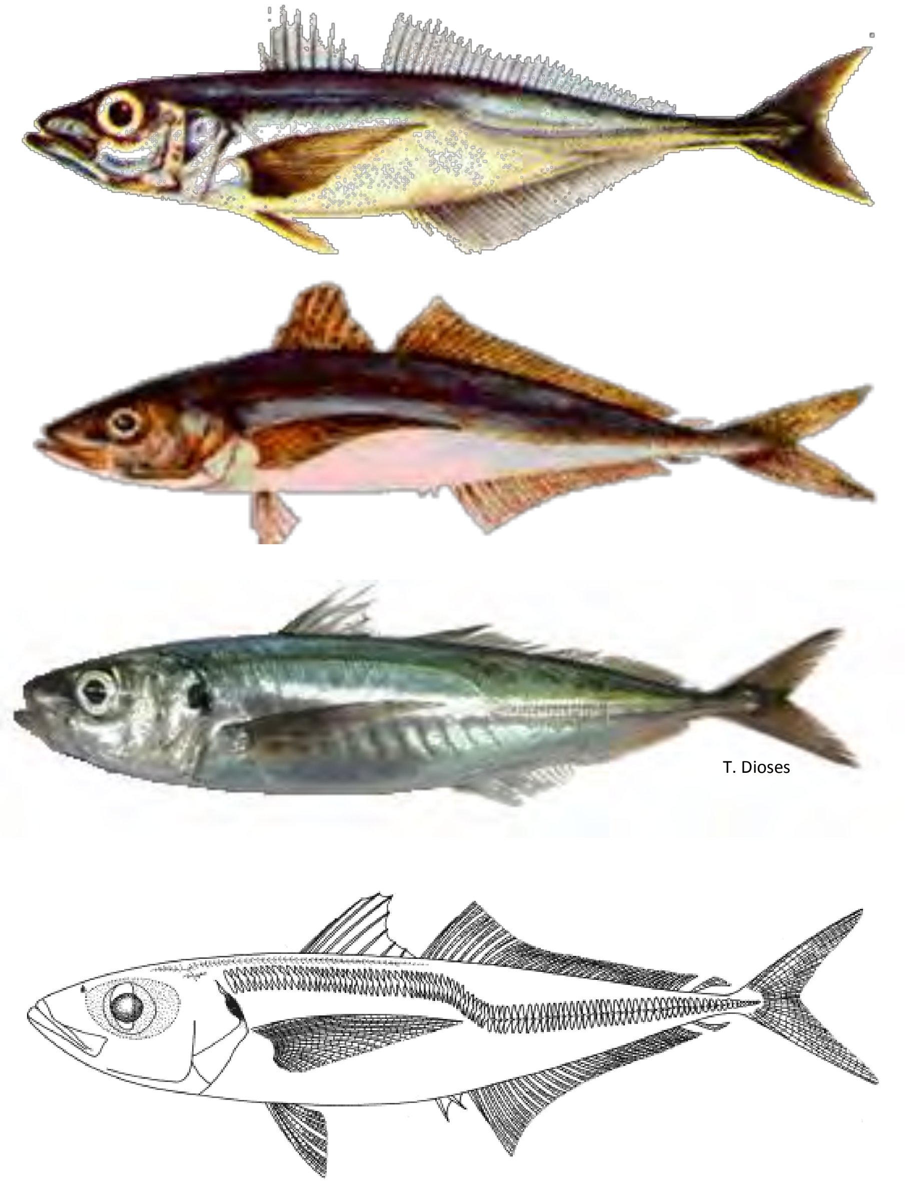


Figure 1. *Trachurus murphyi* (Nichols, 1920).Up to down: two drawings of CJM (ref?); photo from Dioses; drawing from FAO

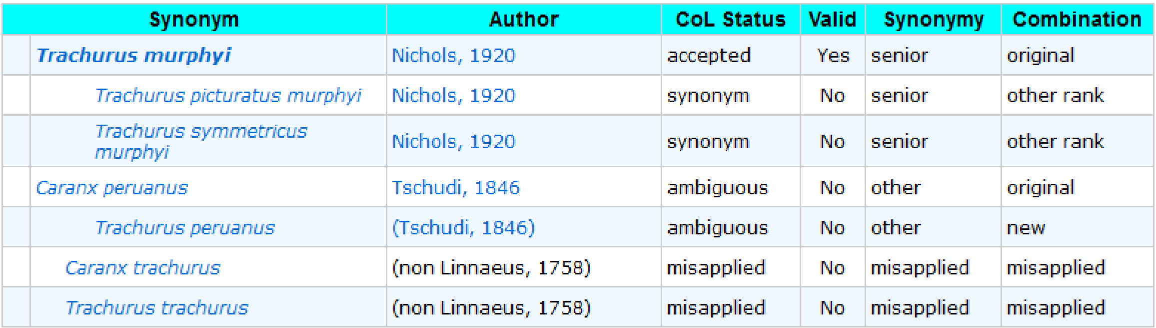
Taxonomic position

Kingdom	Animalia
Phylum	Chordata
Subphylum	Vertebrata
Superclass	Osteichthyes
Class	Actinopterygii
Subclass	Neopterigii
Infraclass	Teleostei
Superorder	Acanthopterigii
Order	Perciformes
Suborder	Percoidei
Family	Carangidae
Genus	*Trachurus* Rafinesque 1810
Species	*murphyi*

Binomial name	*Trachurus murphyi* Nichols, 1920

The list of former synonyms is given in table 1

Table 1 (from FishBase). Synonyms of *Trachurus murphyi* Nichols, 1920



Synonym	Author	CoL Status	Valid	Synonymy	Combination
Trachurus murphyi	Nichols, 1920	accepted	Yes	senior	original
Trachurus picturatus murphyi	Nichols, 1920	synonym	No	senior	other rank
Trachurus symmetricus murphyi	Nichols, 1920	synonym	No	senior	other rank
Caranx peruanus	Tschudi, 1846	ambiguous	No	other	original
Trachurus peruanus	(Tschudi, 1846)	ambiguous	No	other	new
Caranx trachurus	(non Linnaeus, 1758)	misapplied	No	misapplied	misapplied
Trachurus trachurus	(non Linnaeus, 1758)	misapplied	No	misapplied	misapplied

Description

"Chilean jack mackerels are commonly 45 cm (18 in) long, though they can grow to 80 cm. They have elongated and laterally compressed bodies. The head is large with well-developed transparent protective membranes (the adipose eyelid) covering the eyes. The mouth is also large, with the rear edge of the lower jaw aligning with the front edge of the eyes. It possesses small teeth. Each opercula of the gill covers possesses a distinct notch on its rear edge. The second dorsal fin is much longer than the first. The pectoral fins are long and pointed. The origin of the pelvic fins is below the bottom point of attachment of the pectorals. The anal fin is also long, but shorter than the second dorsal fin. At its front are two strong spines. The upper parts of the body are metallic blue in color, while the bottom surfaces are a silvery white." (From Wikipedia)

The SPRFMO made a short description of the taxonomic characteristics of the Chilean Jack Mackerel: "*Shaboneyev (1980) summarises Trachurus to 12 species; the Integral Taxonomic*

Information System (ITIS at http://www.itis.usa.gov/index.html) to 15 species. Three species exist in the South Pacific: T. murphyi, T, declivis[1] *and T. novaezelandiae. The latter two species occur in the Western Pacific almost exclusively in coastal waters within EEZs. Morphology: body elongated and slightly compressed, Enlarged, scute-like scales on the primary lateral line. Termination of dorsal accessory lateral line below 2nd to 5th soft ray of dorsal fin. Pectoral fin tip extension to be above the two detached spines anterior to the anal fin. Eye moderate size with well developed adipose eyelid. Posterior margin of upper jaw below anterior margin of eye. Jaws vomer, palatine, and tongue bearing minute teeth (Kawahara et al. 1988). Colour fresh: dark blue dorsal body, silver-white ventrally; upper posterior margin of opercula bear a black spot; pale pelvic fins; caudal, pectoral, and dorsal fins dusky; anal fin pale anteriorly, dusky posteriorly"* (SPRFMO, document SPRFMO-III-SWG-16, 2007).

FAO (http://www.fao.org/fishery/species/2309/en) presents also a description of *T. murphyi*: *"Body elongate, fairly compressed. Head large; posterior end of upper jaw reaching anterior margin of eye; lower jaw projected. Maxilla large, wide, not covered by lacrymal. Adipose eyelid well developed. Small nostrils closely situated each other, anterior nostril oval and posterior nostril crescent. A distinct notch on posterior margin of opercle. Dorsal accessory lateral line terminating below soft dorsal rays 9-15. Gillrakers, including rudiments, 41-47 on lower limb of first gill arch; total gillrakers 53-65. First dorsal fin with 8 spines and I + 31-36. Anal fin with I + 25-31 preceded by 2 strong spines. Pectoral fin rays 19-22. Pelvic fin moderate in size, originating below end of pectoral fin base. Scales in curved lateral line 45-62 expanded dorsolaterally and scute-like, in straight lateral line 38-50 scutes; total scales and scutes 89-107. "*

Eggs and larvae

Works by Santander & Castillo (1971) described eggs and larvae development (fig. 3). The description of eggs and larvae is detailed in chapter 2-C.

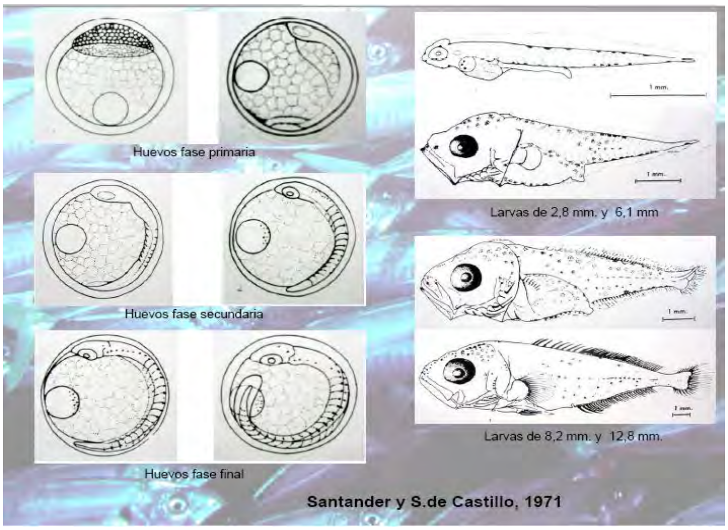


Figure 3. Drawing of eggs and larvae of *T. murphyi* (From Santander & Castillo 1971)

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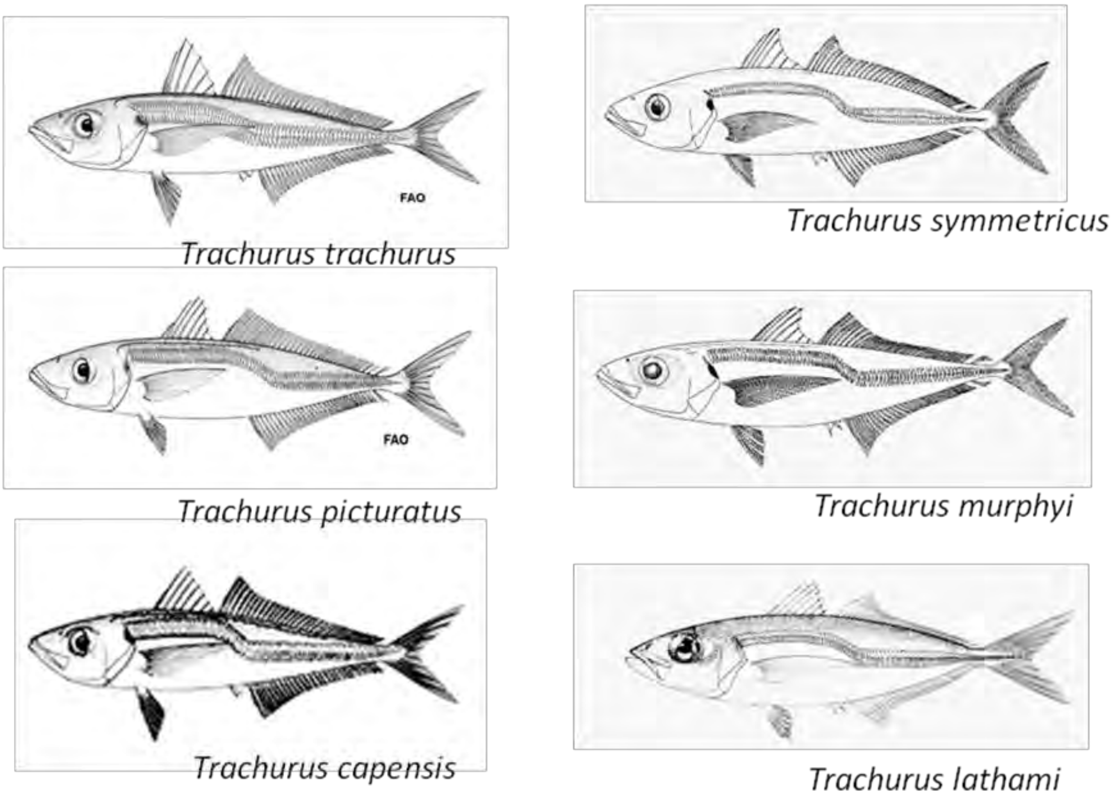
[1] *T. declivis* is the present name of former *T. picturatus*

Similar species

According to ITIS (www.itis.gov), the genus *Trachurus* gathers 16 species presenting a high similarity (figure 4). All of them have a similar common length of around 30-40 cm, strong similarity in their anatomy and their main traits of life and behavioural schemes are almost identical.



Trachurus trachurus

Trachurus symmetricus

Trachurus picturatus

Trachurus murphyi

Trachurus capensis

Trachurus lathami

Figure 4. Drawing of some of the most important species of Trachurus (from FAO)

Among these species, the Chilean jack mackerel has been recognized as a sister species of the North-East Pacific *Trachurus symmetricus*, to which it was long time assimilated, since 2004. Before this date it was considered a subspecies of *T. symmetricus* and known under the name of *T. symmetricus murphyi*. Actually, in its statistical returns, the FAO still treats the Pacific jack mackerel as though it were a subspecies.

The Chilean jack mackerel looks also very much like the greenback horse mackerel *(Trachurus declivis)* found around Australia and New Zealand (figure 2) and often mixed with *T. murphyi*. The two species can be distinguished by the number of gill rakers (*T. declivis* 50–57, *T. murphyi* 51–65) and the number of scales and scutes in the lateral line (*T. declivis* 81–82, *T. murphyi* 89–113).[2]

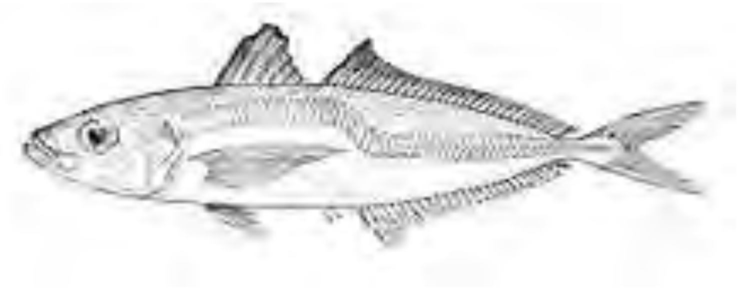


Figure 2. *Trachurus declivis,* common name “greenback horse mackerel”

Several works during the 80s and 90s were done to evaluate whether *T. murphyi* was a sub-species of other species of Genus *Trachurus* or not.

- Parrish (1989) analysed the three main species in the South and Eastern Pacific Ocean (respectively *T. picturatus, T. murphyi* and *T. symmetricus*) and concluded that the differences between the three species of the Eastern Pacific Ocean did not justify a separation in species and considered that they all belonged to the species *Trachurus picturatus* (Bowdich, 1825).
- More recently, Oyarzun (1998) realized a bibliographic analysis and made observations of some other material. He compared the morphological and meristic characteristics of *T. murphyi* and *T. symmetricus* and concluded: “*considering that the comparison of genetic differences between samples of jack mackerel from both the Southeast and Northeast Pacific ocean show almost no difference, they should be considered as components of a single large population (Stepien & Rosenblatt, 1996). Consequently it cannot be applied to them a sub-species statute, as this one present evolutionary and conceptual implications that go further than pragmatic implications in fisheries biology. From all the accumulated information, the correct form of naming the jack mackerel living in the American coast of the Pacific Ocean is Trachurus symmetricus”.*

It is clear that the two populations are extremely close to each other as far as taxonomic characteristics are concerned. Nevertheless, the separation of the Eastern Pacific jack mackerel into two distinct species, respectively *Trachurus symmetricus* for the North and *Trachurus murphyi* for the South has been accepted (e.g. www.Fishbase.org). The NCBI (National Center for Biotechnology Information, http://www.ncbi.nlm.nih.gov) identified *T. murphyi* and *T. symmetricus* as separate species.

List of the most current synonyms of common names (from FishBase)

Common name	country	language
Chilensk hestemakrel	Denmark	Danish
Chilean jack mackerel	Global	English
Horse mackerel	Peru	English
Inca scad	Global	Global English, USA English (old)
Jack mackerel	New Zealand, Peru	English
Oceanic Peruvian jack mackerel	Australia	English
Peruvian jack mackerel	Australia	English
Slender mackerel	New Zealand	English

Southern jack mackerel	Peru	English
Chinchard du Chili	Global	French
Chinchard jurel	France	French (old)
Chiri-maaji	Japan	Japanese
智利竹筴鱼	China	Mandarin Chinese
Ставрида перуанская	Russia	Russian
Ostrobok czarny	Poland	Polish
Carapau-chileno	Portugal	Portuguese
Jurel	Peru, Chile, Ecuador	Spanish
Jurel chileno	Global	Spanish
Jurel común	Ecuador	Spanish
Jurel del Pacifico Sur	Peru, Spain	Spanish (old)

Meristic characteristics

A comparative analysis of the meristic characteristics for *T. murphyi, T. symmetricus* and *T. picturatus* has been presented by Oyarzun (1998). It is summarized in table 3.

Table 3. Comparison of meristic elements for the three species
T. murphyi, T. symmetricus and *T. picturatus (From Oyarzun, 1998)*

	T. murphyi		*T. symmetricus*		*T. picturatus*	
Referencia	1	2	1	2	1	2
(nº datos)	(81)	(14)	(46)	(25)	(156)	(19)
Escudos L. lat.	11.9	-	11.47	-	11.44	-
Long.L.L.acc.	-	-	15.9	-	9.87	-
Nº escamas LLP	51.3	55.6	52	53	52.4	52.4
Nº escudos LLP	46.6	43.6	54.3	44.8	47.5	47.7
Nº escamas+escudos	97.8	99.4	97.4	97.8	99.9	100.1
Nº branquiespinas (S)	15	15.5	16.6	16.5	14.8	15.7
Nº branquiespinas (I)	40.8	41.8	44.3	43.9	40.8	40.4
Nº branquiespinas (T)	56.1	57.2	61	60.4	55.6	56
Radios A. pectoral	21.1	-	20.7	-	20.4	-
Radios a. dorsal II	33.11	33	33.17	33.6	33.4	32.6
Radios a. anal	28.6	28.7	28.6	28.9	28.7	28.1

(ref. (1) Ben Salem, 1988; (2) Berry & Cohen, 1972

Morphometry

Morphometry refers to the main dimensions that can be measured on fish. FishBase gives indications on the major measurements that must be obtained on a fish (figure 1).

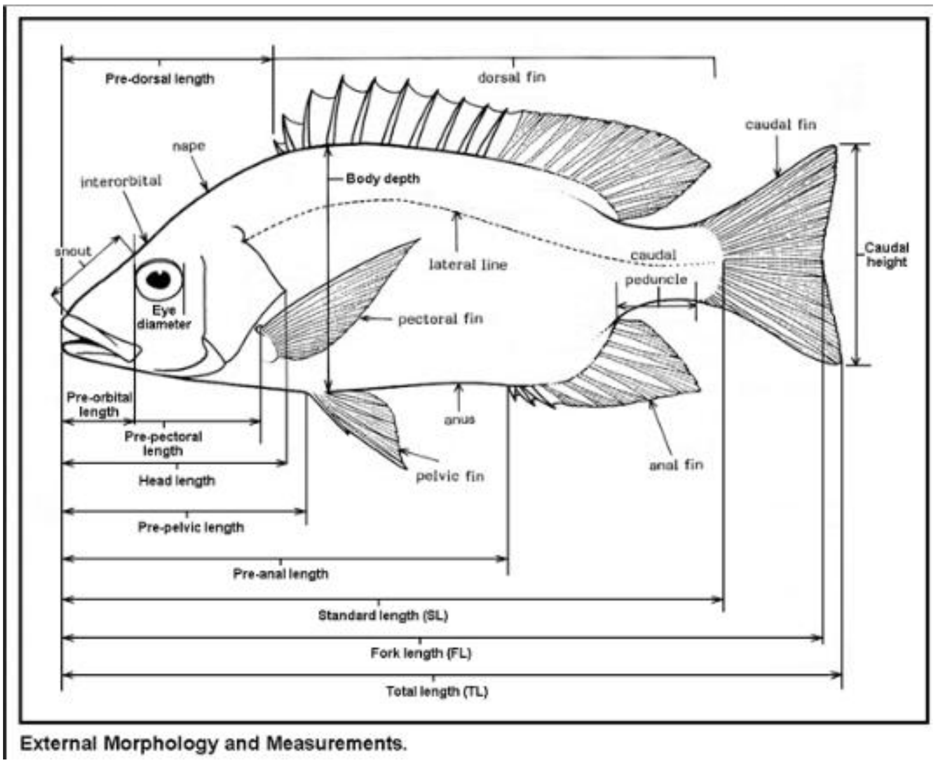
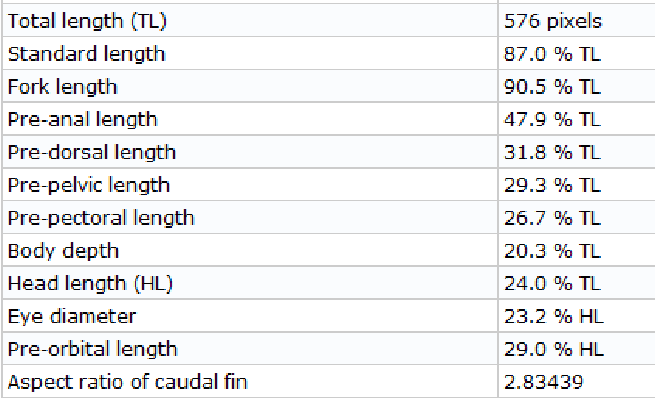


Figure 1. Main morphometric dimensions of fish (from FishBase)

FishBase presents also a table of the mean proportions of the different dimensions compared to the total length, for *Trachurus murphyi* (table 1).

Table 1. Proportions of *T. murphyi* in relation to the total length (from FishBase)



Total length (TL)	576 pixels
Standard length	87.0 % TL
Fork length	90.5 % TL
Pre-anal length	47.9 % TL
Pre-dorsal length	31.8 % TL
Pre-pelvic length	29.3 % TL
Pre-pectoral length	26.7 % TL
Body depth	20.3 % TL
Head length (HL)	24.0 % TL
Eye diameter	23.2 % HL
Pre-orbital length	29.0 % HL
Aspect ratio of caudal fin	2.83439

This chapter is mostly based on two documents: Arancibia et al. (1995) presented a series of results on a work on morphometric differences between several parts of the Chilean population of CJM; later, the SPRFMO prepared a synthesis on this particular activity (see the document "Report of the SPRFMO Chilean Jack Mackerel workshop, 30 June – 4 July 2008, doc. SWG-JMSG-02). A large part of the paragraphs presented here are citations of these works.

A few studies have been done to investigate the stock structure of the jack mackerel based on genetic and phenotypic characteristics. George-Nascimento and Arancibia (1992) described differences in parasites and morphometric features from individuals of three different fishing zones along the Chilean coast. Arancibia *et al.* (1995) conclude the existence of differences in the body morphometry of jack mackerel, comparing individuals collected from local fisheries from the north (Iquique) and the central zone of Chile.

Hernández *et al.* (1998) found significant differences in body shape and meristic counts of jack mackerel sampled in 5 localities along the Chilean coast during 1995 and 1996. However, simultaneous studies based on genetic tracers did not show evidences about the existence of different subpopulations between localities along the Chilean coast (Alay *et al.*, 1996).

Differences in morphological characteristics between putative stocks indicate that the stocks have spent some periods of their lives in different environments (Begg *et al.*, 1999; Cadrin, 2000) and therefore have the potential to develop different life history characteristics. But there is also a possibility that a high grade of interchange or heterogeneity exists that could be affected by environmental changes or life history trends. This could affect management strategies if assumed stock units prove not to be discrete. An example of this is the interannual differences in morphological characteristics of jack mackerel that are observed along the Chilean coast. Individuals from one locality in central-south Chile show significant differences with a locality in the north of Chile during years close to the El Niño event 1997-98, but no significant differences were found between morphometric characteristics of individuals from the localities in the north of Chile sampled 3 to 4 years before the occurrence of this event (Hernández *et al.*, 2007).

Morphometric measurements were based on the methods proposed by Winans (1987) (Figure 2). Hernandez et al (1998) determined that fish size can affect body shape in Chilean Jack Mackerel and they recommended the use of a function to remove the effect of fish size over the morpometric measurements. The transformation was applied by Shaefer (1991):

$$\hat{Y}_i = \log(Y_i) - \beta\left(\log\left(FL_i\right) - \log\left(FLa\right)\right)$$

where $\hat{Y}_i$ represents the transformed measure for the i-th individual, Y_i is the original measure, FL_i represents the fork length of the i-th individual, *FLa* is the average fork length and β represents the coefficient of regression between Y_i and FL_i (Document SPRFMO-III-SWG-21,2007).

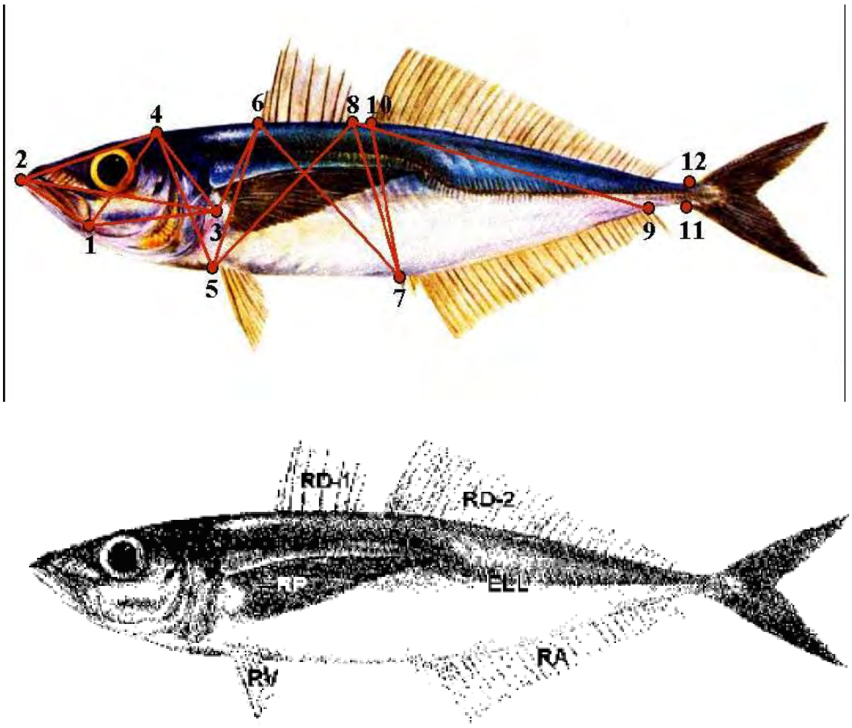


Figure 2. Marks of morphometric measurements and meristic counts in Chilean Jack Mackerel (after Hernandez et al., 1998)

Statistical analysis

SPRFMO presented recommendations for morphometric studies based on this first methodological approach (SPRFMO, op. cit.). The Organization suggested that the reduced set of measurements be used as selected by Arancibia *et al.* (1996) and Hernández *et al.* (1998), based on the work by George –Nascimento and Arancibia, (1992). These measurements correspond with the lines between following points: (1-2), (1-3), (1-4), (2-3), (2-4), (3-4), (3-6), (4-5), (5-6), (5-8), (6-7), (7-8), (7-10), (8-9). This lines needs to be measured with the precision of 1 mm.

We cite the main aspects of the proposal:

"In order to get morphometric measurements that are independent from the size of the fish transformation of the data is necessary. Both logarithmic transformation (Schaefer, 1991) and multivariate types (Winans, 1984; Cortes et al., 1996) have been suggested but Hernandez et al (MS) indicates that the logarithmic transformation give better results.

Exploratory multivariate analysis will be used to find the measurements that explain the largest differences between locations, like multiple discriminatory analyses (Winans, 1987). Analysis of covariance will also be used to assess location and fish size effects

Multivariate analysis techniques like Principal Components Analysis (PCA) should be used to reduce and describe body shape measurements of different regions based on the first three PCA functions.

Analysis of Covariance (ANCOVA) can be utilized to evaluate sources of variation due to effects like locality, year and season of the year, using as covariable the fork length (FL). Finally, discriminant analysis should be used to differentiate morphometric characters between regions."

Chapter 2-A

Reproduction

The jack mackerel has a standard sexuality and does not present any visible sexual dimorphism. It is a partial spawner, which allows a longer spawning season. Fertilization is external. Adrianov (1981), synthesizing the observations on the catches in the South Pacific Ocean found a sex-ratio with 51% males, although when looking more in details, the distribution was in favor of females in the north (10 505 ♀ vs. 10 226 ♂) and in favor of males in the south (23 255 ♀ vs. 25 133 ♂).

Fish usually spawn from winter to summer, spring being the most important season (Santander y de Castillo, 1971; Santander y Flores, 1983; Peña y Mariátegui, 1988).

1, Fish fecundity and maturity.

There is an important number of studies on the fecundity and maturity of Trachurus murphyi, mostly done by Chilean and Peruvian scientists.

- Maturity of gonads.

Histological studies were performed by several scientists. Sanchez et al. (in press)[1] presented results on 350 samples individuals studied between 2006 and 2009, and provide information on the spawning period. They give a key for identifying the maturity stage from theobservation of the ovaries. They confirm the existence of partial spawning activity and precise the maturity stages (from 0 to V) using histological studies. Ruiz et al (2008) in a contribution to the workshop held in Reñaca, Chile in 2008, presented the reproductive parameters and spawning biomass of the CJM in 1999-2006 and some information on histological characteristics of the females allowing calculating the spawning fraction of the gonad. Dioses (2008) gave some details on the external definition fo maturity stages (figure 1)

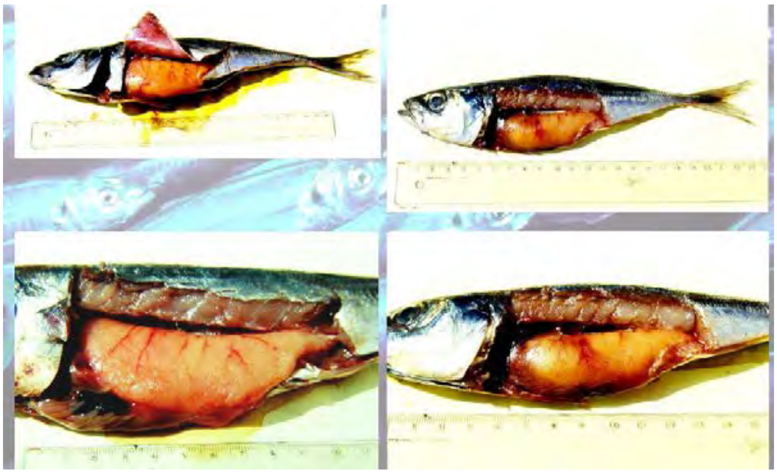


Figure 1. Observation of mature gonads for fish at different lengths (from Dioses, 2008).

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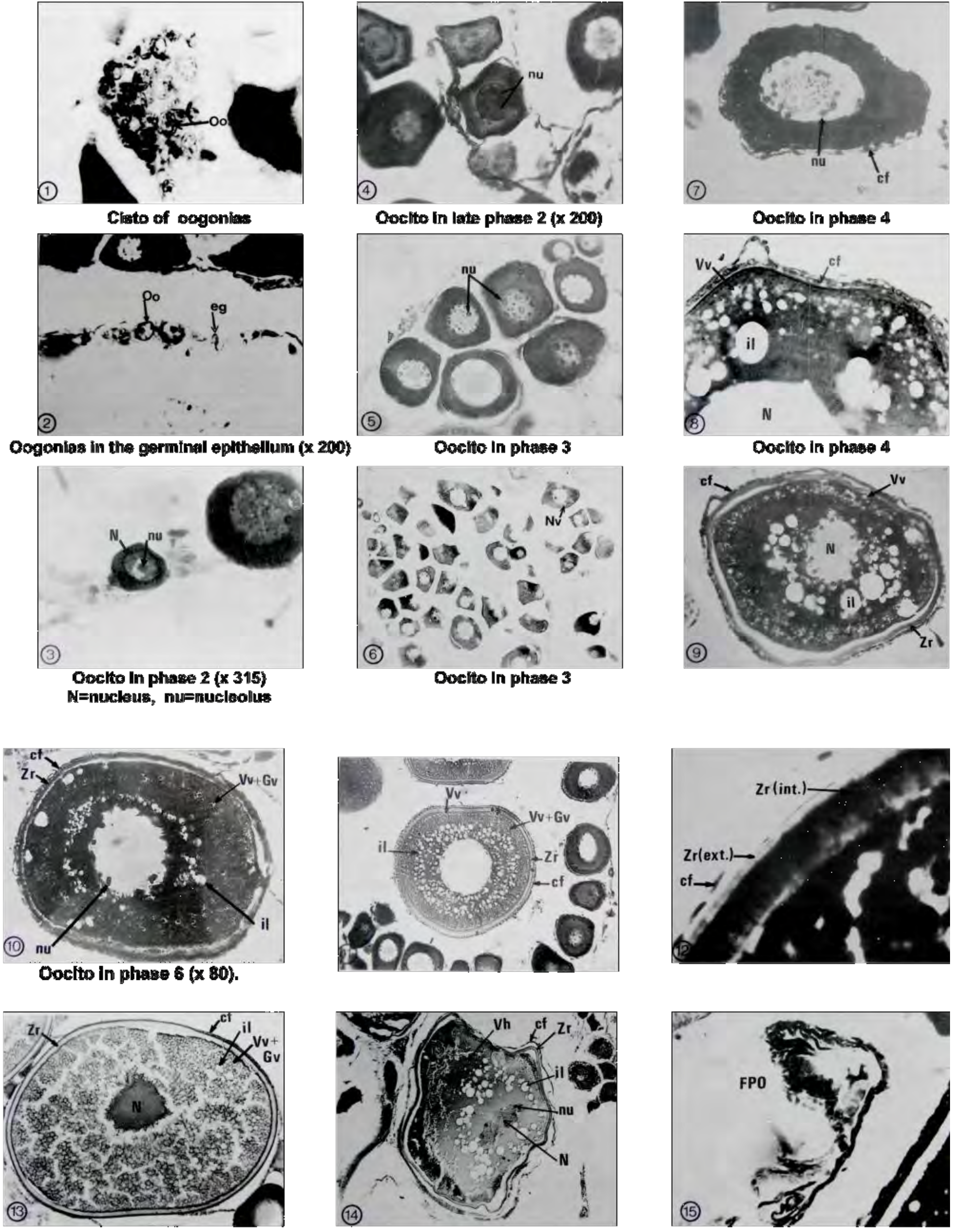
[1] **Sánchez, J., Perea, A., Buitrón, B., Romero, L., in press. Escala de madurez gonadal de jurel *Trachurus murphyi* (Nichols, 1920) [Stages of gonadal development of jack mackerel *Trachurus murphyi* (Nichols, 1920)]**

The same author provides an histological key of definition of the maturity stages (figure 2).

Stages of oocyte


Cisto of oogonias

Oocito in late phase 2 (x 200)

Oocito in phase 4

Oogonias in the germinal epithelium (x 200)

Oocito in phase 3

Oocito in phase 4

Oocito in phase 2 (x 315)
N=nucleus, nu=nucleolus

Oocito in phase 3

Oocito in phase 6 (x 80).

Figure 2. Histological differences between maturity stages for Trachurus murphyi (from Higa and Ishiyama, 1990: *In* Dioses, 2008)

A particularly interesting work from Leal et al. (2012) presented results on the proportion of maturity stages and Gonado-somatic index (GSI) in the CJM population using samples from the whole Chilean area during the year 2011 (fig. 3). their results allow to define precisely the spawning season in Chile.

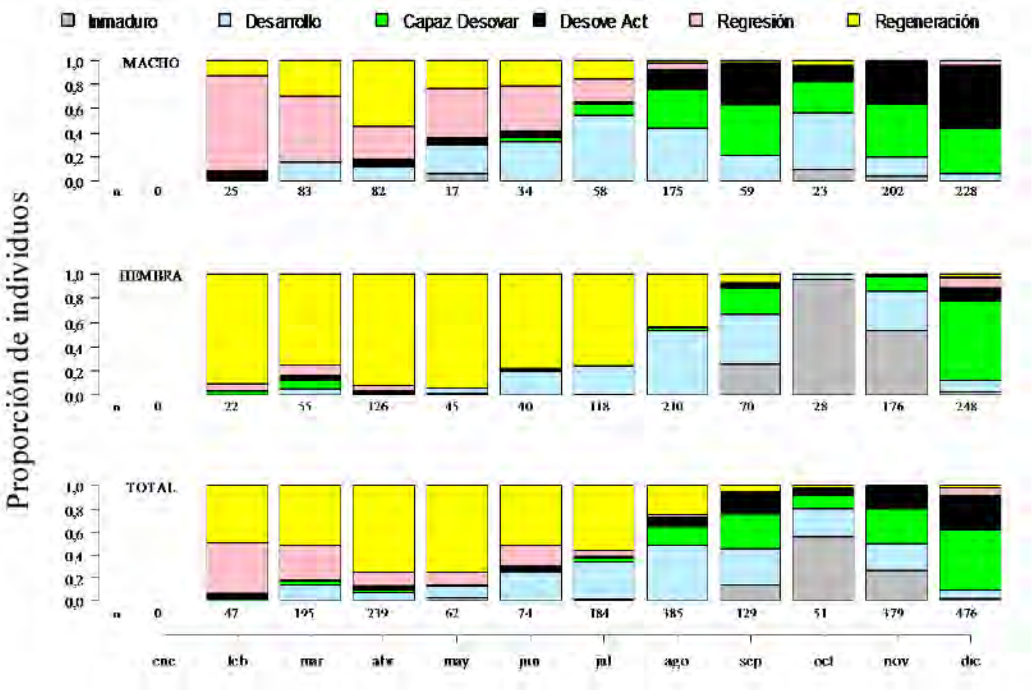


Figure 3. Monthly proportions of stages of biological maturity (EM) of male, female and whole jack mackerel samples along the coast of Chile during 2011. Values under the bars represent the number of samples. From Leal et al., 2012

The annual report of Chile to SPRFMO in 2007 (Reñaca, Chile) presents the evolution of the GSI and length structure in the North and in the South of Chile from 2001 to 2005 (fig. 4). This diagram shows that the spawning season for the CJM is centered on the months of September to January, with a maximum activity in November and December.

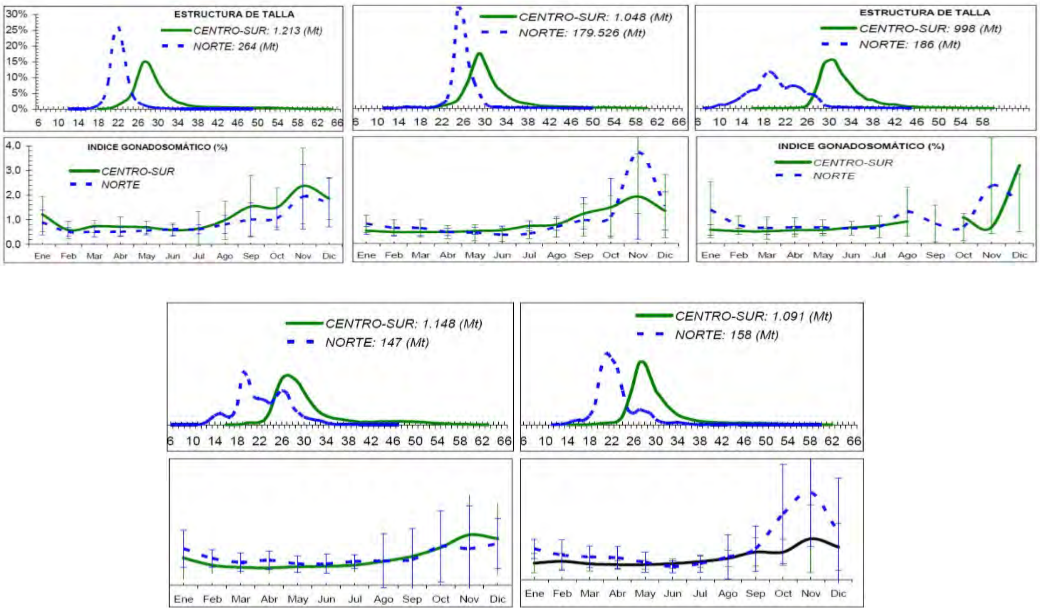


Figure 4. Length structure and GSI for the CJM in the North (blue curves) and centre-south (red curves) of Chile, for the years 2001 (above, left) to 2005 (below, right).
From the Annual report of Chile to SPRFMO in 2007

- Egg and larvae development

In Peru, Santander, H. y O. S. de Castillo (1971) achieved the study of egg and larvae development. They described the external and internal shape of the spherical eggs, with 0.9 to 1.08 mm diameter of the egg shell. The authors described the development of the embryo in three phases. In the description of the larval development they gave special attention to the pigmentation, body shape, ossification, development of the fins in specimen from 2.8 to 12.8 mm (figure 5).

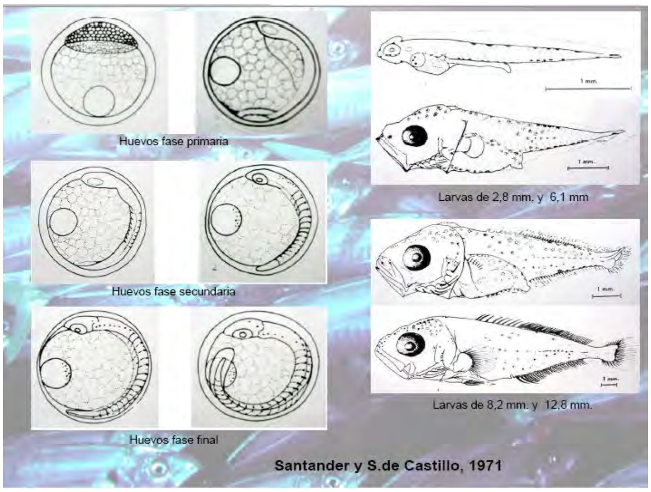


Figure 5. Drawing of eggs and larvae of *T. murphyi* (From Santander & Castillo 1971)

Histological analyses of the ovaries show that the ovule is developing asynchronously and the oocytes are spawned in several periods making the CJM a partial spawner. Shiga, B. y V. Ishiyama, (1992) describe in details four periods and 9 phases in the development and maturation of the based upon the cytoplasm, the genesis of the vitellus, the nucleus and modifications of the follicular cells.

The mean partial fecundity, measured through the counting of hydrated oocytes was evaluated as 78 798 oocytes, varying between 10 000 and 160 000; when evaluated in number of hydrated oocytes per gram of the female body is around 253 (from 91 to 495).

3. Reproduction areas

Areas in the Peruvian waters.

The major spawning area in Peru is the littoral sector (between 100 and 150 nm from the coastline) between 14º00’S and 18º30’S (Santander y Flores 1983, Dioses et. al 1989), inside a front limited by the cold coastal waters (CCW, with salinities less than 35 psu) with strong upwelling, and the subtropical surface waters (STSW, with salinities above 35.1 psu). The water preferendum in Peru for the spawning activity is 18ºC for the temperature and above 5.0 $ml.l^{-1}$ for the DO. Spawning aggregations are found in a surface layer, between 10 and 80 m, where salinity stays between 34.9 and 35.1 ups, temperature between 15º and 18º C and DO between 3 and 5 $ml.l^{-1}$. An example of distribution of CJM aggregations during spawning is given in the figure 6.

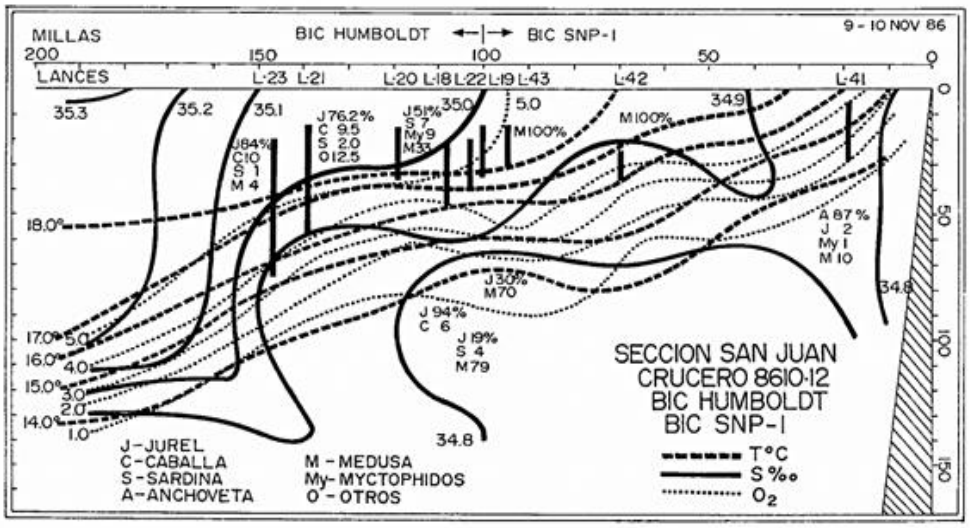
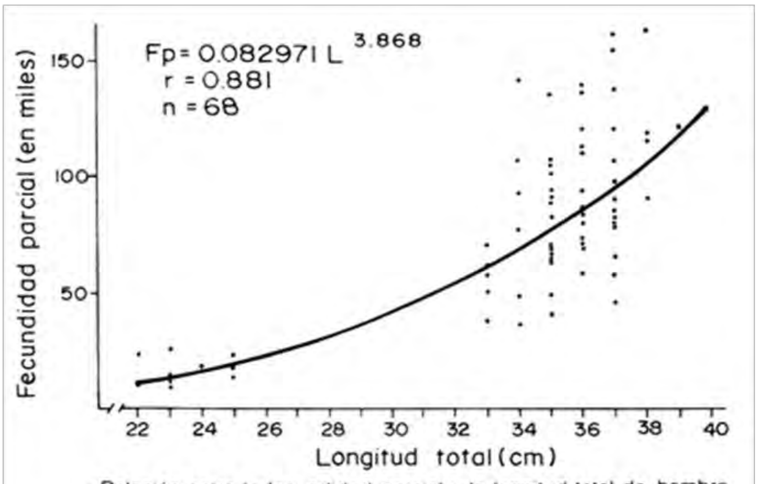


Figure 6. Vertical cross section along a profile from 0 to 200 nm from the coastline in Peru (1986).
Spawning aggregations are represented by vertical lines
(from Dioses, 1995)

As spawning is achieved inside the euphotic zone in shallow layers (less than 50 m) the larvae suffer the influence of currents for their distribution and dispersion, and some of them can be found in the open ocean at more than 200 nm from the coastline thanks to the Ekman transport. The surface drift is also the reason why a consistent part of the abundance of larvae can be found along the Peruvian platform when transported b y the front between CCW and STSW.

Using informations collected from 1984 to 1986, Peña & Mariategui, (1988) found that the jack mackerel has a long spawning period (from winter to summer), the mean length of the adults being between 38 and 39 cm (total length LT). Histological studies in Peru show that the smallest length at first maturity for Trachurus *murphyi* is 21.3 cm LT, and the length at which 100 % of the individuals are mature is 26 cm.

The first spawners (21 cm) produce 10 000 oocytes, while at the length of 26 cm the production is 25 000 hydrated oocytes (figure 7). Fishing regulations in Peru defined the minimal length of catch as 31cm LT; at this age the fish produce 50 000 oocytes, which is still lower than the mean fecundity (78 789 oocytes) and represents one third of the total fecundity observed (above 150 000 oocytes) that would not endanger the CJM population.



Relación entre la fecundidad parcial y la longitud total de hembra sin ovario del jurel *Trachurus murph. yi*

Figure 7. Relationship between the partial fecundity and the total length of female *Trachurus murphyi*.

The results of the reproduction dynamics of the jack mackerel show that this species spawns principally south of 14ºS although some small coastal spawning events took place along the coast at more northern latitudes. This location south of 14ºN inside the front between CCW and STSW with salinities above 35.1 psu were confirmed by works from Santander & Flores (1983) based upon egg and larvae collection and studies and those from Dioses et al (1989) analyzing the spawning aggregations of jack mackerel with hydrated oocytes. According to the location of the front, spawning takes place between the coast and 150 nm far from it.

Pelagic species such as *Trachurus* murphyi display huge variations in their abundance, mostly due to the high variability of the conditions of their environment that have an incidence on their biological functions and especially the reproduction. This is the reason why the recruitment can differ from one sub-population to the other and the number and proportions of cohorts can vary significantly from one sub-population to the other. The case of the abundant year class recruited in the Peruvian waters in 2011 is especially interesting. Indeed according to the gonadosomatic indexes (GSI) of the last years a successful spawning took place in 2007 and a new cohort was observed in 2011 in the catches, measuring 28 cm (LT, modal value) in January, and still present with LT 34 cm in October (producing a total catch of 208 000 t, which fits inside the average catch of CJM since the 70s). The strength of this year class was also demonstrated as it was also encountered and caught in Ecuador (80 000 t). Interestingly, the catches in Peru began during the second half of January, which indicates that the fish came from the north (point that fits with the “Peruvian sub-population” hypothesis)

A synthesis of the data collected on eggs and larvae allowed Ayon and Correa (in press) to give a map of the larvae distribution in the Peruvian waters from 1970 to 2010 (fig. 8). These authors also noted that the spatial distribution in the Peruvian waters was different in three periods: until 1980 larvae were more abundant in the south (latitudes 12-16ºS) in the north during the period 1980-1995 (latitudes 4-12ºS) and rather dispersed from the centre to the north of Peru after 1995 (6-17ºS). It is also interesting to note that during all the period of observation (1960-2010) larvae were found every year in Peruvian waters, which let conclude that a permanent spawning area exists in these waters (Ayon and Correa, in press).

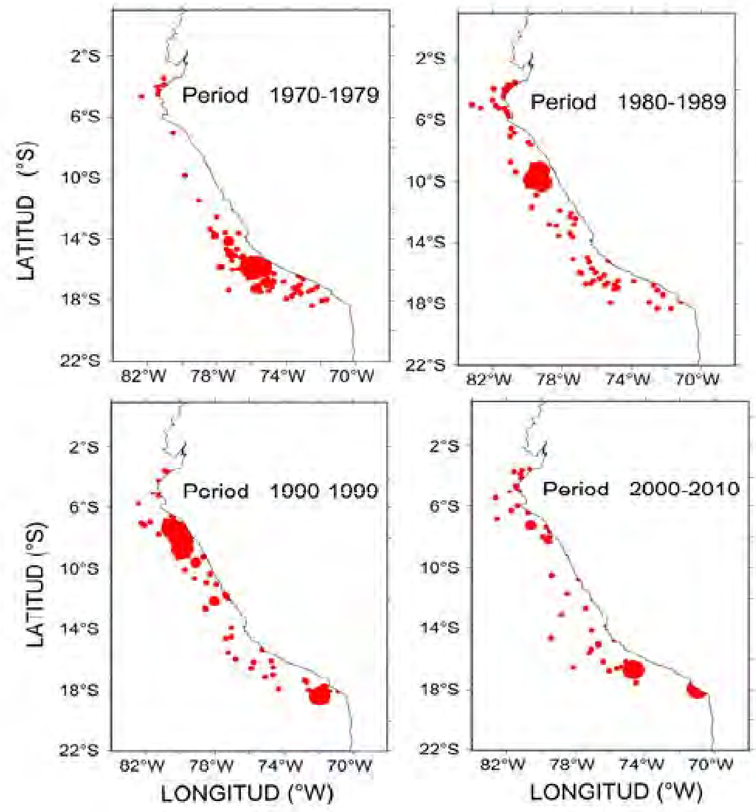


Figure 8. larvae distribution in the Peruvian waters from 1970m to 2010 (From Ayon and Correa, in press)

<u>Reproduction observed in the USSR fishery</u>

Dejnik-Nevinskyi (1994) studied the ichtyoplankton inside the North and South Pacific Ocean subdivisions. In the North subdivision (from 2ºN to 15ºS). Incidentally, it was the first time that CJM eggs were observed in equatorial waters at latitude 1º57S. Eggs and larvae were encountered in the wholestudied area, with SST between 17.5ºC and 22.3ºC and SSS between 34.9 psu and 35.6 psu. The average abundances of eggs were around 0.3 to 6.6 eggs.m^{-2}, and the abundance of larvae from 0.3 to 9 larvae.m^{-2}. In the southern part of the study that covered tha latitudes between 33ºS and 44ºS, the observations were done during the period of maximum spawning, which allowed to define precisely the spawning areas until southern latitudes (47ºS) at long distances from the coast 87ºW). Egg abundance in these areas reached up to 300 eggs.m^{-2} and never lower than 50-100 eggs.m^{-2}. A gradient was observed, eggs being less abundant toward the west and the south. Larvae were also encountered, following the same pattern but in more restricted areas (fig. 9).

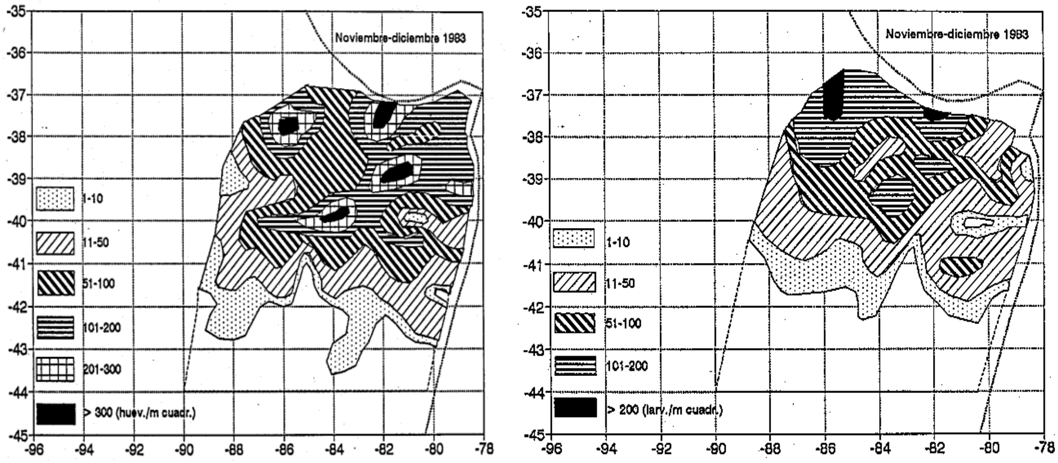


Figure 9. Distribution of eggs (left) and larvae of jack mackerel in the south-east Pacific Ocean in november.december 1983 (from Edjnik and Nevinskyi, 1987; redrawn by Gretchina, 2009)

Adrianov (1981), apart the measurements of sex-ratio, evaluated the fork length structure in the north (19 to 43 cm, average 29.85 cm) and the south (19 to 63 cm with average 35.95 cm). IN the North the mature fish begin to predominate at length 25-27 cm, but some mature fish can be found at lengths 23-25 cm. The same pattern was observed in the south. This allowed Abramov and Kotlyar (1980) and Nekrasov (1982) to consider that the Chilean Jack Mackerel can be mature at lengths 23-27 cm, which length is reached at the end of the second year of live. These authors observed that the individual fecundity increases with the fish length, being around 30 000 eggs for an individual of 32 cm to up to 180 000 eggs for a length of 45 cm (mean fecundity: 60 000 eggs). Evseenko and Karavaev (1986) found CJM eggs in front of Peru during the El Niño in 1972, from August to December, with a maximum concentration (up to 100 eggs.m^{-2}) between 16ºS and 18ºS, with a larger extension of larvaes.IN the whole area under the influence of El Niño, the authors found two areas of high concentration of eggs: one between 4º20'S and 5º00'S, and another one between 12º00'ºS and 18º20'S. Eggs were observed close to the surface, in waters with salinities between 34.3 and 35.0 psu and SST 19ºC to 22ºC for the north; 17ºC-21ºC and 35.0-35.2 psu for the South.

Evseenko et al. (1984) found lower concentrations of eggs outside the Peruvian and Chilean EEZs 40 eggs.m-2 and less than 10 larvae.m-2) during November-December 1981, in waters with SST 17.88º - 19.28º and SSS 34.87 – 35.21psu.

After these pioneer works, a series of routine surveys was performed during the exploitation of CJM by the USSR fleet, and maps of eggs and larvae distribution were provided, which have been redrawn and summarized by Gretchina (2009) and are presented in the figures 10 and 11.

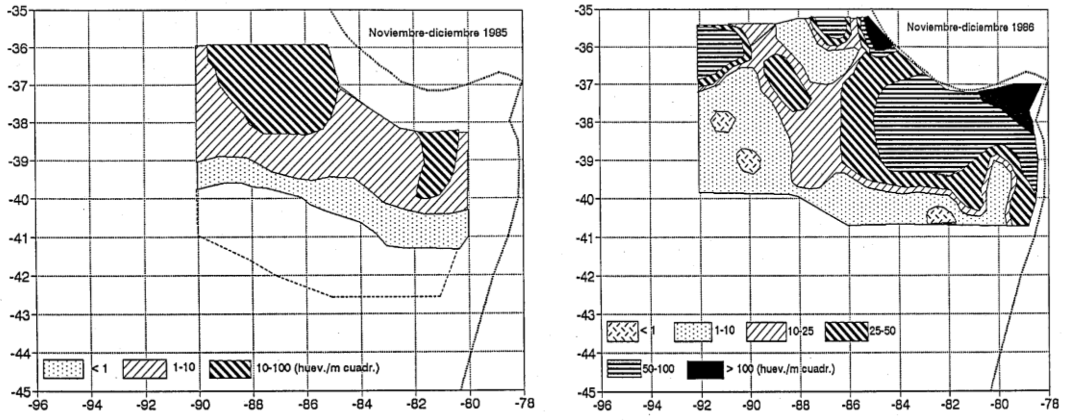


Figure 10. Egg distribution in the South subdivision of SE Pacific Ocean in nov-dec. 1985 (left) and nov-dec. 986 (right), (modified by Gretchina from Zhigalova & Rudomiolkina, 1991)

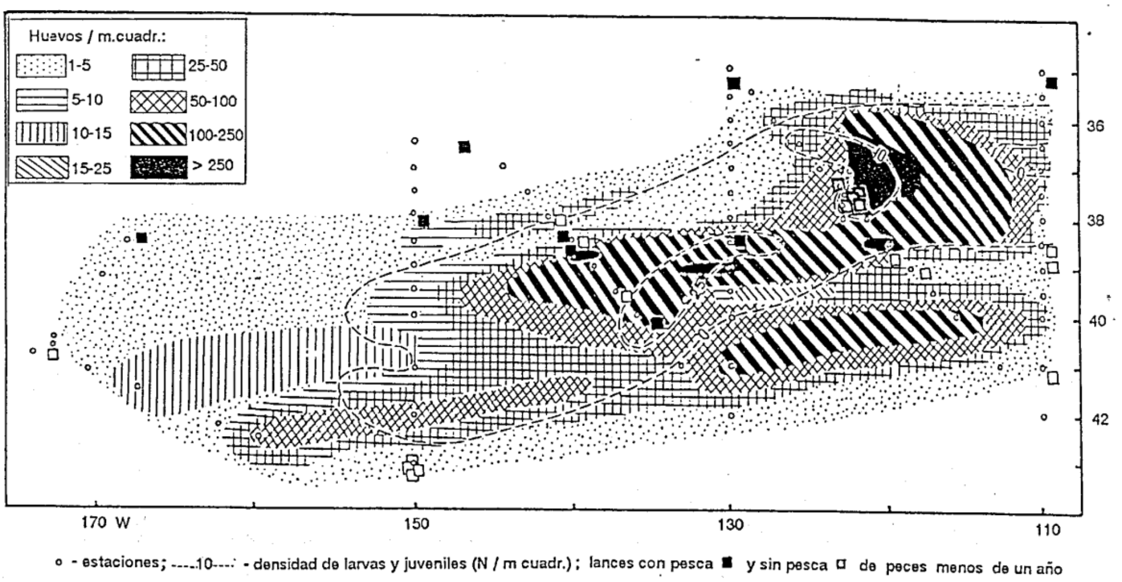


Figure 11. Egg & larvae distribution during January, 1990. Redrawn by Gretchina (32009) from Nosov et al., 1991

From this series of observation, a general mapping of the spawning areas were designed and presented by Gretchina (2009: fig. 12)

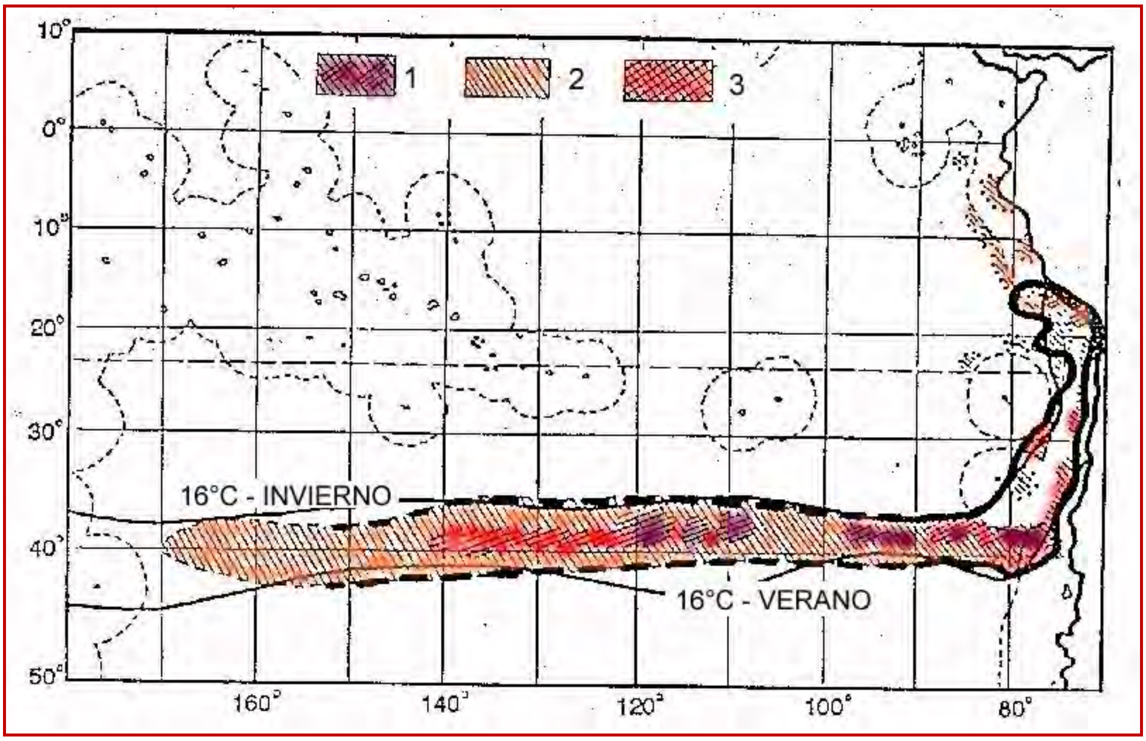


Figure 12. Spawning areas of CJM in relation to the isotherm 16ºC at the beginning and end of the spawning season. 1: principal area of spawning; 2: observed presence of eggs and/or larvae; 3: areas with densities > 200 ind. m-2 (from Gretchina, 2009)

Finally, from all these results Gretchina (2009) presented a synthesis summarized in figure 13.

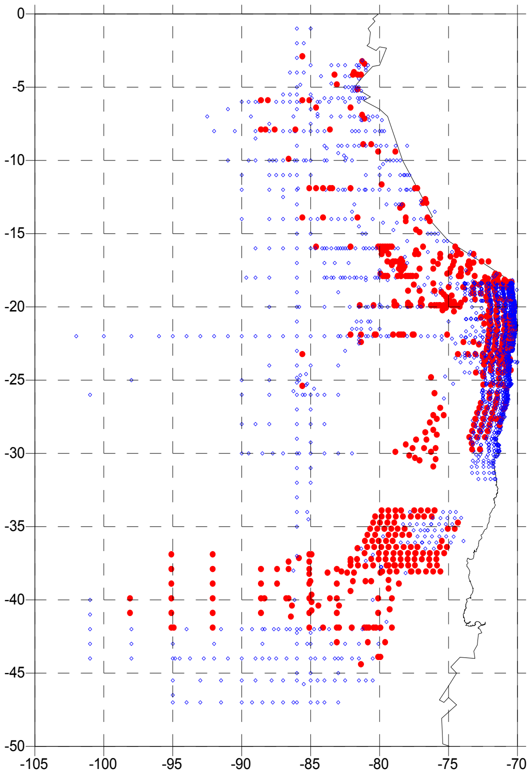


Figure 13. Synthesis of the observations on egg distribution performed by the Soviet research. Red dots: sampling with eggs collected; blue dots: samplings without egg collected. From Gretchina, 2009)

Areas observed in the Chilean waters

The Chilean waters and the connected area west of the centre-south region of Chile represent the largest and most important spawning area, according to most of the studies. In Chile an important series of observation using "Rastrillo" surveys allowed to define and follow this large spawning area, limited approximately by the latitudes 31ºS - 40ºS and longitudes 74ºS – 89ºS, although there are no fixed borders and this area presents a high variability from one year to the other (figure 14).

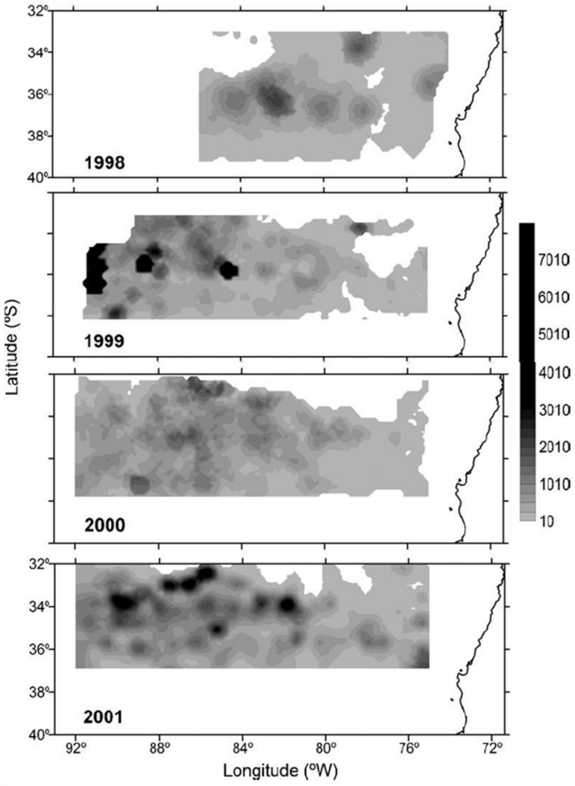


Figure 14. Spatial distribution of jack mackerel egg densities (eggs per 10m^2) as the reproduction of a spatially stochastic process by kriging: December 1998, November 1999, November 2000, and November 2001 (from Cubillos et al., 2008).

The egg survey was repeated yearly and gave important results min terms of distribution mand relationships with the environmental conditions. Cubillos et al. (2008) calculated GASM and variograms on the egg distribution and found relationships with the SST and the authors state: "*The relationship between egg density and SST were domeshaped for all the surveys. In fact, models with degree quadratic were better than linear. In 1998, higher egg and declined abruptly at higher SST. In 1999 and 2000, egg densities peaked in waters ranging between 18 and 19 ◦C while in 2001 higher abundance of eggs was found in waters ranging between 14 and 16 ◦C, peaking at 15 ◦C and then egg density declined at higher SST*". Their results of GAMs are presented in the figure 15.

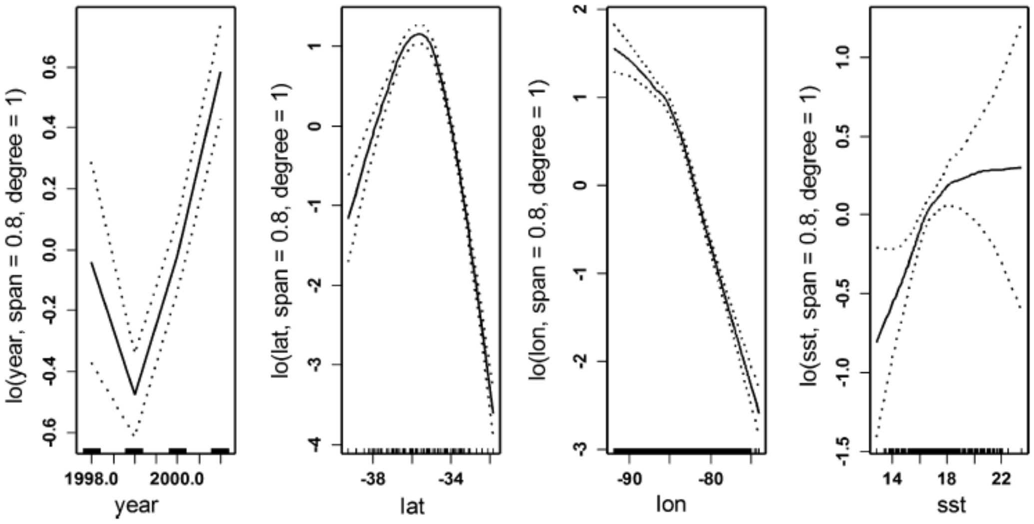


Figure 15. Partial regression GAM plots explaining the jack mackerel eggs density in relation to the year, latitude, longitude, SST. The solid line indicates the fitted model; the dashed lines display the 95% confidence intervals (from Cubillos et al., 2008).

Barbieri et al. (2004) and Cubillos et al. (2008) fitted variogram models on the data of egg and adult spatial distribution. Their major result is to show that the eggs and larvae present a much smoother spatial structure than the adults (fig. 16).

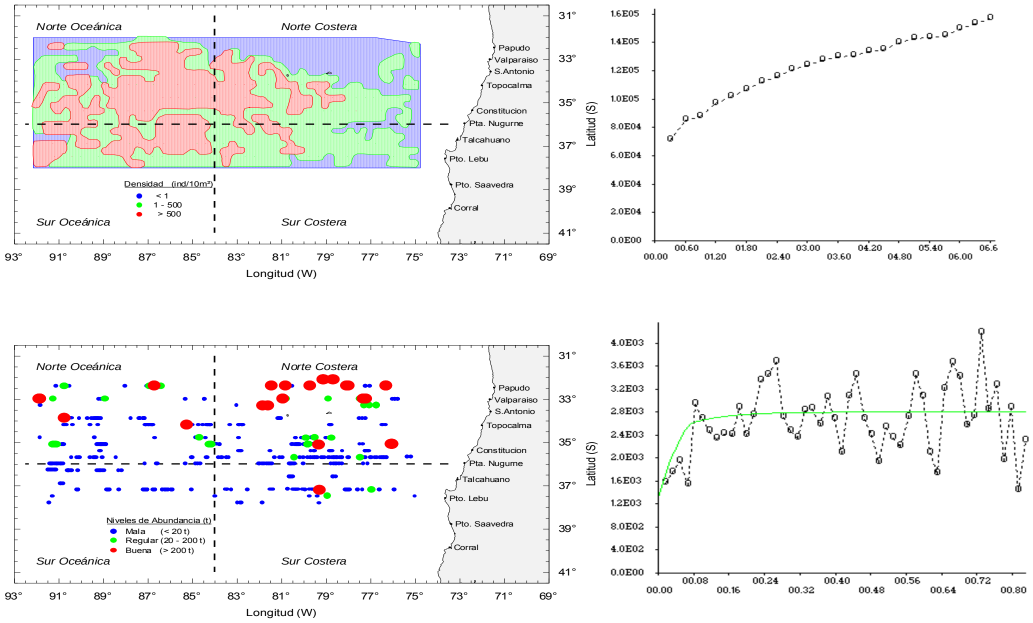


Figure 16. Spatial distribution of eggs (left, above) and relative distribution of adult density (left, below) during the Rastrillo survey in 2002. For the two distribution a variogram was calculated (right). From Barbieri et al., 2004

It is interesting also to display the maps of eggs vs. the map of larvae (Annual Report of Chile to SPRFMO, Reñaca, 2007): it appears in such comparison that larvae might concentrate (or die in a large part of the area) (fig. 17)

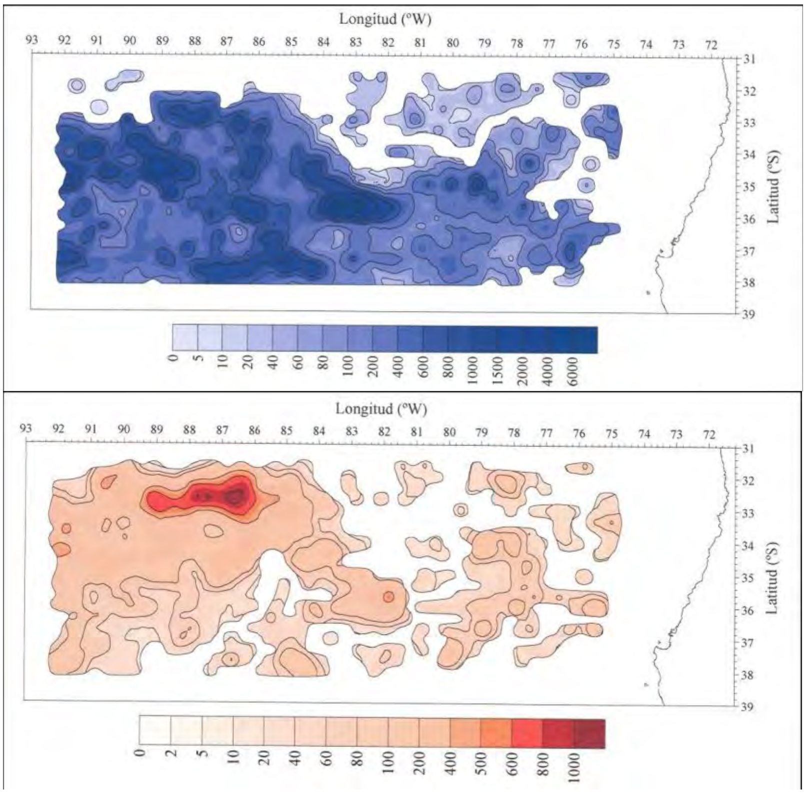


Figure 17. Maps of distribution of eggs (above) and larvae (below) in the Southeast Pacific Ocean in front of the Centre-South Region of Chile (from Annual Report of Chile to SPRFMO, Reñaca, 2007)

Conclusion on reproduction

The CJM reproduction has been studied in details and its reproductive biology is well known. The spawning season, the spawning activity, the egg and larvae shape and biology, the preferenda for spawning, the adult behaviour during spawning are documented.

From this important amount of information, and as far as the population management is concerned, two points must be considered.

- The spawning area. From the data, there is confirmation that there is two areas of high concentrations of eggs and larvae, inside a wide continuum of distribution on the whole SE Pacific Ocean: one centered in the centre-south region of Chile, and one along the Peruvian waters. This point is not trivial as it should lead to the conclusion that there are two sub-populations along the South America coastline. Therefore it is important to document this point in details.
- The recruitment. It is known that the CJM recruitment is linked to environmental conditions and that it is highly variable. Considering that the recruitment is a key parameter for a sound stock management, a monitoring of the CJM reproduction is essential, and any effort of research and monitoring in this field should be supported.

Chapter 2-B

Migrations

Introduction

Migrations represent a key question in the case of the Chilean Jack Mackerel, as it would be the actual answer to the important question of the population structure. Indeed, a migration model for the CJM in its whole area of distribution would allow defining which one of the numerous hypotheses on population structure is the correct one. Unfortunately, there are few studies published in the literature using tagging, and none of them gave any consistent result on fish migration (figure 1).

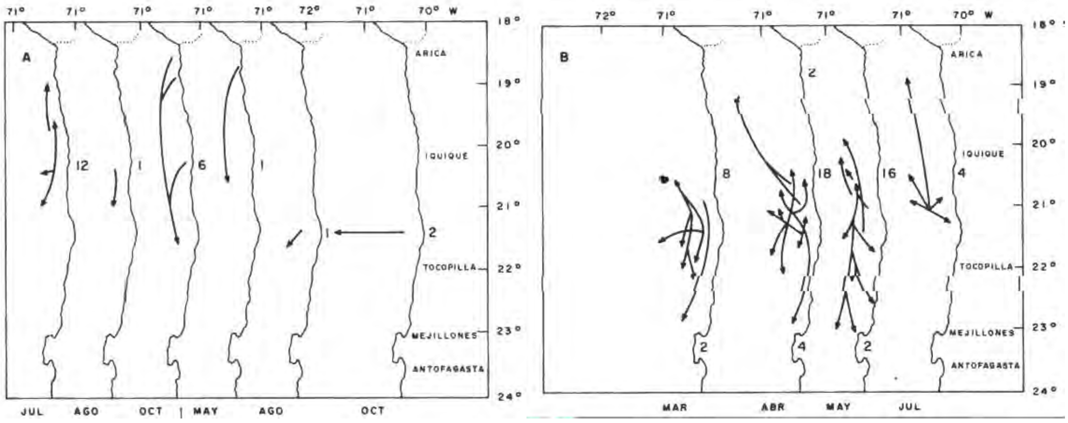


Figure 1. Movements of jack mackerel as observed from tagging experiments held in 1983-1984. Left: winter cruise; right: summer cruise (from Torres, 1986)

Therefore the only results are obtained (apart a few information on larvae movements) by observing the movements of the fishing fleet, One good (and more recent) example of the kind of information the fleet can provide for migration studies comes from the reports of the EU fishery to SPRFMO, where the movements of the fishery during the fishing season show a cyclic movement of the concentrations in the outside of the centre-south region of Chile (figure 2).

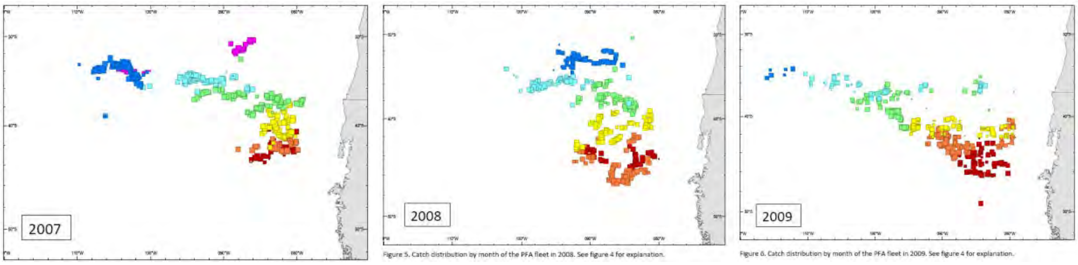


Figure 2. catch distribution by month of the Eu fleet from 2007 to 2009. Red = April; orange = May; yellow = June; green = July; light blue = August; dark blue = September; purple = October. Size of squares proportional to catches (from EU report to SPRFMO SP-08-SWG-JM-01, Auckland, 2009)

General models of fish migrations.

In the 90s the Soviet scientists gave a conceptual model of migration defined from the catch data of their fleet. It is presented in the figure 3. In this particular case, the migrations are accompanied with a general drift westward of the population when the abundance increases.

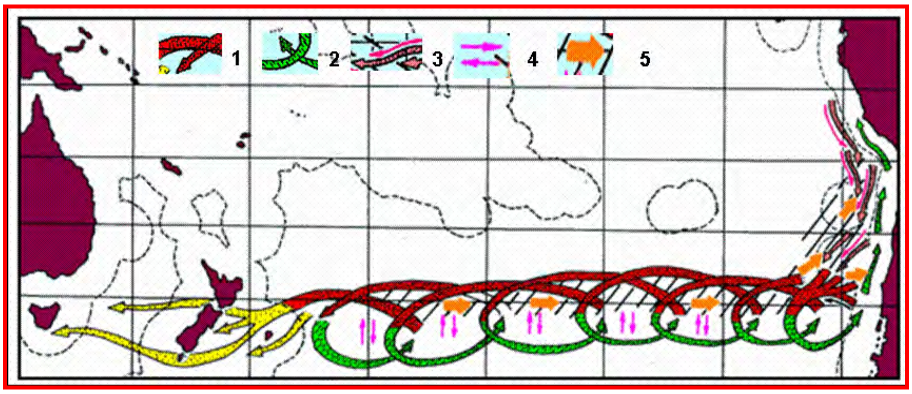


Figure 3. General model of migration of the Chilean jack mackerel in the South Pacific Ocean. 1. Spawning adults; 2. Feeding adults; 3: juveniles; 4: spawning migrations of adults; 5: migrations of juveniles. From Elizarov, 1992, and Gretchina, 1998

From the fishing data too, the Chilean scientists developed another model of fish migration inside a "superpopulation" (Gretchina et al., 2013), which is presented in the figure 4.

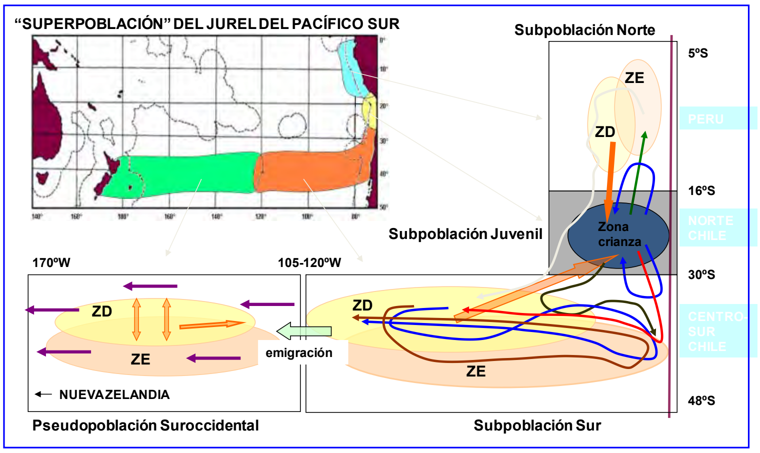


Figure 4. Schematic migration diagram of CJM in the South Pacific Ocean inside a conceptual model of "superpopulation" (from Gretchina et al., 2013)

Another view of fish movements by the Russian research is presented by Gretchina (2009), and although it is not strictly describing a migration cycle, it gives informations on the movements performed by the fish in periods of expansion and contraction (figure 5).

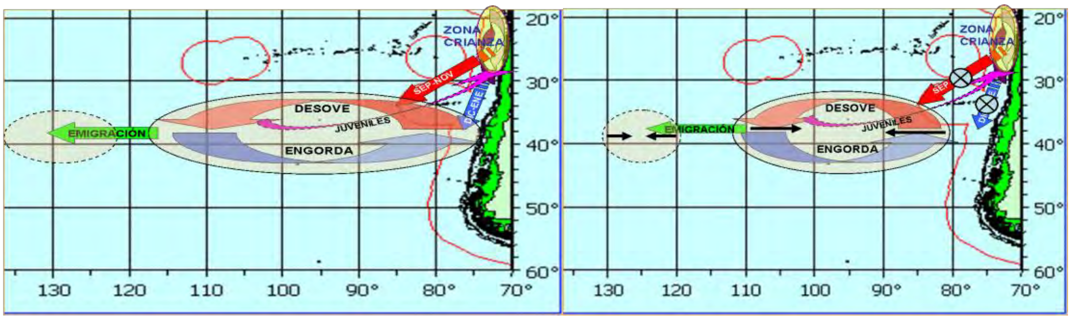


Figure 5. General model of migration of CJM under conditions of increasing abundance (left) and decreasing abundance (right) From Gretchina, 2009. Desove = spawning: engorda = feeding; zona de crianza = juvenile area

Regional migration hypotheses.

Centre-south Chile.

The fish in the centre south region of Chile have been studied by several authors, and a first schema of migration of this part of the population has been given by Arcos et al. (2001). The migration follows the "triangles" theory proposed by Harden Jones (1968)[1]. It is reproduced in the figure 6.

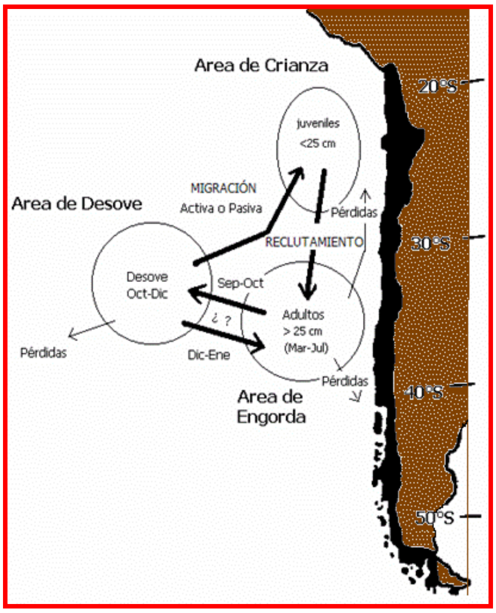


Figure 6. Migration schema of the part of the population located in the centre-south region of Chile. From Arcos et al., 2001)

This diagram gives a first and important image of the migration in the Chilean waters. Nevertheless some questions arose from Chilean and Peruvian scientists on the way larvae and juveniles could migrate from the spawning zone to the juvenile area, in a direction that is opposite to the surface drift (figure 7).

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[1] Harden-Jones, F. 1968. Fish Migration. Edward Arnold Ltd, London

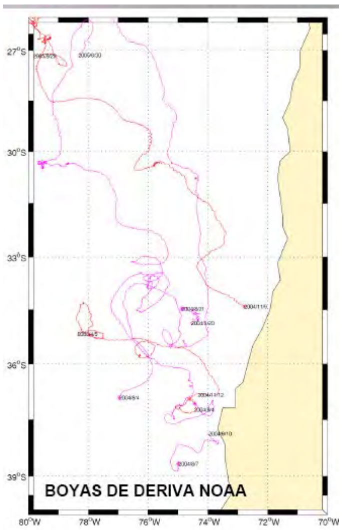


Figure 7. Example of NOAA buoys drift in the Centre-South Region of Chile

Then, although the schema is supported by the observation of the fishing data, which confirms the location of the juvenile and adult concentration areas, there are still some questions on the regional migration in this region.

An interesting synthesis of the movements and their changes in these last years was given by Gretchina (2009), from whom we extract the following informations. This author presented first a summary of the movements of the fleets in the last years (figure 8).

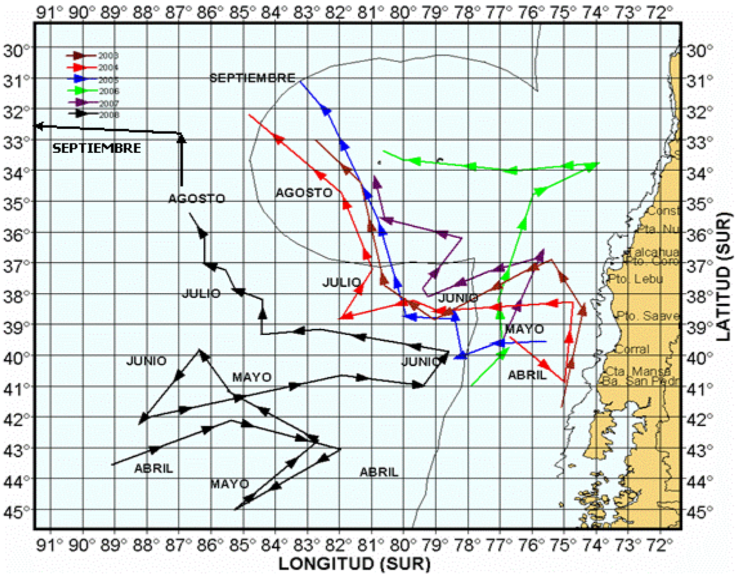


Figure 8. Summary of the migrations of the CJM as indicated by the movements of the fleet in 2003-2008 (from Gretchina, 2009)

One first observation is that there is a period of the year (October-March) where the fisheries are not working, which is likely due to the dispersion of the jack mackerel during the spawning period (see chapter 2 on behaviour). From this series of parallel movements, Gretchina presented a conceptual model and gave some comments (figure 5).

In this diagram (figure 5, right) we can see that the relationships between the juvenile area (“zona de crianza”) and the adult spawning and feeding areas have changed. Gretchina (2009) notes that “*a probable contraction of the whole distribution area since 2002, with a westward shift towards the open ocean*” occurred. The author remarks also that during the studied period no strong year class has appeared, which is likely to play a role in these changes in the migration scheme and on the uncertainties that still remain.

Peru.

Migration in Peruvian waters is harder to model, as it strongly depends on climatic conditions. The location of adults and juveniles in the Peruvian EEZ depending on the years shows how difficult is defining clearly a migration cycle (figure 9).

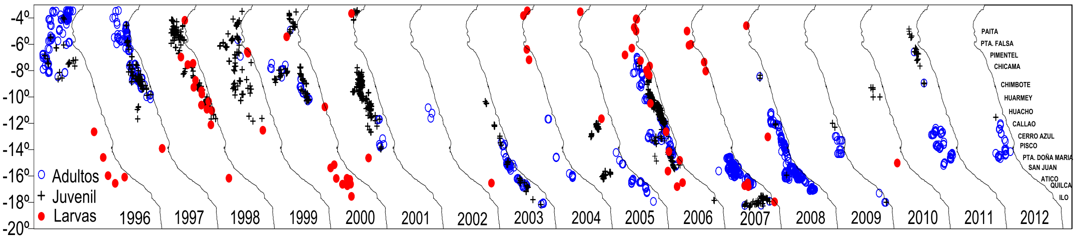


Figure 9. Interannual distribution of adults (blue circle), juveniles (cross) and larvae (red circle) of jack mackerel in the Peruvian waters from 1996 to 2012 (from Ayon and Correa, in press).

Nevertheless some works have been done in order to define a migratory circuit in the “far north” zone of the CJM distribution. Espinoza et al. (2008) presented some hypotheses during the workshop on the Chilean jack Mackerel that was held in Reñaca, Chile, in 2008. They noted (fig. 10) that the CJM which was mostly distributed in the north-Peru and south Ecuador in the 90s moved toward the south since 2000, and almost disappeared in the north since 2002 They hypothesize the influence of the water masses and alimentation that was more abundant in the south in the 2000s. However we must note here that in the last years (since 2011) a new series of cohorts entered the Peruvian waters and were found in the north as well as in the south, and that the lack of catches in the north in 2012 (as well as in the first semester 2013) is more likely due to strategies of the fleet than to lack of fish in this area.

This series of hypotheses were synthesized by Gretchina (2009) in a conceptual model presented in the figure 10.

In this model the author shows the two cases: before and after the year 2000. Before 2000 the adults were moving northward to the feeding zone, and this migration northward disappeared after 2000, the fish remaining in the south.

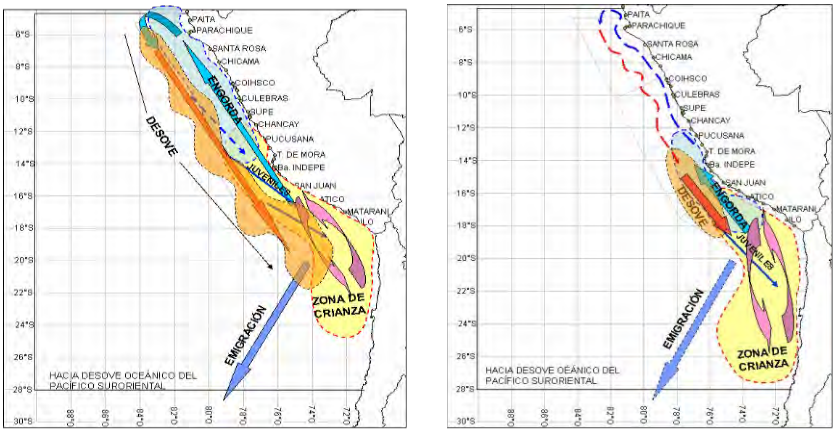


Figure 10. Two different schemes of migrations in the Peruvian region, before (left) and after (right) the year 2000 where the CJM disappeared from the northern waters. In both cases the juvenile area is situated in the south of Peru – North of Chile and seems to be common with the juvenile area of the stock in the centre-south of Chile (from Gretchina, 2009).

In this diagram, an interesting phenomenon can be pointed out: the fact that the juveniles from the Peruvian area are concentrated in the south of the region, in an area that seems to be shared with the juveniles born in the centre-south region of Chile. Although this point is in agreement with the fishing data, the question of whether it is a single juvenile area or two juvenile areas separated by the low productivity area around the 19-22ºS still remains. We will show (see chapter 3: habitat) that this region is likely to act as a border between the two stocks. Which one of these hypotheses is the correct one should be answered by tagging experiments.

The Open Ocean.

There is very few information on the possible migrations in the open ocean, and they come mostly from the fishing data of the Soviet fleet. We have seen that the analysis of the fishing data allowed building a general model (fig. 3). The recent data obtained by the Russian surveys show that the west is occupied by both adults and juveniles (fig. 11) although a consistent part of the juveniles is located in the eastern part of the area.

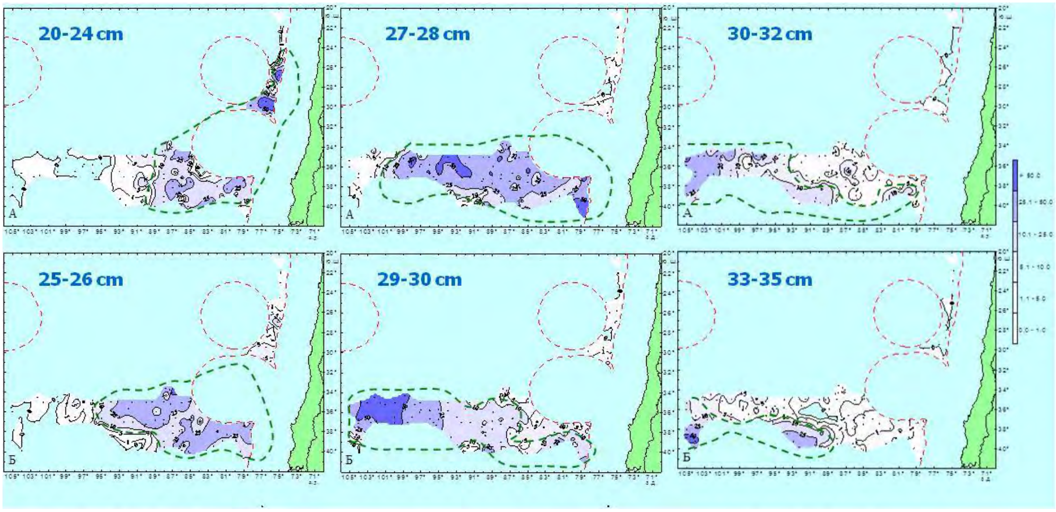


Figure 11. Spatial distribution of jack mackerel by length groups during the survey of R/V Atlantida, Oct. 2002-Jan. 2003 (from AtlantNIRO, 2003)

Although it is still impossible to establish a consistent model of migrations in the central and western part of the South Pacific Ocean, it seems likely that fish has developed a migration route that is not necessarily linked to the eastern coastal areas of the ocean. Still, no clear conclusion can be extracted from a too small number of information.

Conclusion

There is an important number of indirect informations on the spatial distribution of the CJM in the different parts of its distribution area, but due to the fact that the CJM changes its distribution according to climatic events and that the distributions are not always reproducing a single schema, plus the fact that the population structure is not yet clearly defined, then any synthesis on this question is difficult or impossible. There is a need first to agree on a general hypothesis on the population structure (which would allow, for instance, decide whether the far-north (Peruvian) distribution is or is not a sub-population) in order to integrate all the informations. Then a research devoted exclusively to studying fisheries migrations is needed, and especially studies using tagging. As long as no international tagging program is established (including electronic tagging experiments), the knowledge on migrations will remain partial, incomplete and controversial.

Chapter 2-c

Behaviour

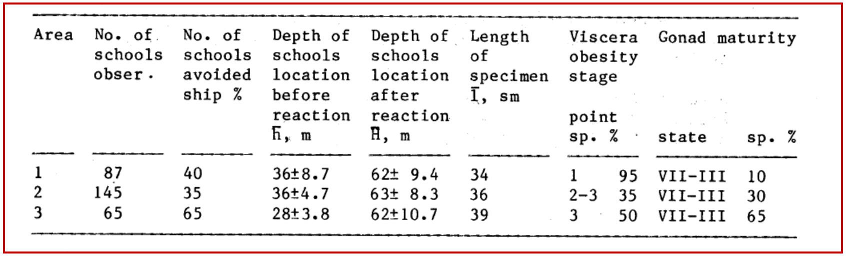
Introduction

The behaviour of *Trachurus* murphyi has been studied exclusively from acoustic surveys and fisheries data. This means that only collective behaviour is known, and in a large part collective behaviour related to fishing activities. Five main behavioural characteristics have been studied: avoidance of schools in front of fishing vessels; schooling behaviour; trophic behaviour; vertical migrations; spawning behaviour.

1. Avoidance behaviour.

The behaviour of schooling fish has been studied first by the Russian scientists, and the work of Radakov (1973)[1] who defined the specific patterns of fish school avoidance manoeuvres based on laboratory observations are seminal.

Table 1. Some characteristics of jack mackerel school reaction and physiological state of the fish (from Goncharov, 1989)



Area	No. of schools obser.	No. of schools avoided ship %	Depth of schools location before reaction $\bar{h}$, m	Depth of schools location after reaction $\bar{H}$, m	Length of specimen $\bar{l}$, sm	Viscera obesity stage		Gonad maturity	
						point	sp. %	state	sp. %
1	87	40	36±8.7	62± 9.4	34	1	95	VII-III	10
2	145	35	36±4.7	63± 8.3	36	2-3	35	VII-III	30
3	65	65	28±3.8	62±10.7	39	3	50	VII-III	65

It is therefore not surprising that the first works on avoidance behaviour have been performed by Russian scientists and the works of Goncharov (1989: table 1 and figure 1) give probably the first results on school avoidance to pelagic trawls.

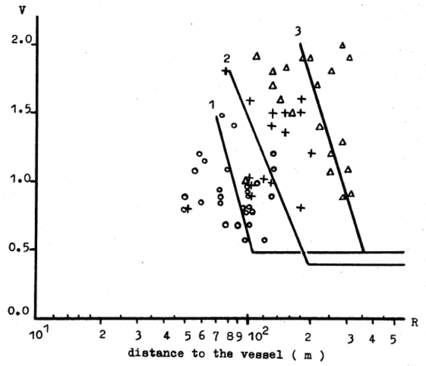


Figure 1. Dependence of speed of jack mackerel schools on distance from vessel. Slope section in diagram is obtained by least square method. Groups of schools were observed in 3 distinct "areas" (see table 1): area 1 (circles); area 2 (crosses); area 3 (triangles) each one with a different regression (from Goncharov, 1989)

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[1] Radakov, D. V. 1973. Schooling in the Ecology of Fish. Wiley, New York.

Goncharov (1989) indicates that the speed of the schools (from 0.5 to 2 m.s^{-1}) varies with the sensitivity of fish towards the “irritant” source (in this case the noise of the fishing vessel) and that the avoidance of schools can produce a bias in the biomass that can be underestimated from 34 to up to 65 %.

Another way to evaluate fish school avoidance is through the observation of echograms recorded during a survey. Interestingly some questioning observations showed that fish are not always avoiding and that some “escorting” can be observed too, i.e. fish following the track of the vessel. This point is well known for marine mammals and tunas, but has not been studied for other fish (except a work from Røstad et al, 2006[2]). Some non published observation showed that fish in Peru were presenting such behaviour (Gutierrez, pers. comm.) although it was not possible to know their species.

2. Schooling behaviour

Typology.

The shape of the fish aggregations allowed for defining some aggregation types, such differentiation being useful for studying the relationships and reactions of the schools to the environmental conditions (see chapter 4 and relationships between the CJM and the oxycline). It can be obtained through the analysis of echograms. The first typology was published in Peru in the 60s (figure 2) with the purpose of allowing some relative and qualitative analysis of the echogram, at a time where e

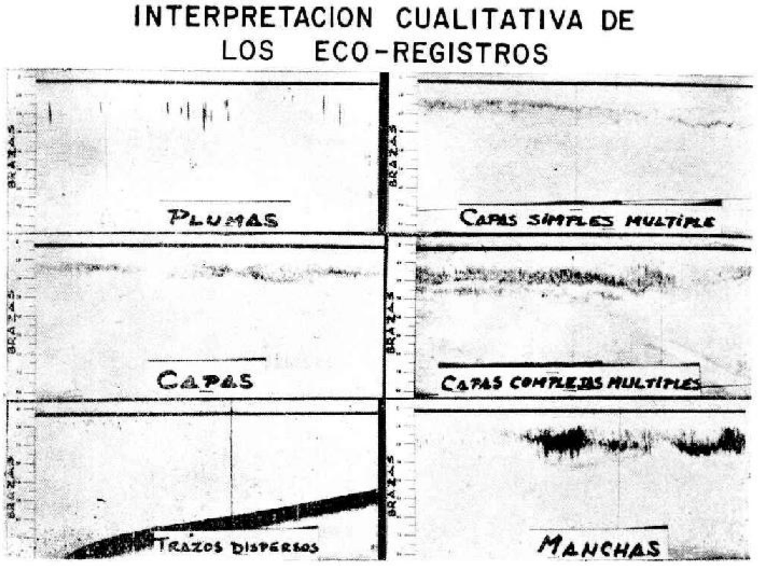

Figura 21. Primera tipología aplicada a estudios pesqueros en Perú. Fue establecida en 1964 especialmente para anchoveta durante las Operaciones Quizás (luego Operaciones Eureka a partir de 1966).

Figure 2. First typology of aggregations defined in Peru, for classification of analogic echograms designed in 1964 especially for the EUREKA surveys (Gutierrez, pers. comm.). The types defined were poles (above, left), layers (medium, left), multiple layers (above, right), multiple complex layers (medium, right), scattered targets (below, left) and schools (below, right)

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[2] Røstad, A., Kaartvedt, S., Klevjer, T. A., and Melle, W. 2006. Fish are attracted to vessels. ICES Journal of Marine Science, 63: 1431-1437.

In Chile, Hancock et al. (1995) described a typology in the 90s with the objective of studying the school behaviour in relation with the fishing exploitation and thus their typology is rather simple (figure 3). Within 4 categories of aggregations, the authors defined 3 categories of aggregations and one of scattered fish. The three aggregations were respectively small shallow schools ("type A" in the figure), large deeper schools ("type B") and layers (which are not CJM schools but represent the micronekton of the Sound Scattering Layer).

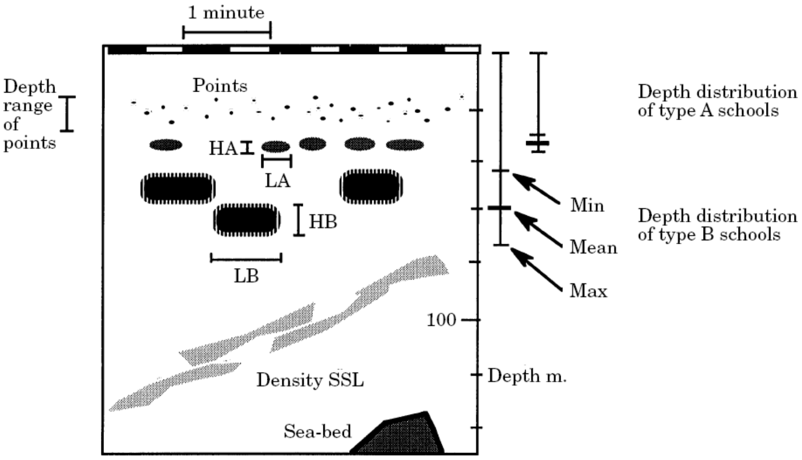

Figure 3. Schematic drawing of an echo sounder screen, with the definition of two types of schools (from Hancock et al., 1995)

Typologies were later defined more precisely in Chile (figure 4: Gerlotto and Barbieri, 1999); later it was applied to the Peruvian acoustic observations, after being simplified into 4 main structures (figure 5: Bertrand et al., 2004). Once the typology defined, it was applied to the acoustic echograms in Chile and allowed to evaluate the reactions of the CJM to environmental parameters. The effect of the dissolved oxygen concentrations on the aggregative behaviour was measured (see chapter 4) and it was observed that large schools and layers require an higher level of oxygen (above 4 ml.l^{-1}) for staying in a given place while scattered fish could survive in waters with DO as low as 1 ml.l^{-1} (Bertrand et al., 2006).

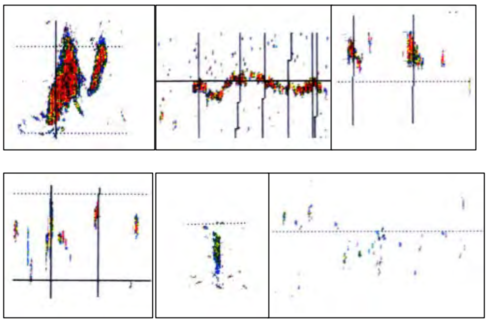

Figure 4. Typology defined in Chile. Above: exploited types. From left to right: dense schools, dense layers, mean layers; below: non exploitable types. From left to right: scattered layers, single small schools, scattered fish (from Gerlotto and Barbieri, 1999).

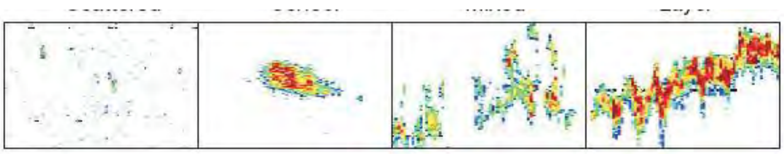

Figure 5. Simplified typology of aggregation. From left to right: scattered fish, schools, mixed structure and layers. Only schools and layers are exploitable by the fisheries. This simplified typology was used in Chile and in Peru (from Bertrand et al., 2006).

The other observation was that the typology was susceptible to change due to environmental conditions and especially the existence of an El Niño event: large schools and layers are less abundant during El Niño than during the normal period (Gerlotto and Barbieri, 1999; Bertrand et al., 2006) (fig. 6).

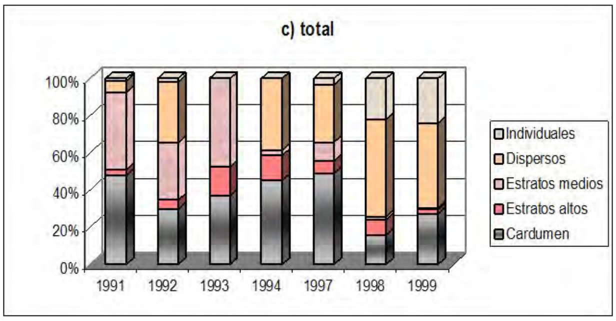

Figure 6. Evolution of proportions in the different aggregation types in Chile. Note that the dense schools are less abundant during and immediately after an El Niño event (1992 and 1998), which makes the population less accessible (from Gerlotto and Barbieri, 1999)

Aggregation behaviour

Schools are gathering in clusters of schools, which are the target of fishers in their searching for fishing grounds. The first dimension of clusters was given by Hancock (1995) using an indirect measure through radar mapping of fishing vessels in operation in Chile (figure 7). The observation selected those vessels that were actually fishing, and the hypothesis underneath was that they were fishing on the same cluster. Under these conditions the authors measured clusters of 3 nm to 6 nm diameter.

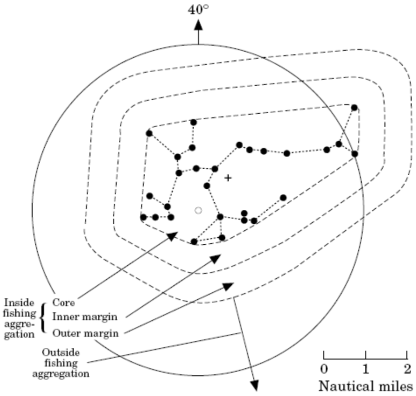

Figure 7. Radar mapping of the fishing vessels in fishing operation (from Hancock et al., 1995). The dots represent the position of the fishing vessels, dotted lines the core, inner margin and outer margin of the fish cluster.

The diameter of clusters was measured in Peru in 2011, 2012 and 2013 using geostatistics methods on acoustic data provided by the fishing vessels. The diameter of the clusters was estimated at 2.5, 2.4 and 1.4 nm for 2011, 2012 and 2013 respectively (fig. 8). Although smaller than the cluster dimensions evaluated by Hancock, they remain in the same order of magnitude.

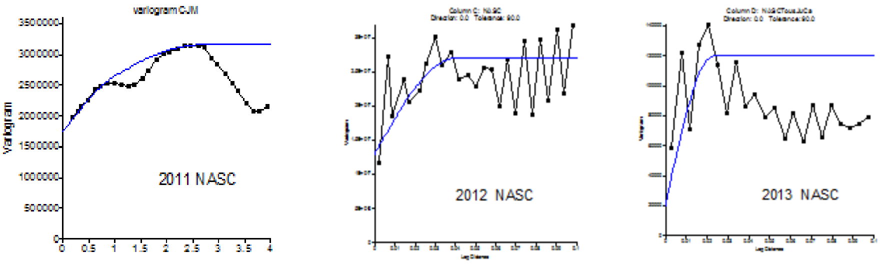

Figure 8. Variograms presenting the estimated diameter of clusters during 2011 (left), 2012 (centre) and 2013 (right). NASC data were collected aboard the fishing fleet and processed using Surfer during the 4 workshops organized by the SNP in Lima from 2011 to 2013 (from SNP, reports of the CJM workshops).

Soria (*in* Gerlotto and Barbieri, 1999) measured the cluster using other methods and data (schools observed with echo sounders along transects). The author synthesized his observations in the following statement: "*The large majority of the observed aggregations observed along transects present a rather small distance between schools (less than 650 m). Schools may have 3 aggregation types: regularly spaced, contagious or "individual" (outside aggregation). The schools that are regularly spaced belong to the richest part of the prospection area while the contagious distributions are observed everywhere*". The dimension of clusters is obtained by considering the number of schools inside a given length as can be seen on the figure 9: for small distances (from 0 to the first red line at around 1500 m), by increasing the distance the number of clusters created in the area increased. Then from 1500 m to 4200 m the number of clusters does not change; eventually when the distance is longer than 4200 m (second red line) the number of clusters decreases. This indicates the extreme dimensions of the clusters: if we arbitrarily define larger distances, then we gather in a same aggregation several clusters. Using this method the author calculated that clusters presented lengths between 0.8 and 2.3 nm.

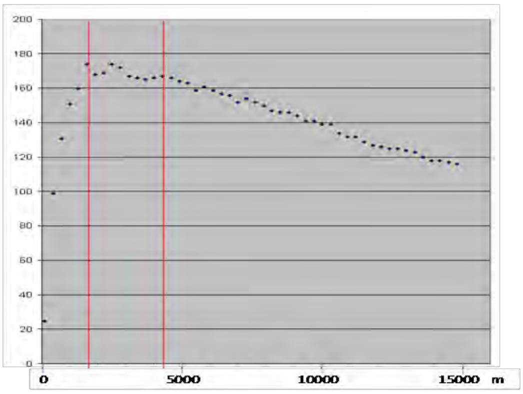

Figure 9. Measurement of clusters along the transects.The two red lines indicate the lowest and longest diameter of the clusters. (from Soria, in Gerlotto and Barbieri, 1999). X: length of a cluster (in m); y: frequency

Another important result presented by Soria (in Gerlotto and Barbieri, 1999) is the fact that the dimension of schools changed depending on their inclusion or not in a cluster. Schools inside clusters are normally bigger than solitary schools. This difference changes (and is reverse) during an El Niño event (figure 10), where all the schools become smaller, those inside cluster becoming even smaller that those outside clusters.

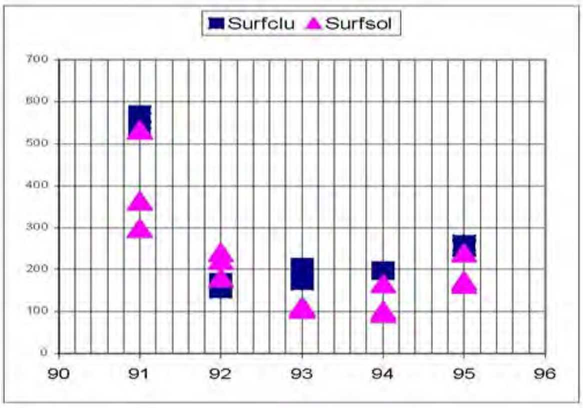

Figure 10. Variation of school diameter inside (triangles) and outside (squares) of clusters (with confidence intervals), depending on the year. Note that solitary schools are usually the smaller, except in 1992 when an El Niño occurred. We can also note that the school dimensions were much higher before El Niño than several years after the event.

Vertical migrations

Vertical migrations of schools are linked to the trophic behaviour and dial cycles. Several works have been performed, using acoustic devices. The first one was published by Hancock et al. (1995) and concludes that the jack mackerel is performing daily vertical movements, from the sub-surface (between 15 and 40 m) by night to depth varying according to the distance from the coast: around 50 m deep at distances inferior to 10 nm from the coast, until over 100 m for distances farther than 30 nm (figure 15).

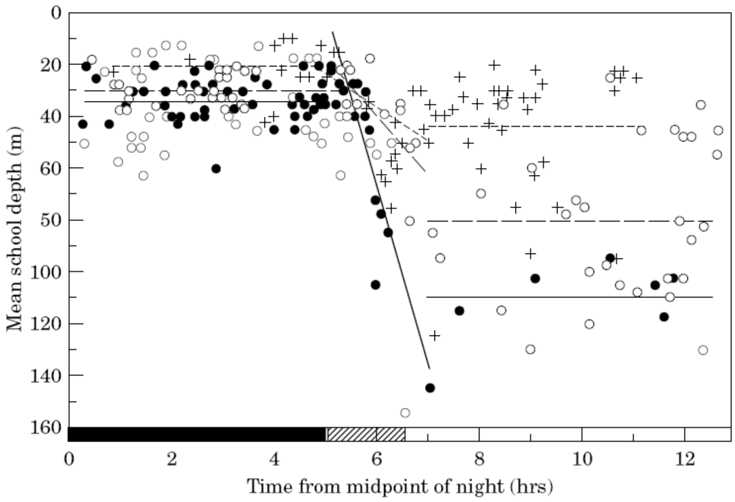

Figure 15. The mean depth of all schools observed against the time from the midpoint of the night, adjusted so that sun-up and sun-down are the same for all days. The bar on the horizontal axis is black for night, hatched fro dawn and dusk and open for daily hours. Horizontal lines show mean depths during day and night at the different distances offshore. Crosses and short dashed lines

denote observations closer that 10 nautical miles offshore, open circles and long dashed lines between 10 and 30 nm offshore; filled circles and solid lines denote observations farther than 30 nm offshore (from Hancock et al., 1995).

Bertrand et al. (2006) presented results on the vertical migration of jack mackerel from the observation of several years of surveys by IFOP in Chilean waters. Their first result considers the density of the aggregations during day and night (figure 15). It shows that fish are aggregated in slightly denser structures by day than by night

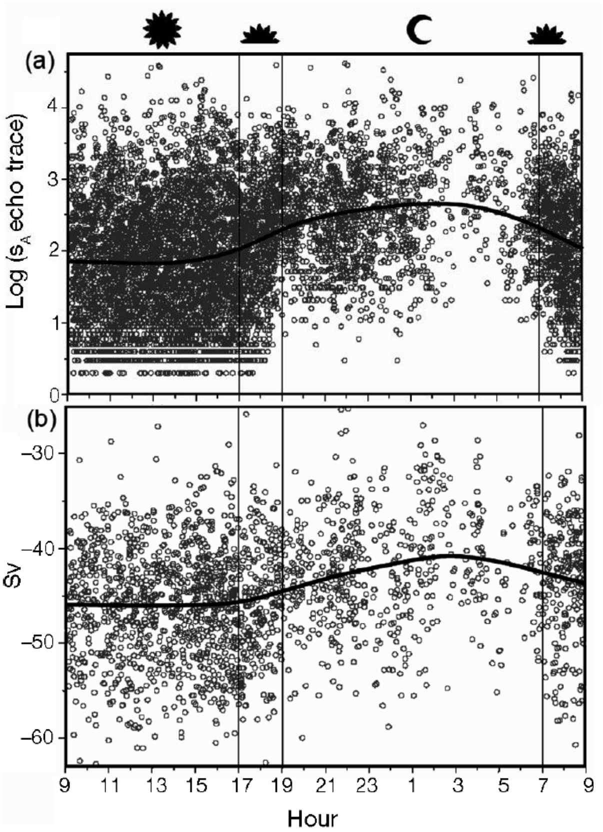

Figure 15. Diel pattern (a) of the log-transformed acoustic nautical area scattering coefficient (S_A in $m^2.nm^{-2}$) and (b) of the volume backscattering strength (Sv in dB re 1m-1) of echo traces (circles: raw data; solid line: a spline smoother fitted to the data). The star represents the day, the semi-star, dusk and dawn, and the moon represents the night. Note: the reduced number of data by day is due to the lower number of samples during this period, and not to the ability to detect fish.

Concerning vertical migrations, the authors observed a strong vertical daily migration, the fish being located at around 20 m by night and 100 m by night, which corroborates Hancock's results, especially considering that the observations made by Bertrand et al. (2006) were performed at large distances from the coastline.

3. Trophic behaviour

Some studies on trophic behaviour have been performed during the last decade. The most important results have been presented by Bertrand et al. (2004, 2006) where the daily migrations, the environmental characteristics etc. were taken into consideration. The authors present a conceptual model of trophic behaviour that is driven by the stratification of the water masses and especially the oxycline (fig. 16).

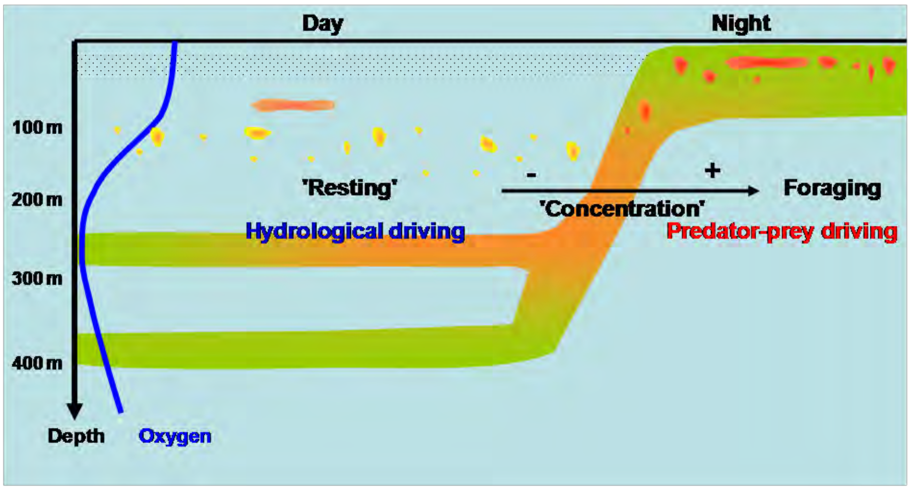

Figure 16. Conceptual model of trophic behaviour of jack mackerel. The model presents a daily behaviour, where the fish is resting above the MOZ during the day, as it is unable to cross this barrier, and begins to feed on the micronekton layer when those are crossing the MOZ during their migration towards the surface at dusk. Fish is actively feeding in schools during the night close to the surface and dives up to the upper limit of the MOZ ad dawn

The authors remark: "*The apparently 'atypical' schooling behaviour of the jack mackerel Trachurus murphyi (Bertrand et al. 2004) was confirmed by the present study. Diel schooling behaviour was the inverse of that usually observed, as fish dispersed by day and aggregated in dense collective structures at night. If fish are able to school at any time of the day, light thresholds are not necessarily key parameters for schooling behaviour dynamics. A major difference between T. murphyi and other obligatory schooling fish species is its habitat since the former is mostly found in oceanic waters, i.e. not on the shelf or shelfbreak*".

4. Spawning behaviour

The jack mackerel presents a peculiar behaviour when spawning: contrarily to most of the species, spawning occurs during a dispersion phase where schools are almost disappearing: This is particularly clear in the works presented by IFOP comparing the distribution of fish and eggs & larvae in Chile (Barbieri et al., 2004)[3] (fig. 17). The spawning season is indeed the period when no fishing activity is possible, due to the extreme dispersion of the fish. There are no behavioural research on this point, and the conclusions on this point are only speculative, but there are two hypotheses explaining the discrepancy between the fish and egg distribution: the first one is that spawning fish is scattered and does not appear in the echograms: such behaviour should limit the risks of cannibalism; the second one is that due to this cannibalism, eggs are less abundant where fish are abundant. Specific works should document this question.

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[3] Barbieri, M.-A., Córdova, J., Gerlotto, F., Espejo, M., 2004. Spatial strategies of jack mackerel (*Trachurus symmetricus murphyi*) off the centrworkshop SPACC, Concepcion, 2004.

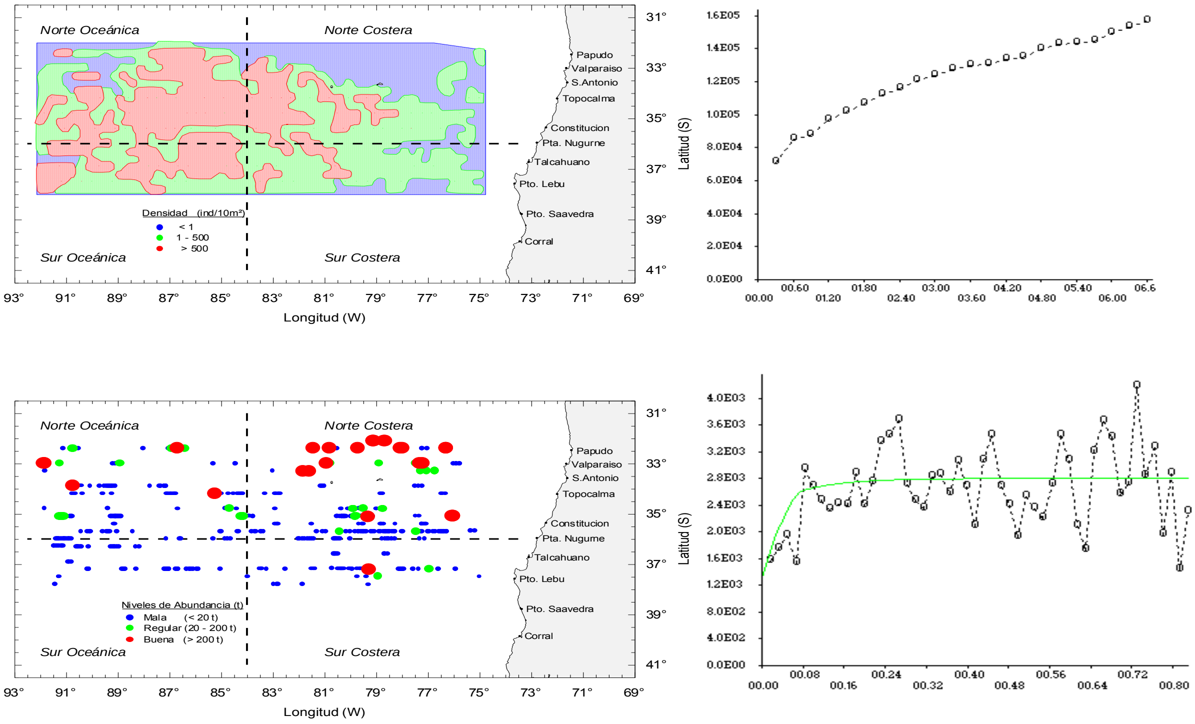

Figure 17. Comparison of spatial structure and distribution of eggs (above) and fish (below) in 2000. Left: geostatistical variograms on egg and fish abundance. It is interesting to note that the major abundance of CJM (relative abundance obtained through RASTRILLO surveys) is observed in the NW part of the observed area, i.e. where the egg distribution is the lower (from Barbieri et al., 2004). It is worthwhile to note also the great difference between the spatial structure of fish and eggs, as observed by comparing the variograms

Conclusion of CJM behaviour

As was stated, there is practically no research dedicated to fish behaviour. Therefore the informations come from catches of acoustic surveys. Therefore the hypotheses are not always strongly supported by data, and some research should be performed. This is particularly critical for migrations and spawning behaviour that condition the general knowledge on the fish and the understanding on the population structure, the recruitment, the connexions between sub-populations, etc. Some recommendations should be done in order to develop project in the fields of tagging experiments, including electronic tagging.

Chapter 3-A

Hydrology

The South East Pacific Ocean, and particularly the Humboldt Current Ecosystem, presents a remarkable characteristic, which is its huge variability in climate. As expressed by Espino and Yamashiro[1] (2012): *"In this region, variability is a common event that meets regulatory standards of macro-scale such as seasonal, inter-annual, periodical and secular as processes of short, medium, long and very long term. In this scenario ENSO (El Niño Southern Oscillation), PDO (Pacific Decadal Oscillation) and PSV (Pacific Secular Variability) appear as the most conspicuous environmental factors or manifestations of variability*". We will not evaluate the relationships between the Pacific Secular Variability (figure 1) and CJM, for the fishery is not old enough to provide information. Works using fish scales in the sediment (Gutierrez et al., 2009) exist, but they mostly refer to the coastal part of the population and therefore are difficult to apply to the CJM whole population.

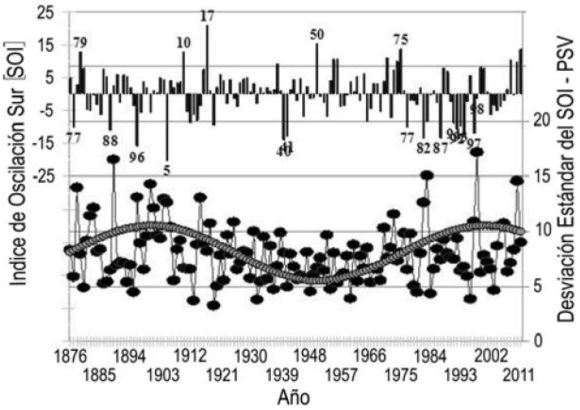

Figure 1. Southern Oscillation Index and its variance. Annual average from 1876 to 2010. The sinusoid curve represents a conceptual model of variability (from Espino and Yamashiro, 2012)

We will focus here only on those environmental characteristics that have an effect on the CJM habitat. We present here the list of the main factors as extracted from the literature review, and that are studied in other chapters of this work (see Chapter 2 among others). They are:

- Climatic: ENSO events, decadal events, Kelvin waves,etc.
- Hydrological: Sea Surface temperature (SST), Salinity, Oxygen Minimum Zone (OMZ), currents, eddies, etc.
- Environmental: water masses, phytoplankton and micronekton abundance and distribution (fig. 2).

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[1] Espino, M., Yamashiro, C., 2012. La variabilidad climatica y las pesquerias en el Pacifico Sur. Lat. Am. J. Aquat. Res., 40(Suppl. 1), 2012. International Conference: "Environment and Resources of the South Pacific". P.M. Arana (Guest Editor)

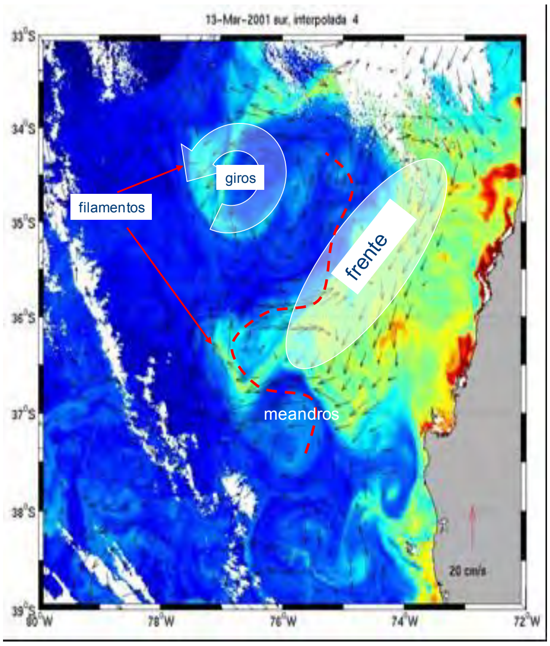

Figure 2. Main hydrographic structures in the SouthEast Pacific Ocean. These structures are recurrent in the coastal and oceanic region off Chile (30-40 ºS); they are mainly associated with upwellings and induce a high variability in the region(from Grechina, 2009).

Most of the information obtained for these interactions between the CJM and the environment that lead to a habitat definition come from satellite data, the fisheries and acoustic surveys developed principally by the Chilean and the Peruvian Research institutes, and in a less intensive way by Russian surveys.

General overview of the South Pacific Ocean current system.

As the other southern oceans, the Pacific Ocean is driven at macroscale by a cyclonic gyre (figure 3).

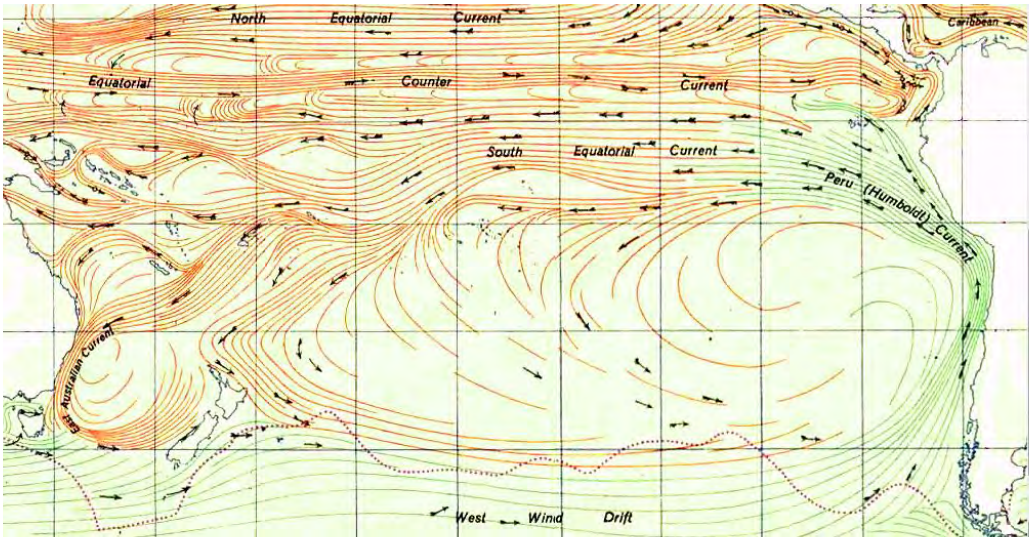

Figure 3. General description of surface currents of the southern Pacific Ocean

The particular effect of the long South American coastline oriented S-N induces a series of specific patterns that make this region one of the most productive in the world.

The Humboldt Current System. Among these currents one presents a particular importance in the SE Pacific ecosystem: the Humboldt Current, transporting Antarctic waters from the pole towards the equator along the South America coastline. This current is responsible for the cold waters found even close to the equator and the high productivity of this part of the ocean, productivity that is at the base of the trophic chain leading to the jack mackerel (figure 4).

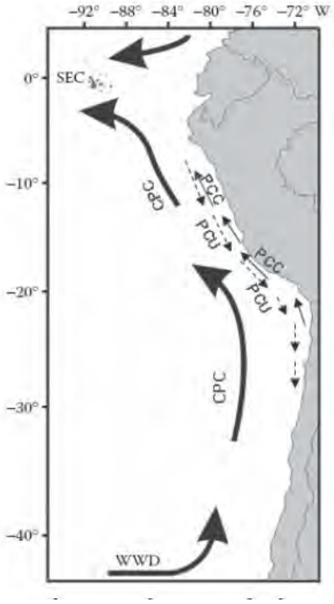

Figure 4. The Humboldt Current System

ENSO events. Another major hydrological and climatic phenomenon is the existence of the "El Niño Southern Oscillations" (ENSO). The figure 5 shows that all the hydrological system is affected by the ENSO events, because the subtropical front oscillates from south to north when an ENSO occurs (Arcos et al., 2001). The table 1 gives the actualized list of the ENSOs observed in Peru since the 19th century (from Quinn *et al.* 1987 *In* Espino, 2013).

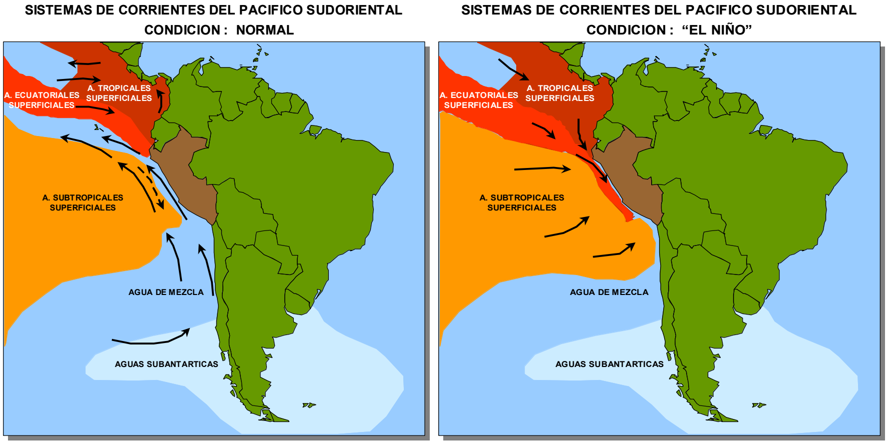

Figure 6. Hydrographic structure of the southeastern Pacific Ocean during normal (left) and El Niño (right) periods

Table 1. List of ENSOs in Peru since the 19th century
(from Quinn *et al.* 1987 *In* Espino, 2013).

Year	Int	Year	Int	Year	Int	Year	Int	Year	Int
1803-1804	S+	1844-1845	S+	1880	M	1917	S	1957-1958	S
1806-1807	M	1850	M	1884	S+	1918-1919	W/M	1965	M+
1812	M	1854	W/M	1887-1889	W/M	1923	M	1972-1973	S
1814	S	1857-1858	M+	1891	VS	1925-1926	VS	1976	M
1817	M+	1860	M	1896-1897	M+	1930-1931	W/M	1982-1983	VS
1819	M+	1864	S	1899-1900	S	1932	S	1987	M
1821	M	1866	M	1902	M+	1939	M+	1991-1994	M
1824	M	1867-1868	M	1905	W/M	1940-1941	S	1997-1998	VS
1828	VS	1871	S+	1907	M	1943	M+	2002	M
1832	M	1874	M	1911-1912	S	1951	W/M	2009-2010	S
1837	M	1877-1878	VS	1914	M+	1953	M+		
Int = Intensity; W/S = Weak-Moderate; M = Moderate; S = Strong; VS = Very Strong									

The ENSO of 1998 is considered the strongest in the 20th century; therefore several works have been performed on results from this particular period to evaluate the impact of El Niño on fish populations.

In 2001, Arcos et al. presented an important analysis on the effect in Chile of the ENSO 1998. The work was specially focused on the effect on recruitment. Among their conclusions, the following one deserves full citation: "*Environmental impacts associated with El Niño cannot be overlooked in the management of Chilean jack mackerel fishery. Our results suggest that there is a one year lag in the response of an increased incidence of juvenile jack Mackerel to ENSO phenomena. Therefore, the continuing high incidence of juveniles in 1999 was still a consequence of the environmental changes in the period 1997–1998. In central–southern Chile the oceanographic conditions were cooler in 1999 and the persistence of juveniles in the fishing regions, has been taken to indicate the overexploitation hypothesis is correct*" (Arcos et al., 2001).

These different (not exhaustive) effects show that the ENSO has a global effect on the CJM population. We agree with the conclusion from Bertrand et al. (2004) who recommend an "integrative context" for the analysis of factors occurring at different spatio-temporal scales which play a role in the habitat of the CJM as synthesized on figure 7.

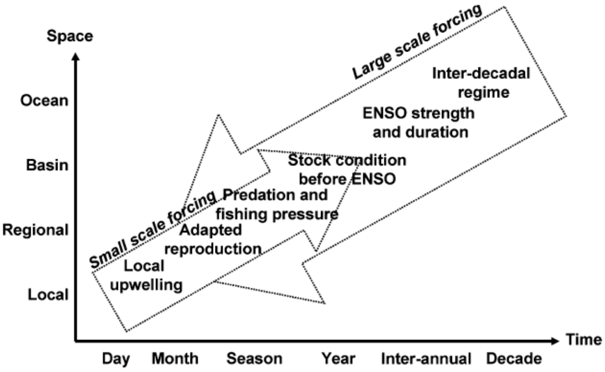

Figure 7. Synthesis of factors occurring at different spatio-temporal scales that should be considered for interpreting the effects of an El Niño on a pelagic fish population such as the Chilean Jack Mackerel (From Bertrand et al., 2004)

In any case, the most visible effect of an ENSO event is to make the habitat oscillating from north to south according to El Niño and the CJM changing several patterns of its behaviour.

Decadal events. These cycles, on a decadal frequency, have been described by Chavez (2003).. Although it remains controversial (e.g. McClatchie, 2012; Vert-pre et al., 2013), the effect of these decadal cycles on the CJM distribution have been interpreted (figure 8) mostly as factors of overall abundance and spatial movements of the populations (Dioses, 2007; Espino and Yamashiro, 2012, among others).

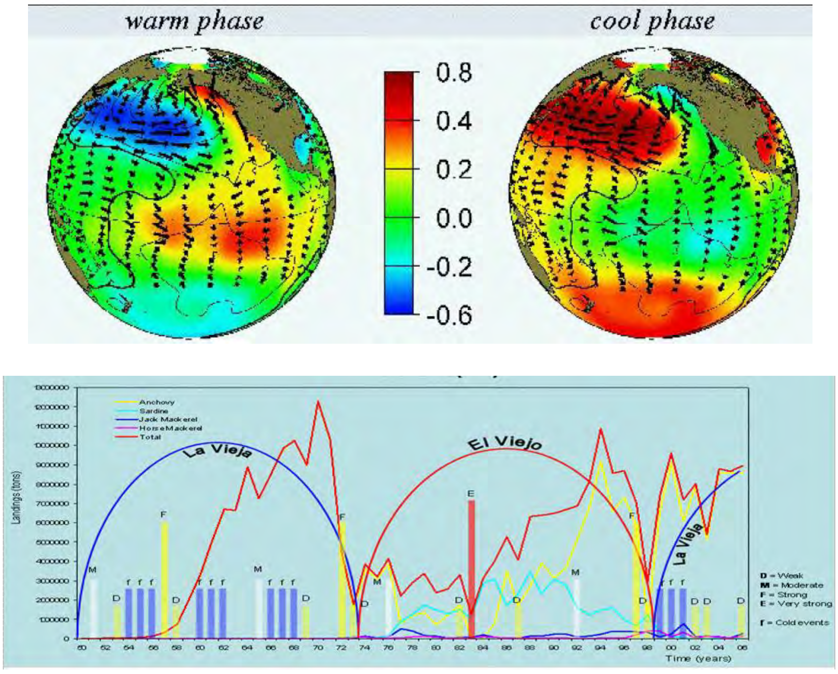

Figure 9. Above: the two phases of the decadal events (from Chavez, 2003). Below: Fluctuations of pelagic fish landings in Peruvian waters during El Viejo and La Vieja periods. (from Dioses, 2007).Note: These decadal phases have been named in some occasion El Viejo (warm decadal phase) and La Vieja (cold decadal phase) in reference to El Niño and La Niña. These terms can be encountered in some papers.

Kelvin waves. They are linked to the ENSOs, and produce a series of changes in the Eastern Pacific Ocean. How these events affect the CJM can be extrapolated from a work from Bertrand (2005) concerning the Peruvian Anchovy (Figure 10). There is no doubt that all the pelagic species suffer the same kind of effects from Kelvin waves, although they can produce distinct results according to the biology of the species and the fisheries. There is no work performed on CJM at this scale yet, but it seems important for the future to consider it.

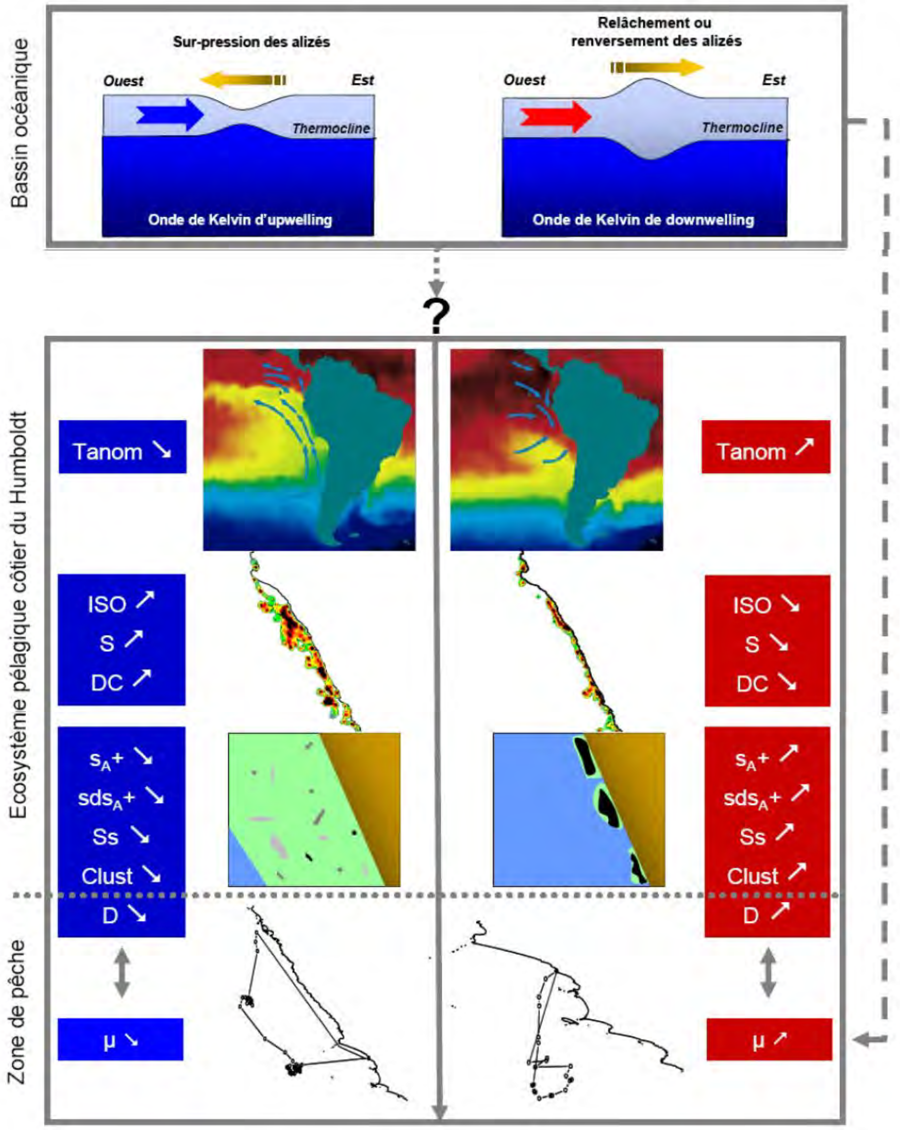

Figure 10. Schematic synthesis of the relationships between the Kelvin waves and the dynamics of some components of the ecosystem, confirmed (solid lines) or still hypothetical (dotted lines) for the particular case of anchovy. From Bertrand, 2005

Sea Surface temperature. This is the easiest value to measure thanks to satellite images. It has been studied since the beginning of the CJM fisheries and a long series of results have been produced (fig. 11; see also chapter 3-A of this work).

Salinity. There are few works on salinity, and it is assumed that this variable does not play a significant role in the definition of the CJM habitat. The figure 11 seems to show that the variation of salinity in the distribution area is not among the strongest parameters, but still play a role in the preferendum of the fish (Dioses, in press; see also chapter 3: Habitat).

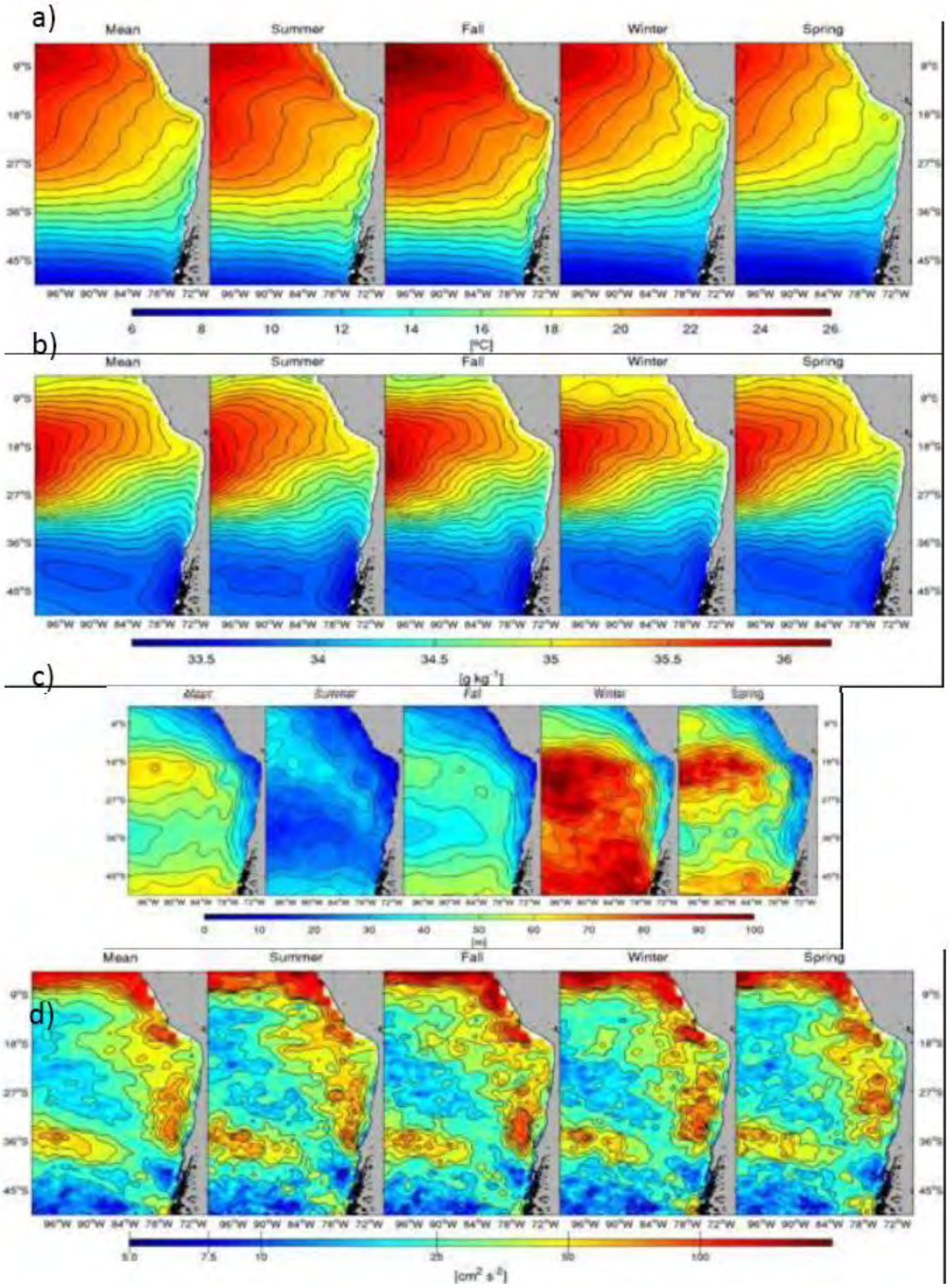

Figure 11. Spatial average distribution of a) Sea Surface Temperature (ºC), Sea Surface Salinity (g.kg^{-1}), c) mixed layer depths (m) and e) Eddy kinetic energy (cm^2.s^{-2}) in the Southern Pacific Ocean. Figures a, b, c, consider 1975-2005 and figure d considers 1997-2005 periods. (from Nuñez et al., 2009)

Oxygen Minimum Zone. This parameter, contrarily to salinity, seems to be a key parameter, and probably the one that plays the principal role in the vertical distribution of CJM, as well as in the vicinity to the coastline. An important synthesis has been presented on this topic by Bertrand et al. (2004; 2006; 2010). According to these authors, indeed the OMZ is crucial in the

SE Pacific, as it can be present at very shallow depths (up to 20 m below the surface along the Peruvian coastline). The figure 12 displays the average depth of the OMZ during the period 1960-2005 in Peru (7ºS-18ºS).

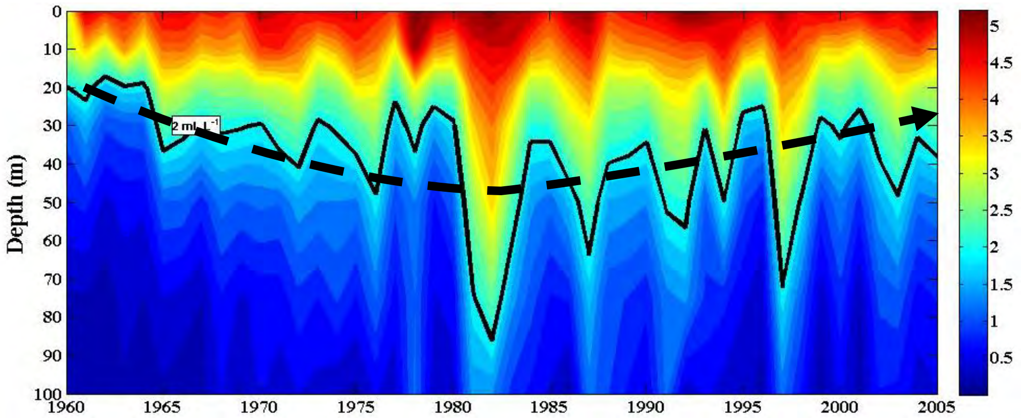

Figure 7. Disolved oxygen (mL/L) evolution in the first 100 m of the coastal region of Peru 7°S to 18°S). Data obtained using Niskin bottles and CTDO.

Figure 12. Dissolved oxygen (ml.l^{-1}) and OMZ evolution in the first 100 m of the coastal region of Peru (7ºS to 18ºS), as described through CTDO samples, for the period 1960 to 2005 (from Bertrand, pers. comm)

Currents. The Humboldt Current System is strongly driven by currents either from the Antarctic or the equatorial areas. It is logical to conclude that the CJM is highly adapted to these currents and that its habitat depends on these features (fig. 13).

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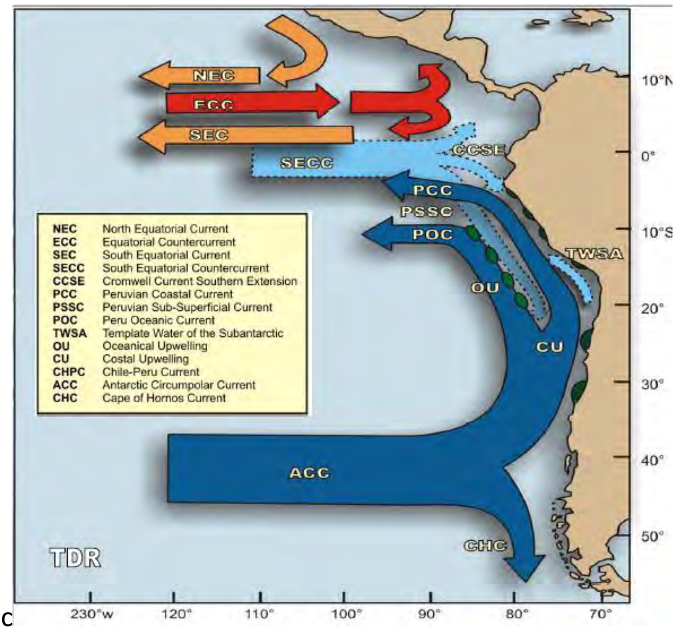

Figure 13. General current diagram in the Southern Pacific Ocean (from Dioses, 2008).

When entering more in details, one can see a more complex pattern e.g. along the Peruvian coastline (figure 14).

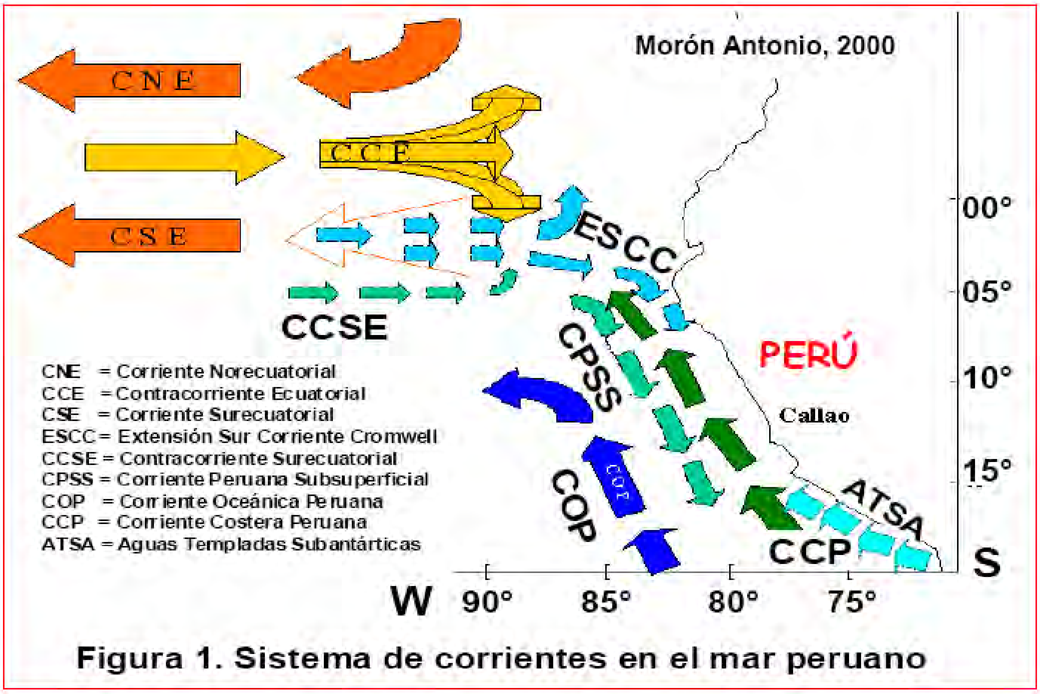

Figure 14. Current system in the Peruvian sea (from Espino, 2003[2], redrawn from Morón, 2000[3])

Finally the current system is also driven by undercurrents which can be important in this area as stated by the studies of Chaigneau et al. (2013[4]) who used results from ADCPs (fig. 15).

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[2] Espino, M., 2005. Estrategia de gestión ambiental para el pacifico Oriental con Especial mención a la pesquería peruana. MS thesis, Universidad Nacional Mayor de San Marcos, Lima, Peru, Nov. 2005

[3] Morón, A., 2000. Características del ambiente marino frente a la costa peruana. Bol. Inst. Mar Perú Callao, 19(1-2):179-203

[4] Chaigneau, A., Dominguez, N., ldin, G., Vasquez, L., Flores, R., Grados, C., Echevin, V., 2013. Neaqr-coastal circulation in the Northern Humboldt Current System from shipboard ADCP data. Journal of Geophysical research: Oceans (DOI 10.1002/jgrc.20328)

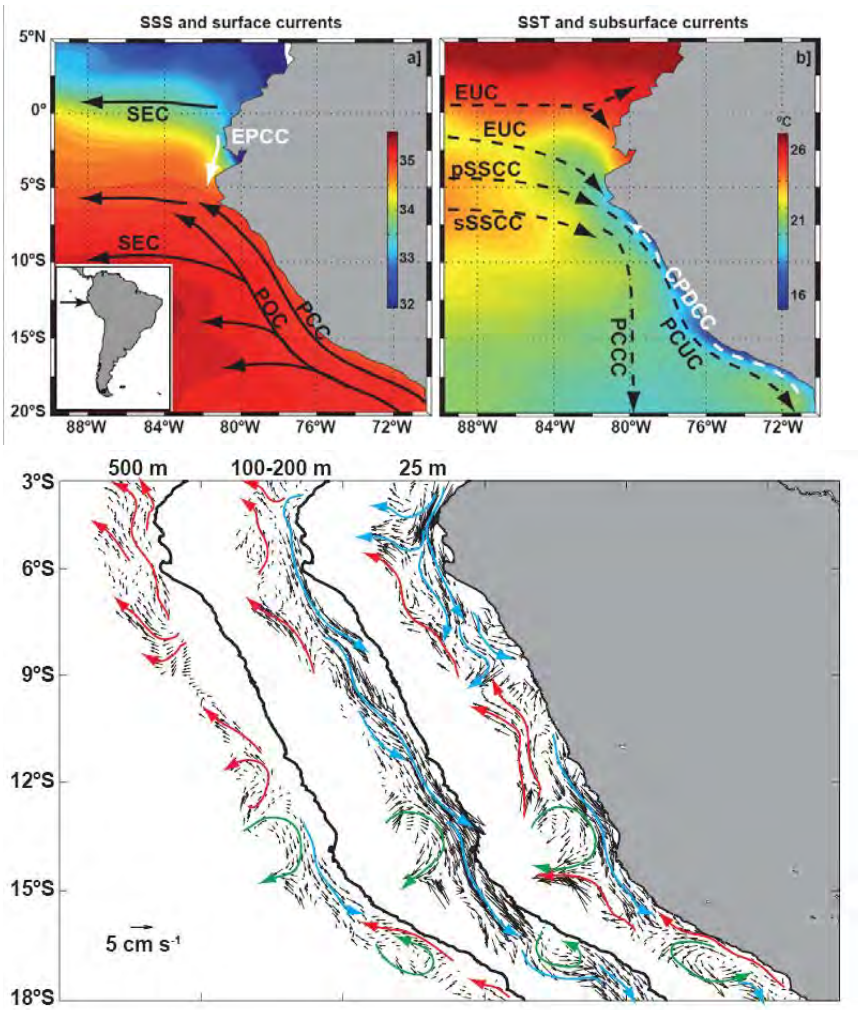

Figure 15 .

Above: Sea surface properties and oceanic circulation scheme. (a) Sea-Surface Salinity (SSS, color shading) and surface circulation. (b) Sea-Surface Temperature (SST, color shading in °C) and subsurface circulation. SST and SSS were derived from the CARS 2009 climatology [Ridgway et al., 2002]. This Figure was adapted from *Penven et al.*, 2005; *Kessler*, 2006; *Montes et al.*, 2010; *Czeschel et al.*, 2011; *Mollier-Vogel et al.*, 2012. The newly defined Ecuador-Peru Coastal Current (EPCC) and Chile-Peru Deep Coastal Current (CPDCC) are indicated by white arrows. Surface currents. SEC: South Equatorial Current; EPCC: Ecuador-Peru Coastal Current; POC: Peru Oceanic Current; PCC: Peru Coastal Current.

Subsurface currents. EUC: Equatorial Undercurrent; pSSCC: primary (northern branch) Southern Subsurface Countercurrent; sSSCC: secondary (southern branch) Southern Subsurface Countercurrent; PCCC: Peru-Chile Countercurrent; PCUC: Peru-Chile Undercurrent; CPDCC: Chile-Peru Deep Coastal Current.

Below: Mean current obtained from the interpolation of SADCP profiles at 25 m, between 100 m and 200 m, and 500 m depth. Colors represent the mean speed in cm s-1. Red and blue arrows represent schematically the equatorward and poleward flows, respectively. Green arrows indicate the presence of mesoscale cyclonic (~14°S) and anticyclonic (~17°S) eddy-like features. (from Chaigneau et al., 2013)

Eddies. The importance of eddies and gyres in the distribution of the CJM has been described by several authors (Demarcq, Pizarro, Hormazabal, Sierra, Dewitte, etc. ref.) (fig 16).

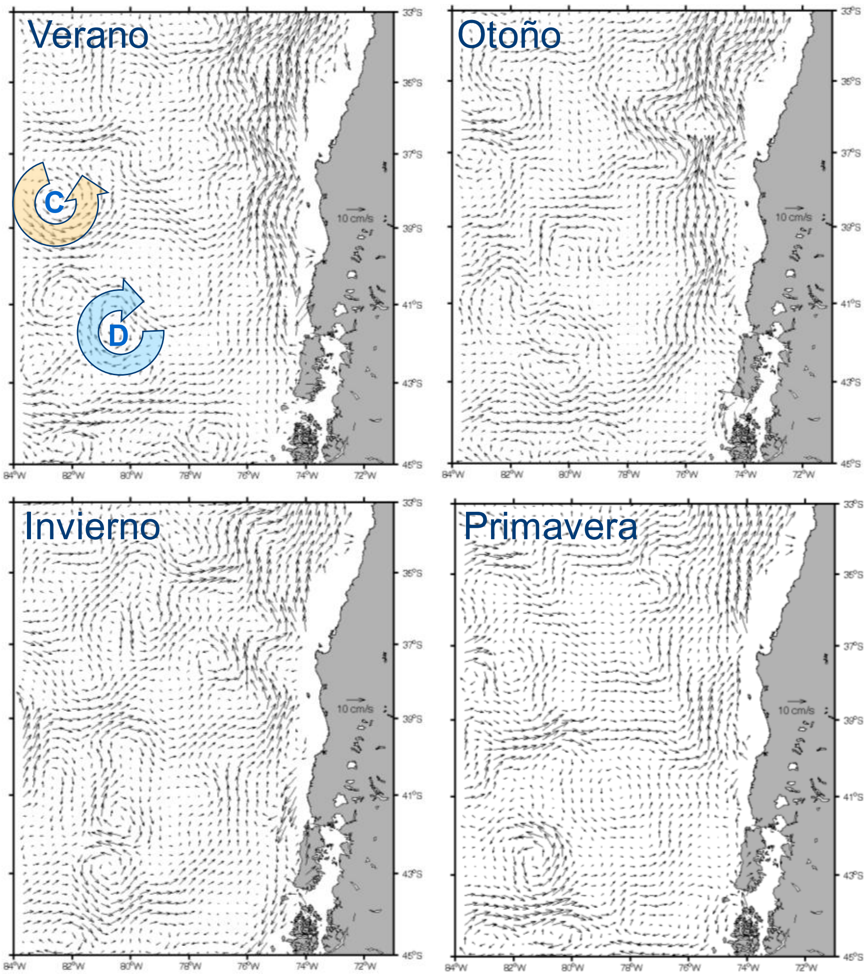

Figure 16. Description of eddies (cyclonic and anticyclonic) in summer (Verano), Autumn (Otoño), winter (invierno) and spring (primavera) along the centre-south coast of Chile (Hormazábal *et al* in press, Correa *et al*., in prep.).

No final conclusion has been presented as far as gyres are concerned and more work is to be performed. Nevertheless, these mechanisms of concentration of dispersion of the productivity are likely to play an important role in the distribution of the CJM and especially the spawning success and recruitment. They also play a role in the retention-dispersion of eggs and larvae in the surface layers, which can affect considerably the success of recruitment of fish (Brochier et al., 2013: fig. 16).

Brochier et al. (2013) note: *“Our results show that future climate change may significantly reduce fish capacity in the HCS, which may have strong ecological, economic, and social consequences. Ocean stratification is a general feature of global climate change; however, its impact in the other EBUS may be different from what is described here, in particular because of deeper OMZ (Paulmier & Ruiz-Pino, 2009), allowing different larval behavior. Also, in the context of significant wind stress changes the relative impact of mesoscale structure vs. stratification may differ from that found in the HCS. Thus, it may be worth performing similar impact studies in the other major EBUS”.*

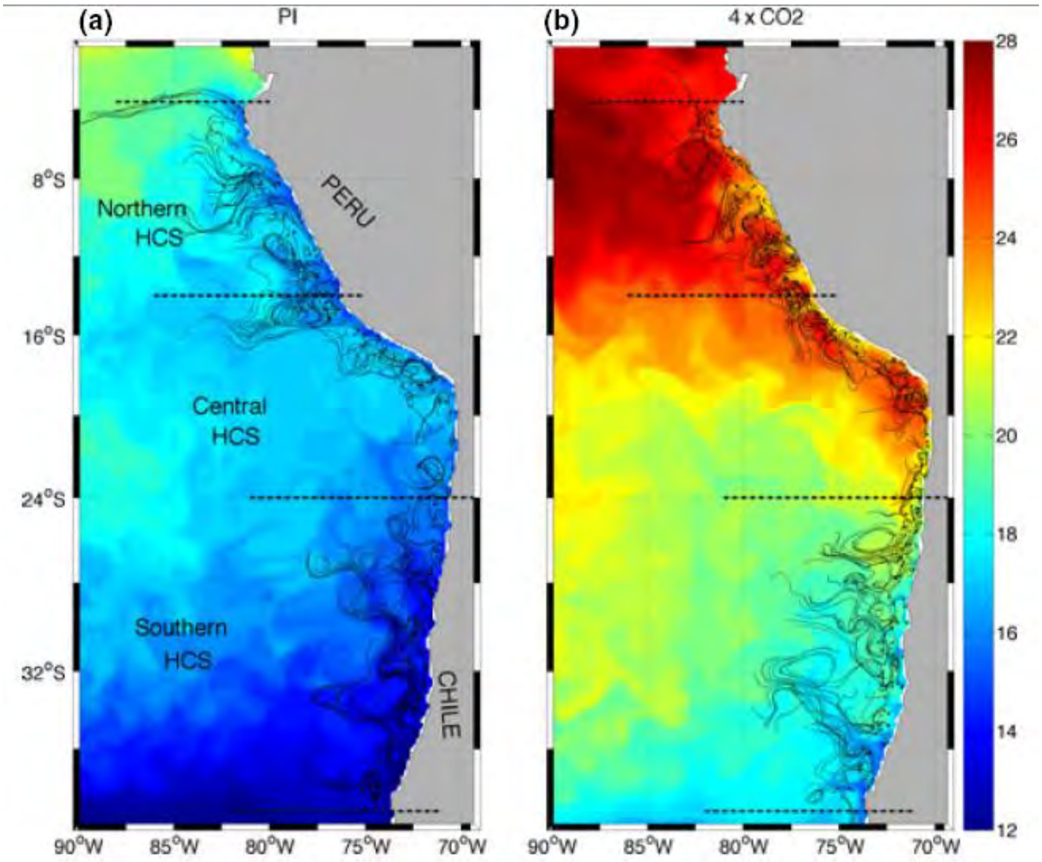

Figure 17. Sea surface temperature (snapshot) and 30-day trajectories for a sample of 200 individuals released over the continental shelf, during November, for 1 year of the solution for (a) PI, and (b) 4 9 CO2 scenarios. Thick horizontal dashed lines delimit the northern, central, and southern Humboldt Current System (HCS) areas.(from Brochier et al., 2013[5])

Water mass stratification. Water masses are synthesizing the characteristics of the sea water, therefore are likely to be the most important pattern describing the distribution and habitat of a given species. The SE Pacific Ocean hydrological patterns are described through a series of different water masses, which are listed in the figure 18. Special attention has been given in the literature to these water masses in Peru because of their strong effects on the anchovy population. We can assume that they play also a role on the CJM distribution, migrations and horizontal movements.

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[5] Brochier, T., Echevin, V., Tam, J., Chaigneau, A., Goubanova, K., Bertrand, A., 2013. Climate change scenarios experiments predict a future reduction in small pelagic fish recruitment in the Humboldt Current system. Global Change Biology (2013), 19: 1841-1853

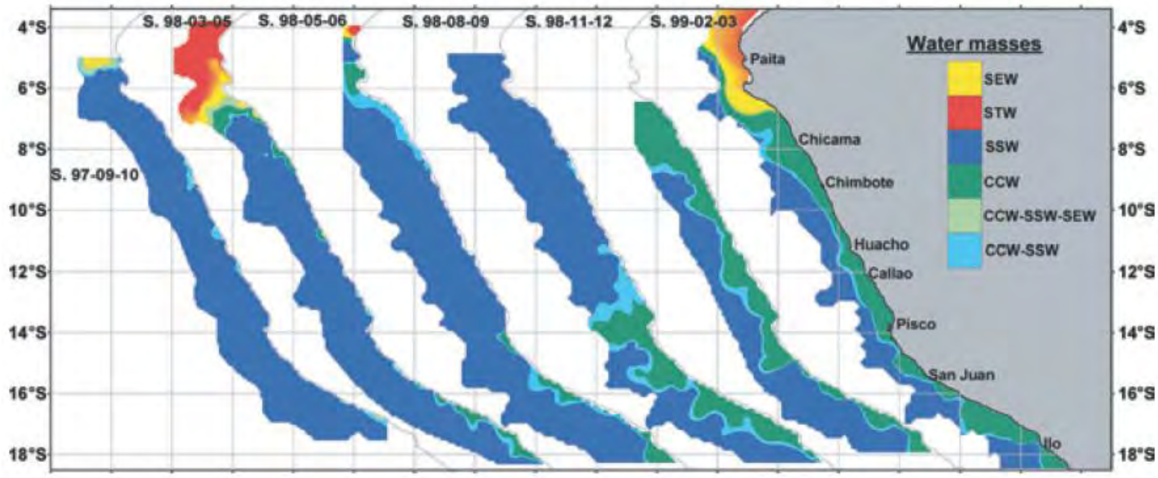
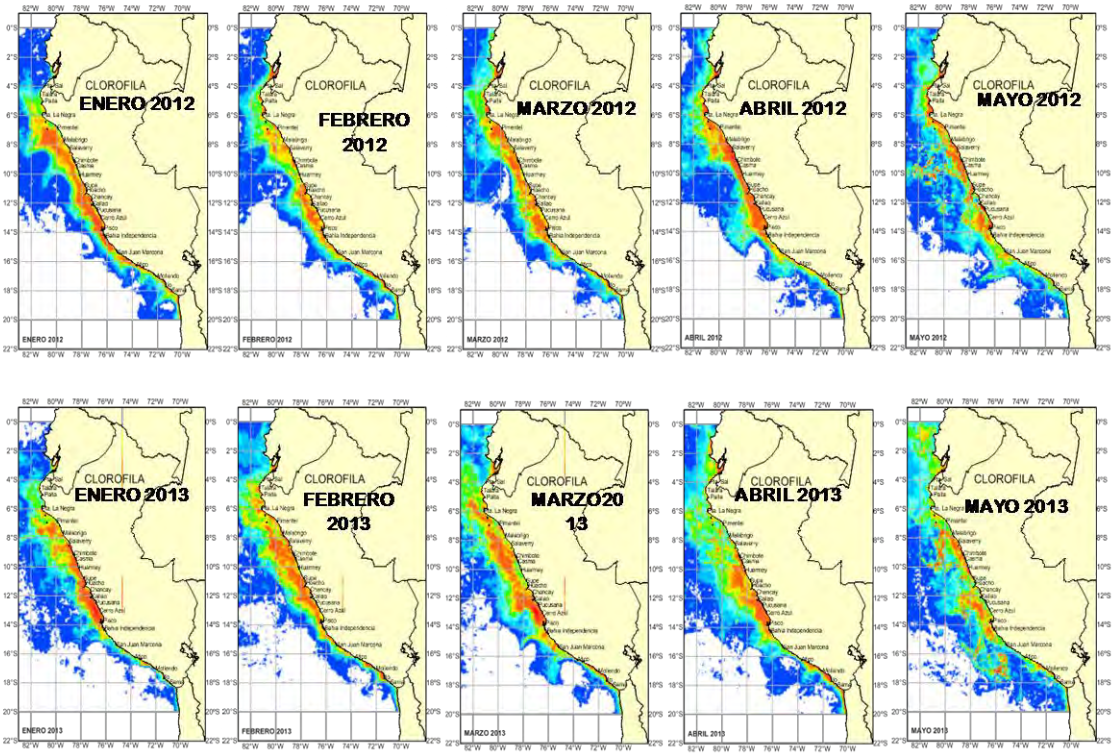


Figure 18. Water masses distribution for the surveys performed along the Peruvian coastline from 1997 to 1999. CCW cold coastal waters; SEW superficial equatorial waters; SSW superficial subtropical waters; STW superficial tropical waters. From Bertrand et al., 2004

Relationship with Chlorophyll a has been studied since the 2000s and some results have been published. We give for example the Cl-a concentration off Peru during the summers 2012 and 2013 (fig. 19). The most recent works (e.g. SNP, in press; Habasque, pers. comm.) seem to indicate that the CJM is found on the external border of the high Chl-a concentrations.



Fuente: Aqua Modis

Figure 19. Distribution and concentration of sea-surface Chl-a during summers 2012 and 2013

Conclusion

Two major points characterize the SE Pacific Ocean: the strength of the climatic signals (e.g. El Niño) and their high variability. Fish populations had to adapt to these characteristics which means to develop a high resilience and flexibility to hydrological patterns. This is particularly the case to the Chilean Jack Mackerel that lives in the whole southern subtropical Pacific Ocean. This resilience can take several aspects, one being the ability to produce huge cohorts through extremely successful recruitments when the conditions are favorable, helping to survive unfavorable periods. Another aspect is the capacity to colonize the whole ocean, seeking the most favorable areas for maintaining a correct abundance. Finally a last point is that the CJM should present a great individual plasticity to the local environment, making the fish able to survive in waters with extreme temperatures, salinity, etc., as well as being an opportunistic feeder. These characteristics are the ones through which can be defined the fish habitat.

CHAPTER 3-b

Trophic ecology and interactions

1. Interaction with other pelagic species.

Trachurus murphyi presents the original characteristic to be both a coastal and an oceanic species. Therefore it is necessary to study its interactions with both groups of species, and principally the tunas in the oceanic area and the Clupeiforms (Clupeids and Engraulids) in the coastal area.

Interactions with tunas. The figure 1 displays the distribution of tuna catches by longline fisheries in the period 1994-1997, i.e. during the period of maximum extension of the Jack Mackerel Belt in the South Pacific; and the distribution areas (observed through fishery data) of *Trachurus murphyi* in the South Pacific and *Trachurus symmetricus* in the North Pacific Ocean. There is practically no overlapping between the two groups, except with the southern albacore *Thunnus alalunga* (Bailey, 1989) which stomach contents show an important proportions of juvenile jack mackerel (figure 2).

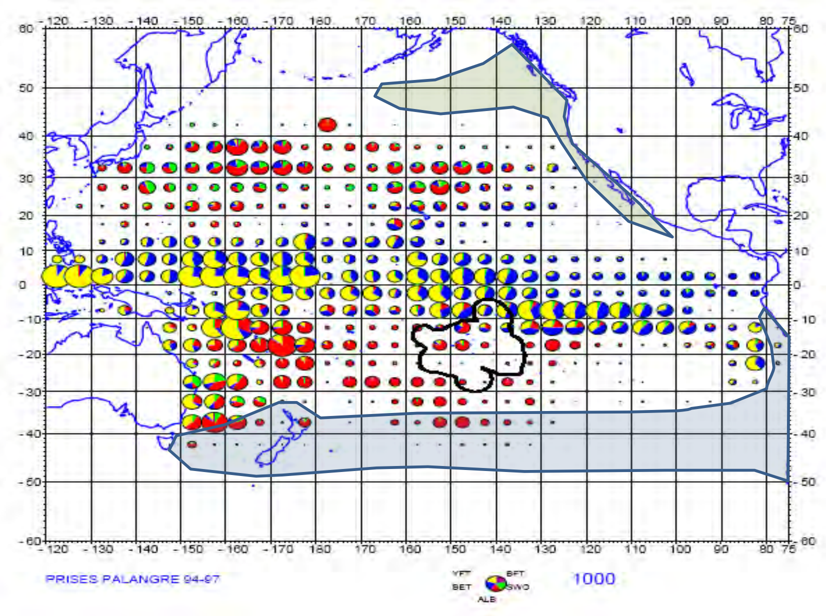


Figure 1. Comparison of distribution areas of *Trachurus murphyi* (blue area), *Trachurus symmetricus* (green area) and tunas (pie charts) in the South Pacific Ocean, during the period of maximum extension of the Jack Mackerel Belt. Redrawn from Grechina, 2008 (CJM belt), FishBase (*T. symmetricus* extension) and Bertrand, 1999 (Tuna distribution of longline fishery catches, 1994-1997)

This characteristic may help to better define the CJM habitat, at least through a negative definition: CJM habitat is a place where tropical tunas don't live.

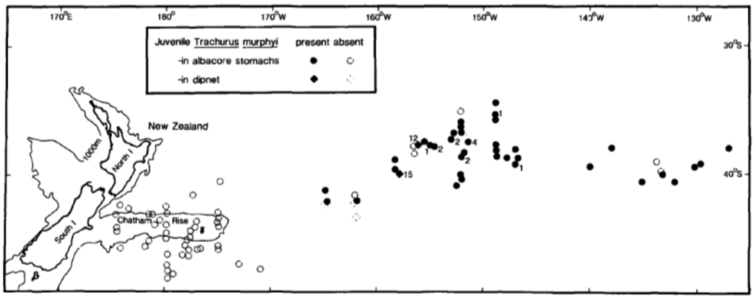


Figure 2. Interactions between South Pacific albacore *Thunnus alalunga* and juvenile CJM (from Bailey, 1989)

Interestingly the two jack mackerels present a general oceanic distribution in subtropical waters, where no tuna is present (with exception of large bluefin and the extreme distribution of albacores), but are also present in tropical areas closer to the coast than where tunas usually go. This means that these two groups (tunas vs. jack mackerels) could easily overlap if the water quality (salinity and temperature) was the only criteria of habitat selection. Therefore the question becomes: what characteristics of the environment or the biology of the two groups are incompatible?

In order to go further we present in figures 2, 3 and 4 comparative observations of the micronekton distribution in the tuna and CJM habitats, as observed through acoustic surveys. For tuna the figure 3 synthesizes the vertical distribution of micronekton in part of the French Polynesia EEZ, i.e. a rectangle from 135ºW to 155ºW and 4ºS to 20ºS (Bertrand, 1999), by day and by night. Figure 3 presents this distribution according to the latitude in the same area, on which the OMZ was overlapped.

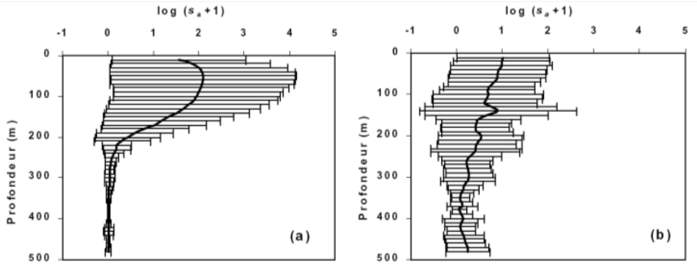


Figure 3. Night (a) and day (b) vertical profiles of mean acoustic backscattering (Sa) in logarithm scale, with standard error, in the Polynesian EEZ study area (from Bertrand, 1999)

For *T. murphyi* the figure 4 displays the distribution of CJM and micronekton as measured in backscattering coefficient in the Chilean EEZ (Bertrand et al, 2006), also by day and by night (note that the densities of trophic levels are order of magnitude different from those in the tuna distribution area).

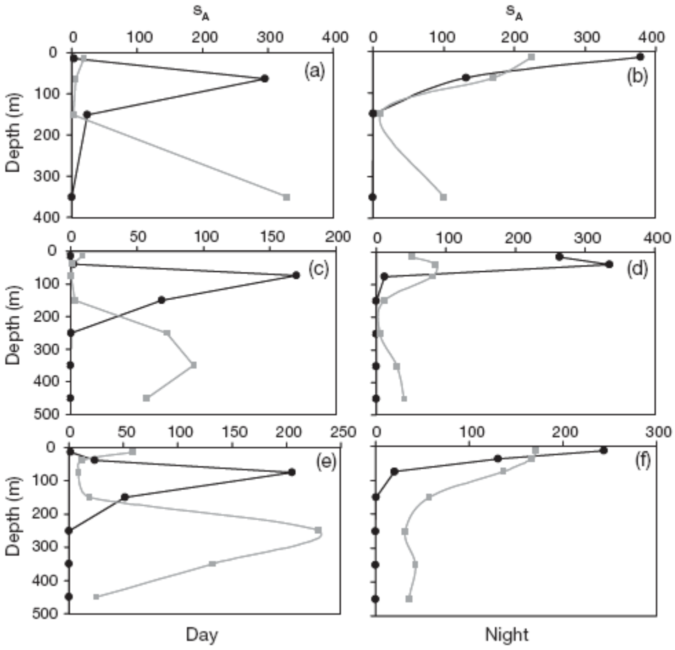


Figure 4. Vertical profiles of CJM (black line) and micronekton (grey lines) acoustic nautical scattering areas coefficient (S_A in m^2.nauticam mile^{-1}) during the day left) and the night (right) in 1997 (a, b), 1998 (c, d) and 1999 (e, f), from results of Chilean acoustic surveys. From Bertrand et al, 2006.

One interesting point comparing these distributions is that the micronekton seems to perform stronger and deeper vertical migration during day and night, in places where *T. murphyi* cannot follow them for the low oxygen available. We cannot see clear differences in the micronekton behaviour in the two case, except that its density is much lower in tuna areas. The limiting factor for tunas is probably more related to physiology and temperatures, which explains why their incursions in deep areas are limited in time; not to DO or depth. Indeed tunas present a high metabolism and body temperature regulation. Although their metabolism allows for incursions in deep cold waters, they cannot live long in such temperatures and need to get their body warmed (Holland et al., 1992[1]); this is not the case for the Chilean Jack Mackerel which presents a higher plasticity towards water temperature.

Interactions with coastal pelagic species. Being able to live in the coastal areas, the CJM presents potential interactions with the sardine (*Sardinops sagax*) and the anchovy (*Engraulis ringens*). These relationships have been widely studied in Peru where the overlapping is the most pronounced.

One first point is that there is positive correlation between the variations of abundance of jack mackerel vs. sardine and mackerel, and negative correlation between jack mackerel (and the two other species) vs. anchovy (figure 5). These correlations appear both in time (high vs. low biomasses) and in space (jack mackerel going south when anchovy is concentrated in the north). Incidentally we can observe

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[1] Holland K.N., Brill R.W., Chang R.K.C., Sibert J.R. & Fournier D.A. 1992. Physiological and behavioural thermoregulation in bigeye tuna (*Thunnus obesus*). Nature, 358: 410-412.

the permanent and perfect overlapping between jack mackerel and mackerel (*Scomber japonicus*).

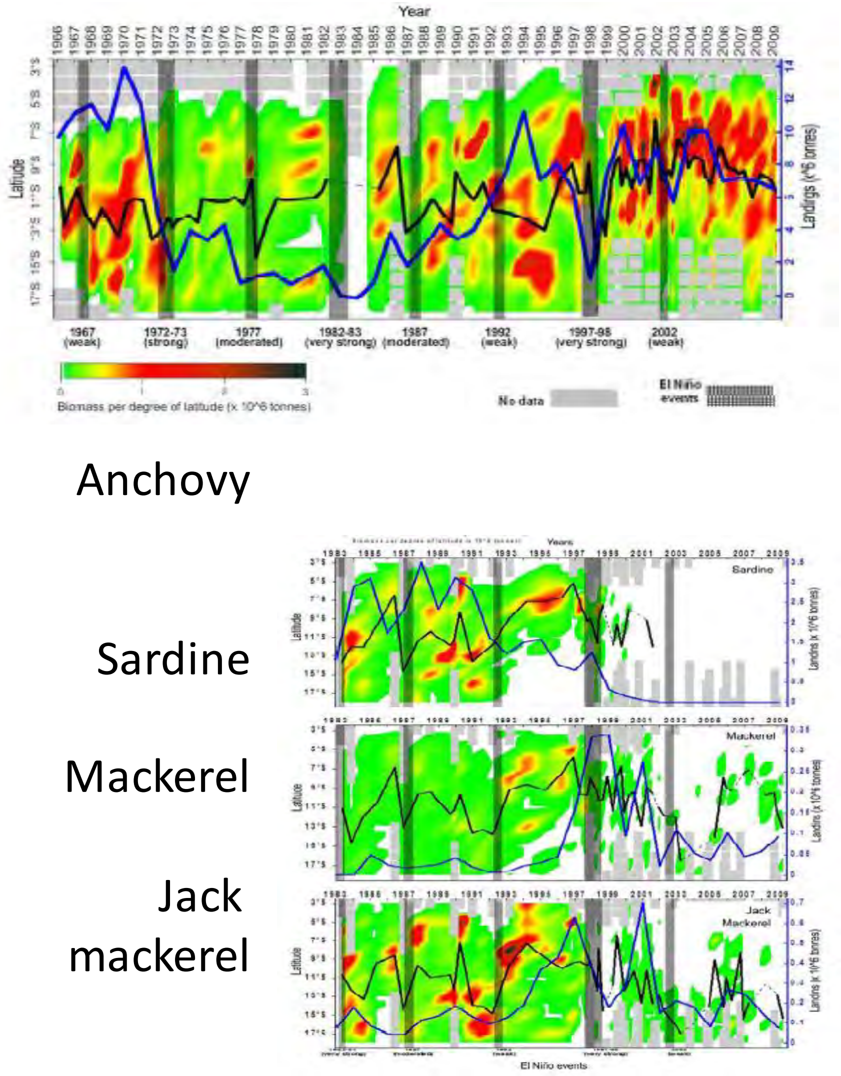

Figure 5. latitudinal representation of acoustic abundance per year for (from above to below) anchovy, sardine, mackerel and jack mackerel in the Peruvian EEZ, period 1956-2009 for anchovy, 1989-2009 for the other species. Diagram at the same temporal scale. Grey lines represent the El Niño southern oscillation events. Grey areas in the diagrams show non sampled latitudes. From Gutierrez et al., 2012.

Things are not so simple when entering more in details and it seems that there is no overlapping between spatial distributions of anchovy and jack mackerel, this one being usually farther from the coastline than anchovy (see SNP reports of CJM workshops in Lima, 2011-2013). This balance between jack mackerel and anchovy is also perfectly visible on the catch statistics (figure 6).

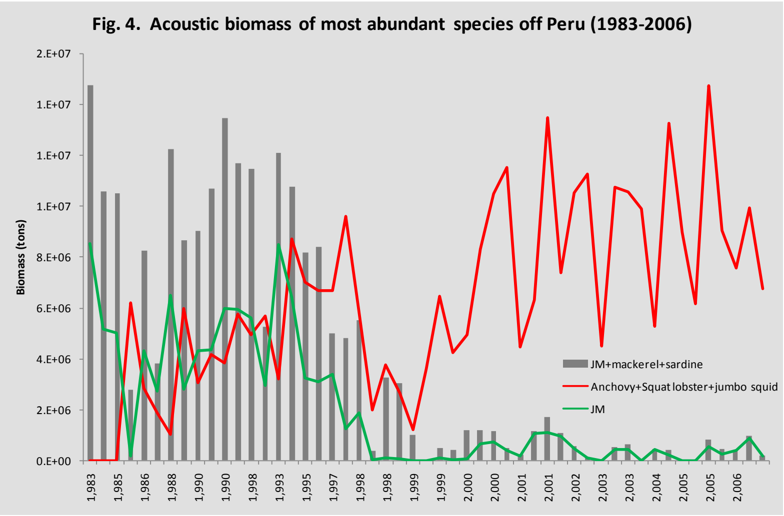

Figure 6. Evolution of catches for anchovy (red line) and jack mackerel (green line). The summed catches of CJM, mackerel and sardine are presented in histogram at the same scale; period 1983-2007.

This is also visible on the proportion of anchovies in the diet of the CJM (see chapter 2): anchovy is clearly an opportunistic prey, but not the target of the CJM (figure 7).

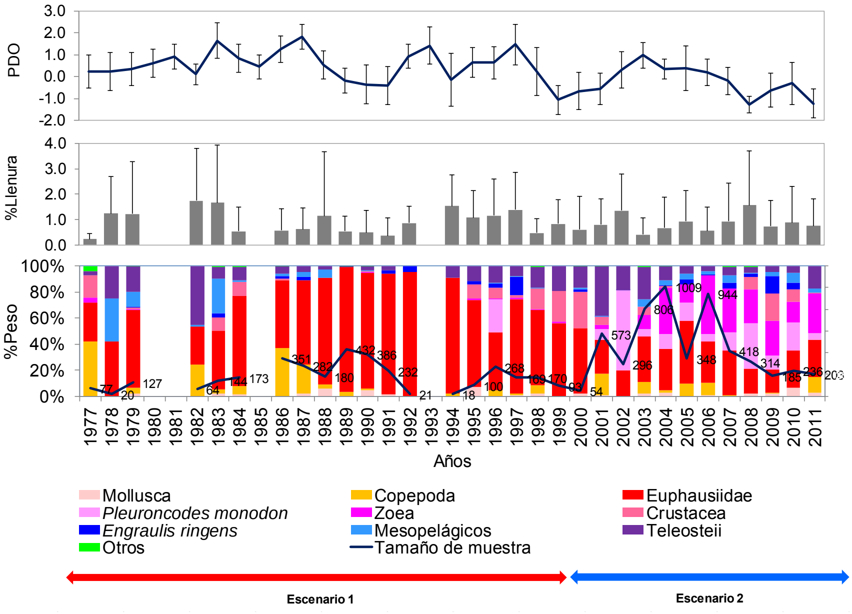

Figure 7. Index of fullness and proportion of prey in stomachs of jack mackerel *Trachurus murphyi* off Peru from 1977 to 2011 (from Alegre et al., in press[2])

In conclusion of these observations on interactions between the CJM and other coastal pelagic, we can assume that there are no real interactions: the balance between these species is more likely due to adverse reactions to the hydrology. The figure 8 gives some indication on this point.

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[2] Alegre, A., Espinosa, P., Espino, M., in press. Ecología trófica del jurel *Trachurus murphyi* en el mar peruano entre 1977-2011. Revista Peruana de Biología.

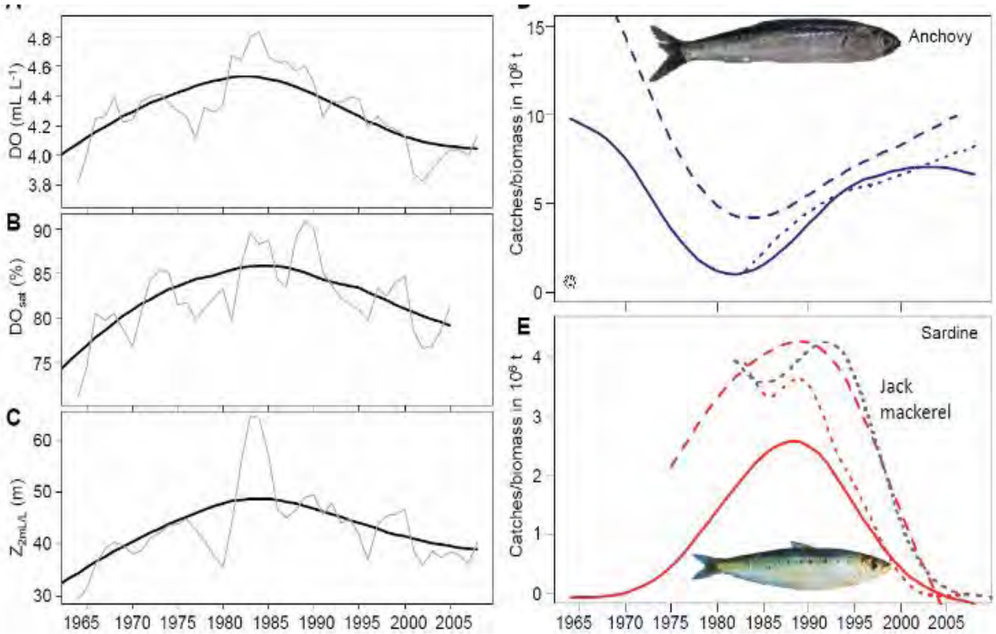

Figure 8. Comparative relationships between hydrography/biogeochemistry for anchovy, sardine and Chilean Jack Mackerel stock structure interactions in the Peruvian area (from Bertrand, 2010)

Espino and Yamashiro (2012) go further and propose a scenario of interactions with the environment that allow them drawing scenarios for the ten coming years (figure 9)

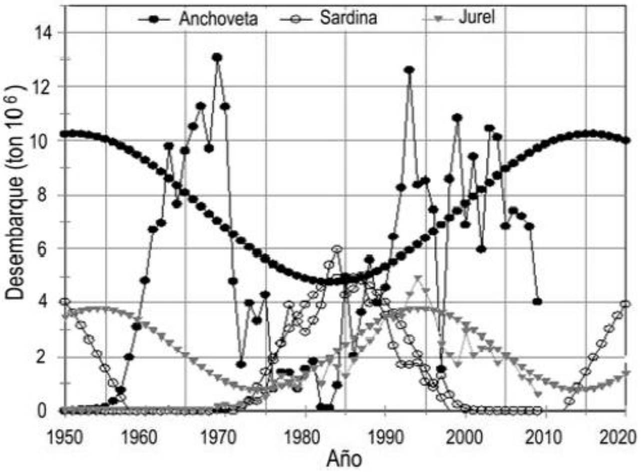

Figure 9. Landings of anchovy, sardine and jack mackerel and their trends in the Southeastern Pacific Ocean. Carches by species and climatic cycles (decadal and centenal) are presented on the graph, from 1950 to 2020 (from Espino and Yamashiro, 2012).

2. Trophic interaction.

We have seen that the CJM is a micronekton feeder principally (chapter 2 and paragraph above, figure 6). The feeding behaviour of the CJM is complex, and directly linked to the hydrology (Bertrand, 2006): the CJM is unable to cross the OMZ by day for feeding on the deep micronekton and has to wait above it until their daily vertical migration make the micronekton organisms available to the CJM (figure 10)

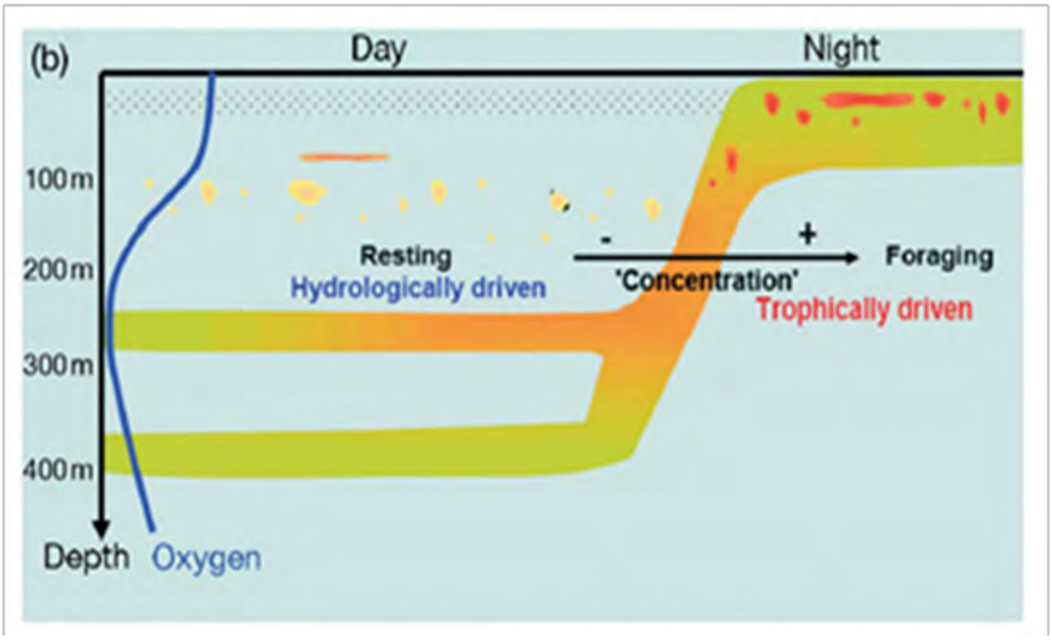

Figure 10. Behavioural model of jack mackerel distribution and schooling behaviour in relation to DO concentrations across the diel cycle, as observed in Chilean waters. CJM are represented by the red (densely aggregated) to yellow (scattered) structures. Preys (micronekton) are represented by continuous layers (green to orange). Due to the OMZ, CJM has to "wait" in the upper part of the water mass, until the micronekton enter the oxygenated water layer at dusk, for foraging (from Bertrand et al., 2006).

Another interesting point in trophic relationships is that the CJM presents the characteristics of being present in high abundance and being a strong predator, there is often a spatial shift between the high densities of preys and the high densities of CJM. This capacity of the CJM to deplete an area is also clearly visible on the echograms, where schools of jack mackerel are surrounded by empty volumes that represent their "path" inside the micronekton layers (figure 11). The consequence of such behaviour is that where the fish is present and feeding, the micronekton tends to deplete quickly (figure 12)

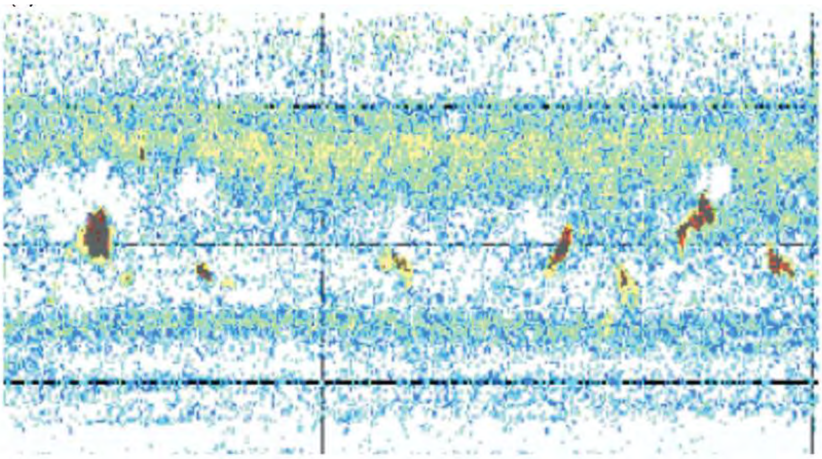

Figure 11. example of echogram showing the path of CJM inside dense micronekton layers (from Bertrand et al., 2006)

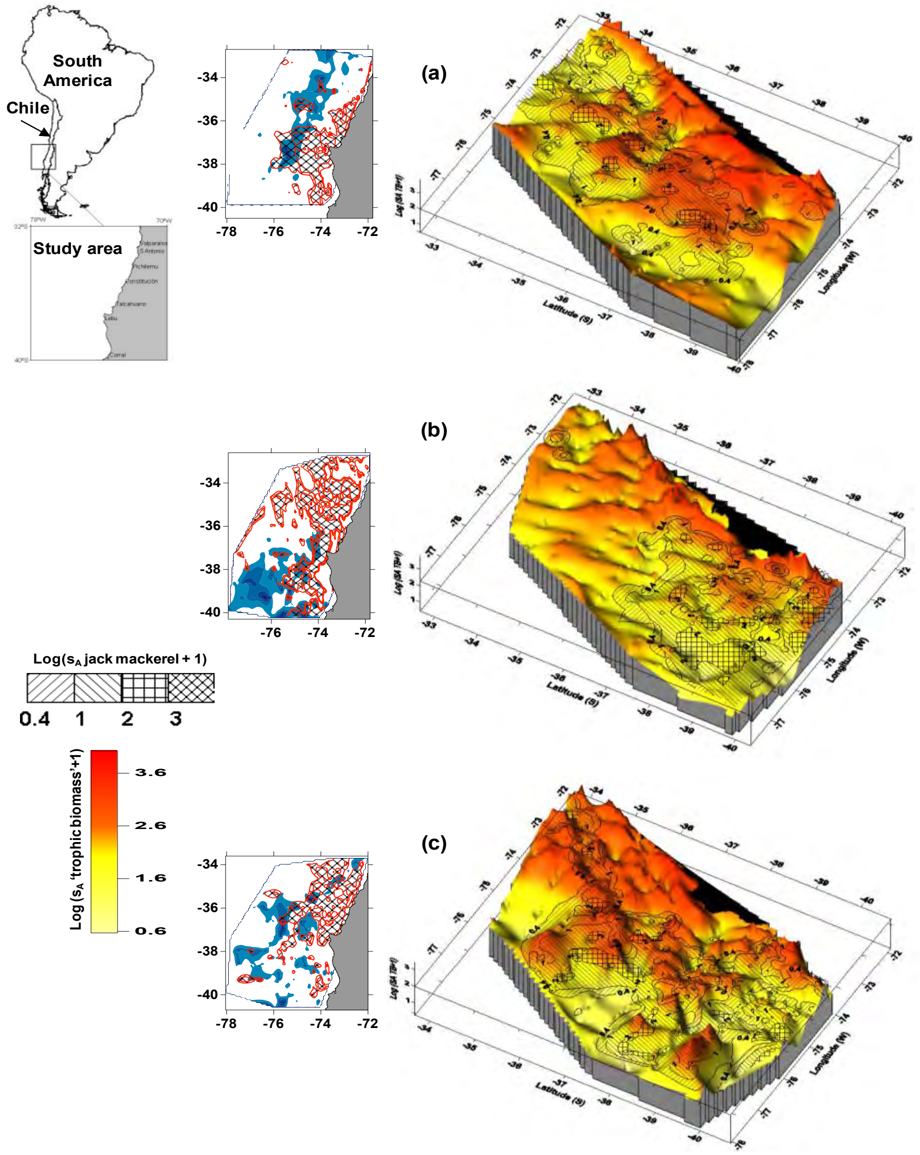

Figure 12. Spatial relationships between CJM and micronekton distributions of abundance in Chilean EEZ. It appears that high densities of jack mackerel are not exactly located on high densities of preys, this being likely due to feeding behaviour of the fish. From Bertrand et al., 2006.

3. Predation

We have seen that in the overlapping limits between albacore and CJM, the first one was predator for juveniles, at least in the New Zealand area. There are very few other information on CJM predators. One of them could be the giant squid (*Dosidicus gigas*) although we do not know about papers published on this question, but CJM otholiths were encountered in *D. gigas* stomach contents (Dioses, pers. comm.).

Another possibility was proposed by Konchina (1996), who hypothesized that the fact that CJM large oceanic stocks were unknown before the 1970s was due to two main possible reasons: “(*1) the fishery resources were not investigated in this zone before the late 1070s and (2) the mackerel populations were low at this time (Vinogradov et al., 1990). Thus, an increase of the mackerel biomass in the 1980s is supposed to result from the elimination of whales. This supposition is based on the idea that the jack mackerel feed on the same resources as whales and that it occupied their ecological food niche in the Subantarctic zone*” (Konchina, 1996). If the idea presented by the author is of competition between CJM and whales, it can be also possible that whale feed on juvenile CJM. Nevertheless there is no information on this point.

Conclusion of chapter 3 - interactions.

One first conclusion, that is rather common with the other chapters, is that the CJM presents a high plasticity in its ecology and is able to live in variable areas inside a wide range of hydrological characteristics. This shows that hydrology does not seem to the unique limiting factor for CJM. Moreover, apart in some limits of its habitat (relationships with albacore tuna), the species has no major predator (interactions between juvenile CJM and the giant squid *Disodocus gigas* should be studied).

Therefore the main limiting factor is likely to be the prey availability. The fish seems to have a high metabolism that requires a permanent feeding and preys permanently available. Most of the CJM behaviour is centered on prey accessibility (Bertrand et al., 2004; Hancock, 1995; etc.).

The last observation is that although there is a great plasticity, the fish has preferenda, both in terms of water masses and temperature and salinity that are clear when observing its interactions with the anchovy *Engraulis ringens*: this small fish is a prey for CJM when the two species share a common area, which is rarely the case. We may easily understand why CJM and tunas do not overlap: prey availability in the open tropical ocean is low and requires specific physiological specificities existing in tunas but not in CJMs. The fact that the CJM is not overlapping with *E. ringens* is more questioning, and is certainly linked to these preferenda.

Chapter 3-c

Habitat

INTRODUCTION

The question of habitat has been asked a number of times during the 30 last years, but took a new importance in October 2012 when the hypothesis of "potential habitat" arose (2nd national report, Peru, 2012 SWG-11-8a). Indeed this new research field has taken importance as it presents three major applications:

a. Allow an a-priori definition of the distribution area of a given species, in order to adapt the sampling or the fishery exploration to a limited positive area, in order to save research time or effort for fishing (Zwolinski et al., 2010);
b. Analyze the way the extension or the shrinking of the habitat may affect the abundance and distribution of a fish (Bertrand et al, 2010).
c. Another use of the potential habitat has been expressed in the Peruvian Report to SPRFMO in 2012: developing a method to extrapolate the measured abundance in the "window" of an acoustic survey to obtain the true biomass of the species (see this document, introduction). After studying "*the habitat, with high productivity related to the high environmental variability*" and the "*adaptive response to this habitat (in respect to other stocks of the region)*" (SWG-11-JM-03, 2012), the authors of the report conclude that "*The oceanic front between the ASS* [Antarctic Sub-Surface waters] *and the CCW* [Cold Coastal Waters] *is the preferred habitat of jack mackerel off Peru. Its complex dynamics determines the main characteristics of this stock unit, such as its general distribution, spawning areas, spawning seasonality, food consumption, growth rate, etc.* " (2nd national report, Peru, 2012 SWG-11-8a).

According to these different potential uses of habitat recognition, it seems important to evaluate the results that have been presented and how they answer the questions. Indeed any error on the definition of the habitat would induce a dramatic error in the results (over or underestimation of the biomass; cost in fisheries activity; misunderstanding of the role of the CJM in the environment and errors in the abundance estimates).

1. General study of the Habitat and its relations with the environment.

The first approach to the concept of habitat was performed in the 90s by the Soviet scientists using the movements of the fishing fleet, considered as a proxy of distribution and migration of the fish, and the eggs and larvae collection aboard the fishing and research vessels. The CJM movements are described in more details in the chapter 2-D (migrations). They showed what the global hydrological and physical limits of the habitat for the adults and for the spawning areas are (figure 1).

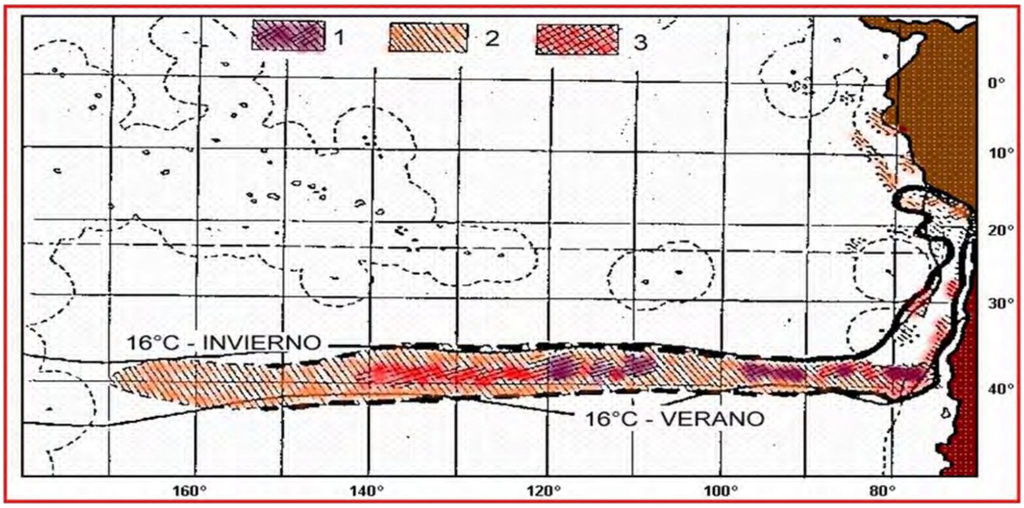

Figure 1. Spawning areas of CJM in the Pacific Ocean, related to the isotherm 16º at the beginning and end of the spawning season ("invierno" = winter; "verano" = summer). 1. General spawning area; 2. Area where eggs and/or larvae were collected; 3. Area where concentrations of eggs and larvae are above 200.m^{-2} (from Gretchina, 2008, modified from Gretchina, et al., 1998).

Gretchina in his synthesis (2009) dedicated a full chapter on the habitat definition and analysis, to which most of this paragraph will refer. This author shows how the overall distribution of CJM shrank since 1999 in the western, southern and northern limits of its area (figure 2). This is an indication on how much environment is responsible of the extension of the CJM habitat.

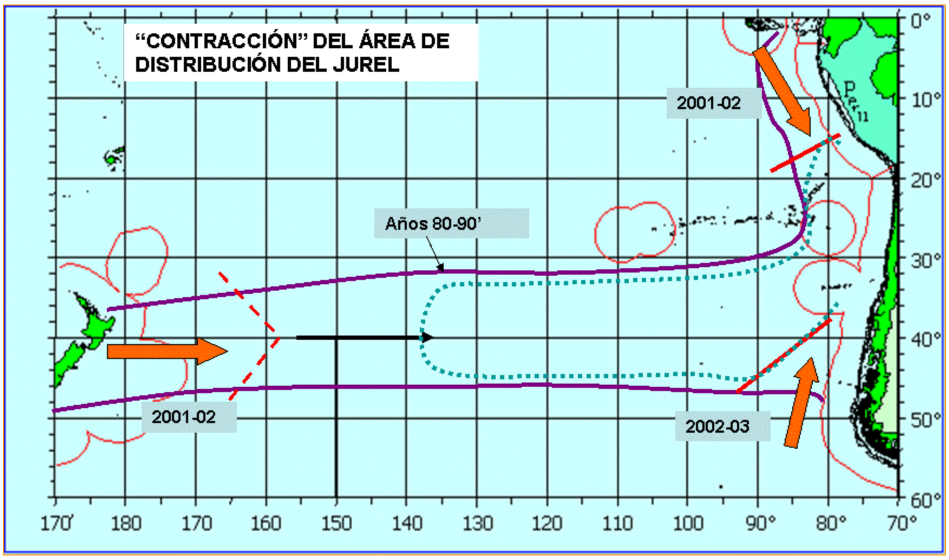

Figure 2. Reduction of the distribution area of CJM between the 1980 and 2003 (from Gretchina, 2009)

This figure is particularly interesting as it shows the importance of understanding what the environmental requirements of CJM to live are: such important changes can be used to define the habitat, studying what environmental factors change and induce a parallel change of the distribution area. More specific relationships were studied (figure 3) and allowed the definition of a first approach of habitat, called the "Jack mackerel belt" (figure 4).

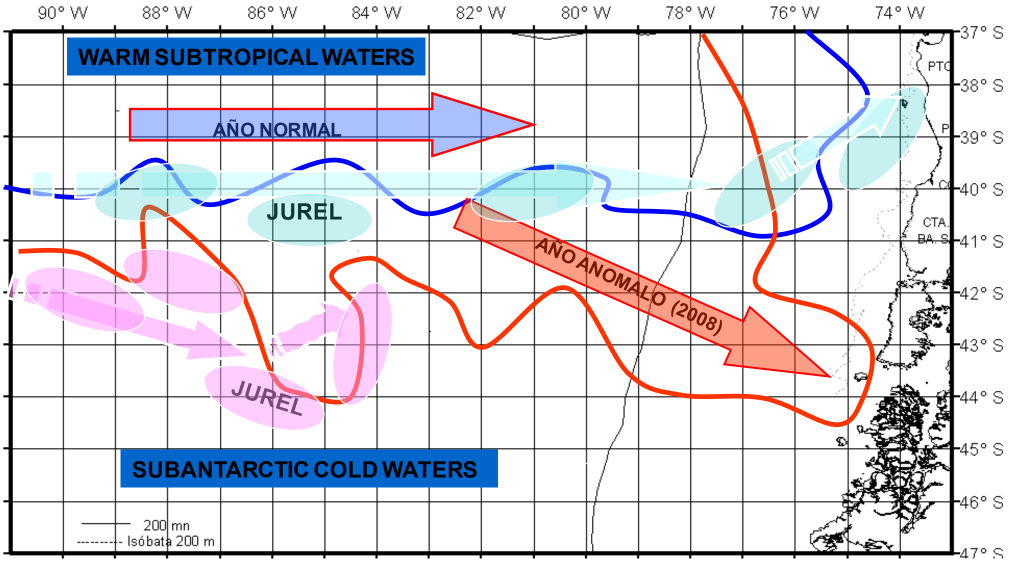

Figure 3. Migrations of the CJM in March-May during normal (year 2006-7) and abnormal (year 2008) oceanographic conditions (from Gretchina, 2009)

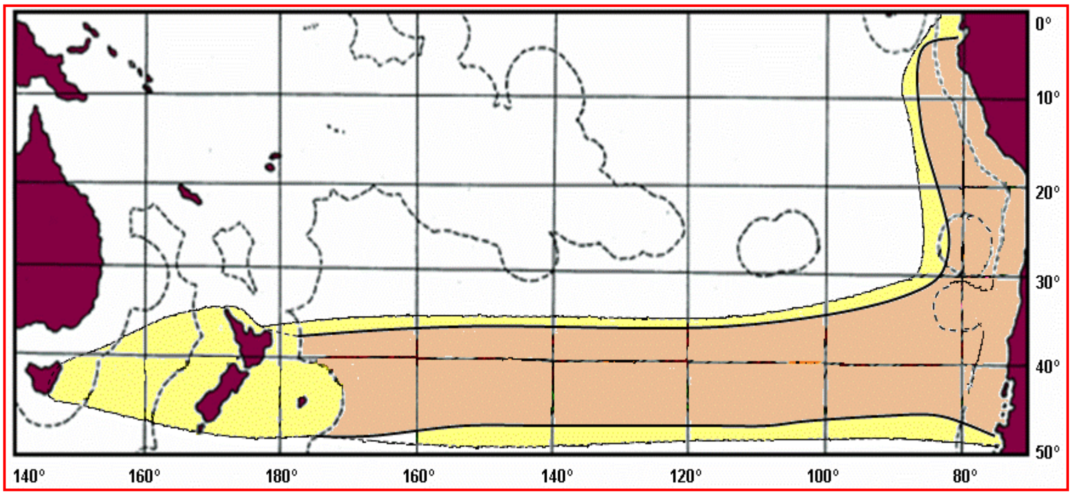

Figure 4. The “Jack mackerel belt” (from Gretchina, 2008: modified from Elizarov et al., 1998)

2. The main environmental factors affecting the habitat

Áreas distribución del jurel en el Océano Pacífico Sur (modificado de Elizarov et al., 1992; Grechina, 1998).

The Humboldt Current Ecosystem presents a remarkable characteristics, which is its huge variability in climate. As expressed by Espino and Yamashiro[1] (2012): “*In this region, variability is a common event that meets regulatory standards of macro-scale such as seasonal, inter-annual, periodical and secular as processes of short, medium, long and very long term. In this scenario appear as environmental factors or manifestations of variability, ENSO (El Niño Southern Oscillation), PDO (Pacific Decadal Oscillation) and PSV (Pacific Secular Variability) as the most conspicuous*”. We will not evaluate the relationships between the Pacific Secular Variability (figure 5) and CJM, for the fishery is not old enough to provide information.

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[1] Espino, M., Yamashiro, C., 2012. La variabilidad climatica y las pesquerias en el Pacifico Sur. Lat. Am. J. Aquat. Res., 40(Suppl. 1), 2012. International Conference: “Environment and Resources of the South Pacific”. P.M. Arana (Guest Editor)

More detailed analyses (see chapter 3-A) show that a certain number of environmental characteristics have an effect on the CJM habitat. Se present her the list of the main factors as extracted from the literature review, and that are studied in other chapters of this work (see Chapter 3-A and 3-B; Chapter 2; etc.). We have noted in the chapter 3 – hydrology what these factors are. To these we should add biological factors: spawning activity, predation, competition, behaviour

a. ENSO events. The figure 3 shows that the habitat limits of the CJM are related to the ENSO events, because the subtropical front oscillates from south to north when an ENSO occurs (Arcos et al., 2001). Apart the population movements, these ENSO affect also the aggregative behaviour of the fish, the schools being smaller and less numerous during an ENSO (see chapter 2-E). It has also a strong effect on the egg and larvae distribution, as stated by Barbieri et al (2003) and shown on figure 5: the strong difference of this index between 1998 (el Niño) and the years before (1997) and after (1999: La Niña) is clearly visible. Another effect concerns the school shape and type (see chapter 2) that are sensitive to ENSO events.

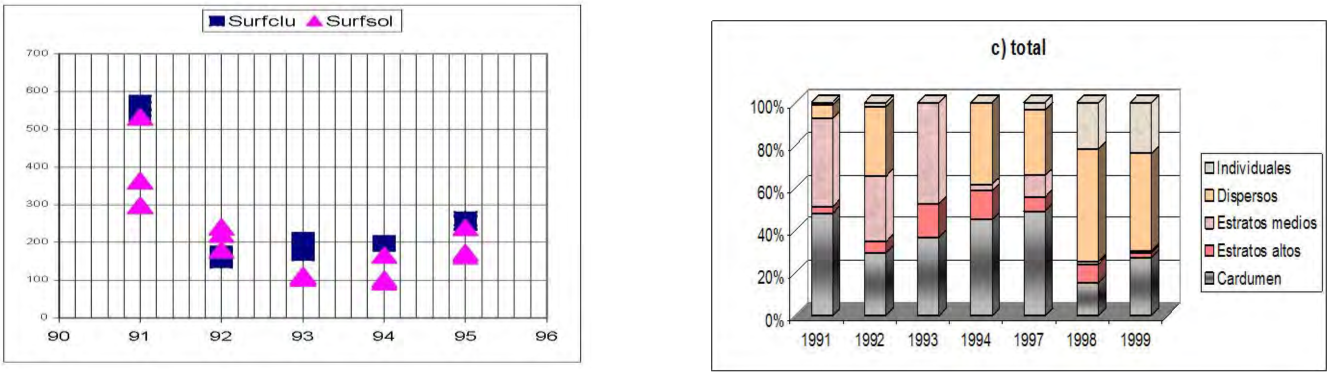

Figure 5. Description of the changes occurred in the school and cluster shapes due to El Niño in Chile. Left: dimension of schools surface inside clusters (squares) and solitary (triangles) from 1009 to 1996. The strong El Niño in 1992 induced a strong decrease of the school surface. Right: Proportion of the different types of schoolsfrom 1991 to 1999: the El Niño of 1992 and 1998 produced a similar change in the proportions, the type "Cardumen" (large schools) decreasing significantly during and after El Niño (Gerlotto and Barbieri, 1999[2])

Besides, it has been showed many times that there is a relationship between the ENSOs and the recruitment success of CJM. Gerlotto et al. (2012) synthesized this point representing the abundant classes in the demographic structure of the fish and the ENSO events (figure 6).

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[2] Gerlotto, F., Barbieri, M.-A., 1999. Presión pesquera y dinámica del comportamiento espacial de los carcdúmenes de jurel (*Trachurus symmetricus murphyi*). ECOS, Proyecto nºD97B06, 1999.

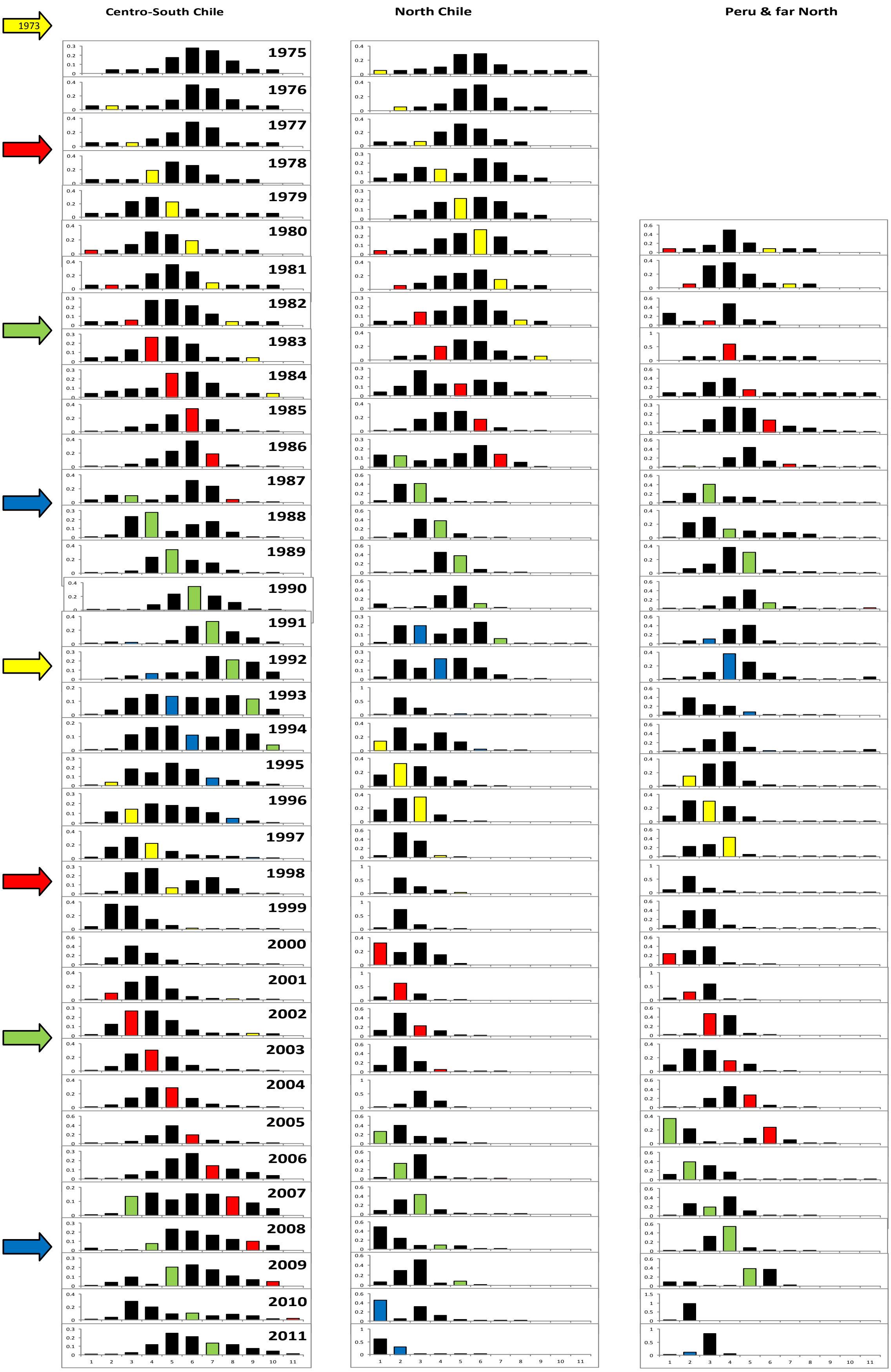

Figure 6. Demographic structures of CJM catches in Centre-south Chile (right), north Chile (centre) and Peru (right), from1975 to 2011 (from SPRFMO). Colored arrows indicate the ENSO events, and corresponding colored year classes are those born in ENSO years.

The ENSO of 1998 is considered the strongest in the 20th century; therefore several works have been performed on results from this particular period to evaluate the impact of El Niño on fish populations.

In 2001, Arcos et al. presented an important analysis on the effect in Chile of the ENSO 1998. The work was specially focused on the effect on recruitment. Among their conclusions, the following one deserves full citation: *"Environmental impacts associated with El Niño cannot be overlooked in the management of Chilean jack mackerel fishery. Our results suggest that there is a one year lag in the response of an increased incidence of juvenile jack Mackerel to ENSO phenomena. Therefore, the continuing high incidence of juveniles in 1999 was still a consequence of the environmental changes in the period 1997–1998. In central–southern Chile the oceanographic conditions were cooler in 1999 and the persistence of juveniles in the fishing regions, has been taken to indicate the overexploitation hypothesis is correct"* (Arcos et al., 2001).

An important analysis of the effect of the ENSO 1998 to several species, including the CJM, was published by Bertrand et al. in 2004. The figure 7 shows the relationships between the CJM populations and the major hydrological changes during this ENSO.

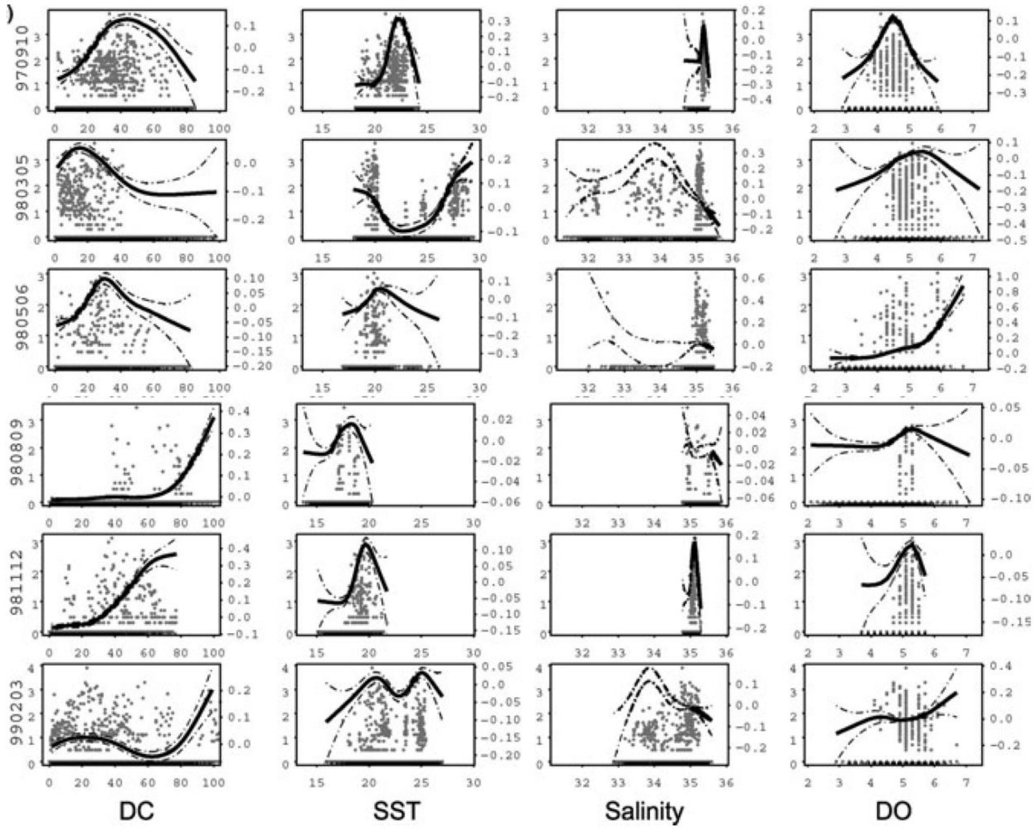

Figure 7. Scatter plot (grey dots) and cubic spline (black solid lines) of bivariate GAM models based on jack mackerel log-transformed fish back-scattered acoustic energy by surface unit (S_A) according to distance to the coast (DC) in nautical miles, SST in degree centigrade, salinity and dissolved oxygen (DO) in mL.L^{-1}. The 6 horizontal series of diagram present the results for 6 acoustic surveys performed by IMARPE in Peru in1998-1999 (the two first digits give the year; digits 3-4: the month of beginning of the survey; digits 5-6: the month of ending the survey). The black dotted lines show the 95% confidence limits of GAM models. The left y-axis displays the log-transformed S_A. The right y-axis

legends display relative scales that correspond to the spline smoother that was fitted on the data. Positive values indicate a positive effect on the response, negative value a negative effect (From Bertrand et al., 2004).

In any case, the most visible effect of an ENSO event is to make the habitat oscillating from north to south according to El Niño and the CJM changing several patterns of its behaviour.

b. Decadal events. The abundance of CJM seems in part also related to the decadal cycle, fish being more abundant during warm periods than cold periods (Dioses, 2007; Espino and Yamashiro, 2012, among others).

c. Kelvin waves. Although there is no doubt that the effect of Kelvin waves is probably effective on the CJM population ans it is on anchovies, maybe with difference consequences, there is no work performed on CJM at this scale yet, but it seems important for the future to consider it.

d. Sea Surface temperature. The major conclusion about tenperatures (Bertrand et al., 2004; Dioses, 1995; Gretchina. 2009; etc.) is that (a) the CJM is largely plastic as far as hydrological conditions (specially temperatures) are concerned and can live in waters from 9º to 28º, both in the spatial (horizontal) and vertical dimensions; (b) nevertheless its distribution area can be limited by the subtropical waters, i.e. from 17 to 28ºC (Bertrand et al., 2004) and more specifically for Peruvian waters inside a prerendum of 15-20º (Dioses in press); the “limit effect” of these isotherms being probably more due to the fact that they are proxys of water mass delimitation than to a physiological effect on fish (figure 8).

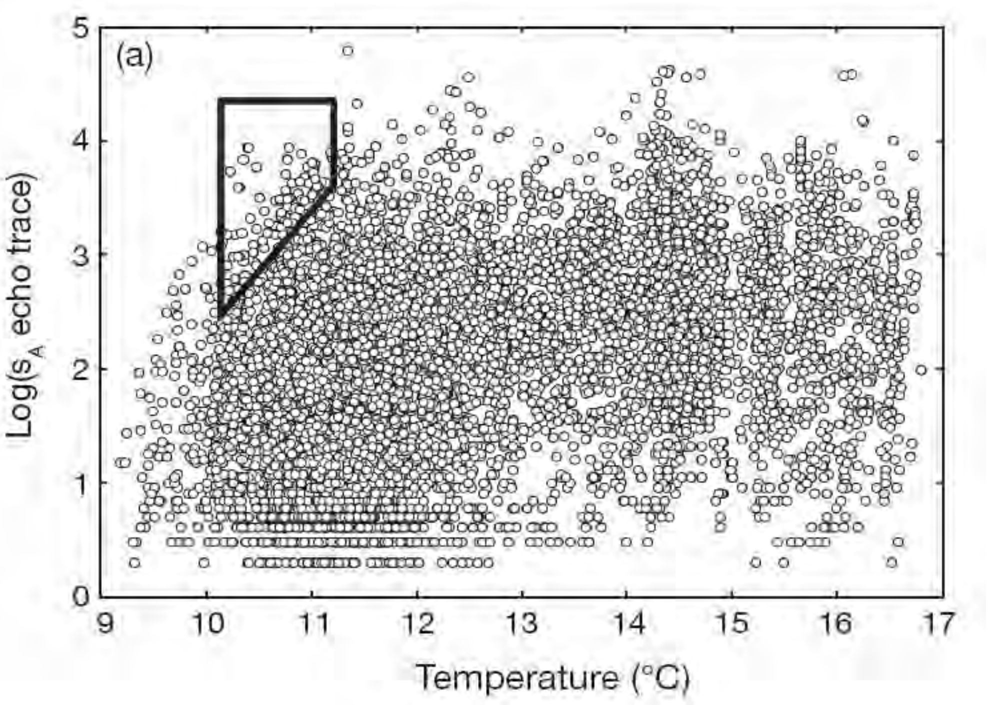

Figure 8. Log-transformed acoustic area scattering coefficient (S_A, in m^2.nautical mile^{-2}) of jack mackerel echo traces relative to temperature (in ºC), during the day. The polygon illustrates the

"exclusion zone" where almost no fish were observed (from Bertrand et al., 2006). The data have been collected from echograms at depths up to 200 m. Each point represents one aggregation referring to its corresponding hydrological values as interpolated from CTD stations during the acoustic surveys.

Galaktionov (1994) presented a synthesis of the echograms of CJM in the Pacific Ocean, from 10 to 40ºS of the vertical migration fo CJM according to the latitude (figure 9) where the maximum depth of the migration is linked to the depth of the thermocline (9ºC).

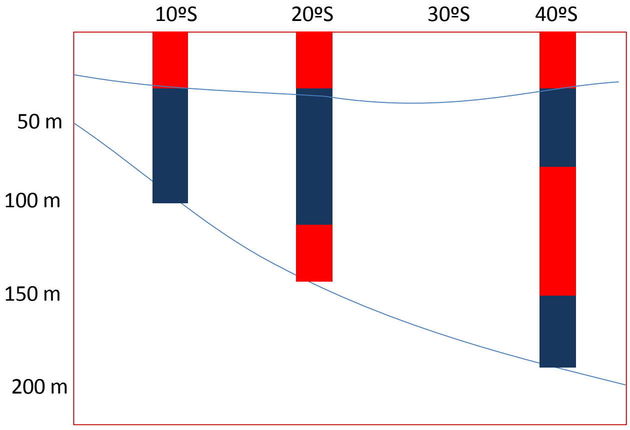

Figure 9. Distribution of jack mackerel concentrations on echograms by day (red) and by night (blue) from 10ºS to 40ºS, related to the thermas gradient and the thermocline (redrawn from Galaktionov, 1994)

Espinoza et al (2008) show a complete analysis of the relationships between SST and CJM catches in summer inside the Peruvian EEZ (figure 10)

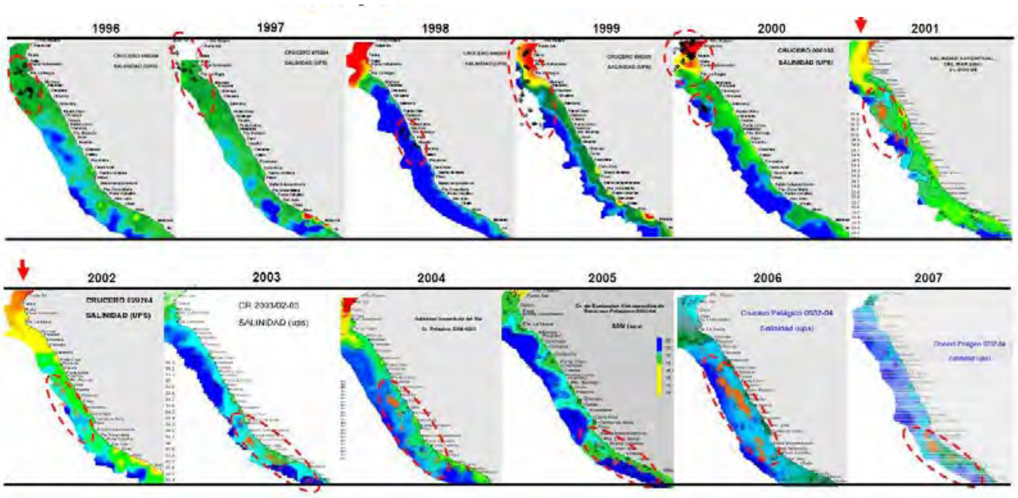

Figure 10. Relationships between the CJM distribution and water masses as represented by the SST in Peru, during summer, 1996-2007. Dotted lines represent the fishing area, dots represents fishing sets

It is interesting also to cite Dioses (in press) who found three patterns of CJM distribution in the vertical dimension in the Peruvian waters, depending on the ENSO events. (figure 113).

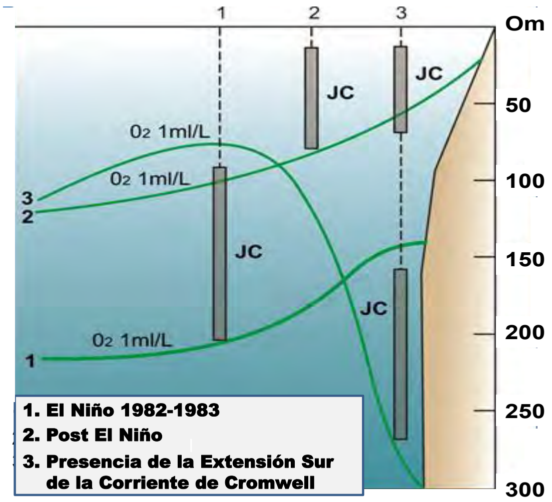

Figure 11. The three patterns of CJM vertical distribution related to temperature and oxygen:(1) during El Niño, the CJM cannot go below the oxycline and stays in waters below 20º, which maintains it at depths below 50-100 m. (2) post-El Niño" period, the upwelling favors a shallow oxycline and cold coastal temperature. The CJM is pushed offshore and maintainel in the surface layers. (3) during warm periods (ESCC), the oxygenated warm tropical waters sink the oxycline at depths below 300 m, allowing the CJM to colonize the whole water column but without reaching the surface due to the depth of the 20º isotherm (from Dioses, in press).

e. Oxygen Minimum Zone. An important synthesis has been presented on this topic by Bertrand et al. (2004; 2006; 2010). According to these authors, indeed the OMZ is crucial in the SE Pacific, as it can be present at very shallow depths (up to 20 m below the surface along the Peruvian coastline). They have observed that the CJM is unable to live in waters with oxygen concentrations below 1 ml.l$^{-1,}$ and up to 4 ml.l^{-1} depending on the aggregation of the fish (large schools are unable to survive in water with DO less than 4 ml.l-1) (figure 12).

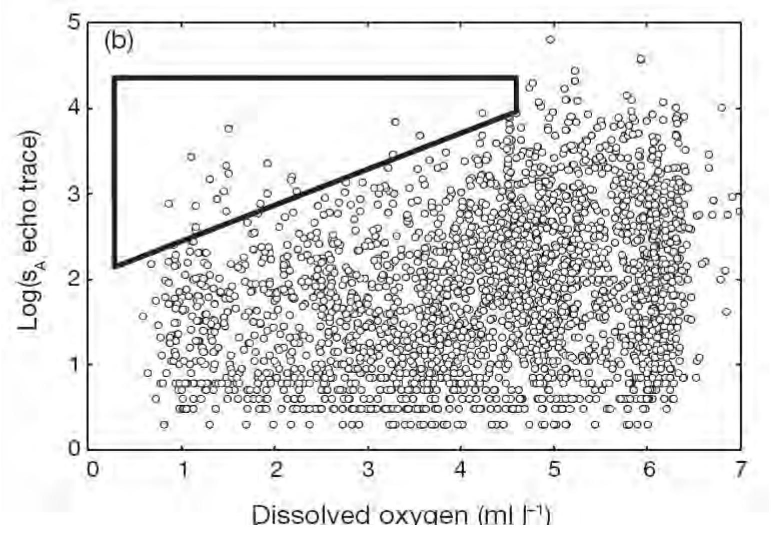

Figure 12. Log-transformed acoustic area scattering coefficient (S_A, in m^2.nautical mile^{-2}) of jack mackerel echo traces relative to dissolved oxygen (in ml.l^{-1}), during the day. The polygon illustrates the "exclusion zone" where almost no fish were observed. As in figure 11, each point represents one aggregation referring to its corresponding hydrological values as interpolated from CTD stations during the acoustic surveys (from Bertrand et al., 2006).

Moreover, according to the same authors, it seems that besides a minimum DO concentration, the CJM requires a rather important height of the DO: if it present a height lower that 40 m, CJM could not stay in the oxygenated volume.

Finally the OMZ is also a key factor in the daily vertical movements of the CJM, as suggested by the biological model synthesized on the figure 13 (from Bertrand et al., 2006).

The importance of this observation is that what really matters is the volume of the habitat, not only its horizontal spatial distribution. This has been described by Bertrand et al (2010) on Peruvian anchovy (figure 13) but the principle is obviously valid for the CJM too.

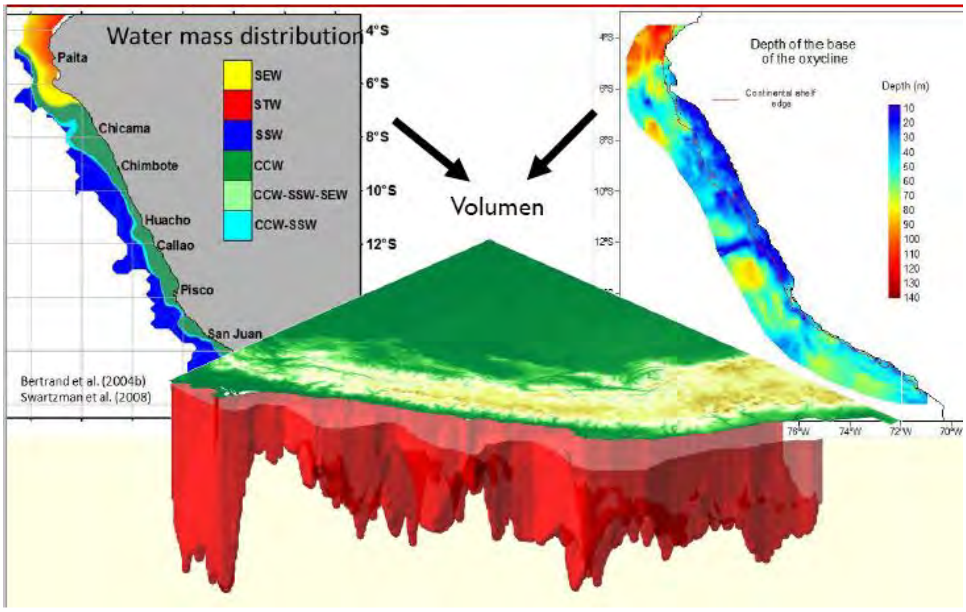

Figure 13.Three-dimensional habitat of the Peruvian anchovy. The 3 dimensions are obtained through the delimitation of the Oxygen zone (DO above 1 ml.l^{-1}) obtained by mapping the coastal cold waters where anchovy can extend for the 2D horizontal dimensions, and analyzing the epipelagic concentration of plankton as a proxy of the OMZ for the vertical dimension of the habitat (Bertrand et al., 2010; Ballón, 2009), knowing that anchovy is never encountered below the OMZ (from Bertrand et al., 2013[3]).

f. Salinity. There are few works on salinity, and it is assumed that this variable does not play a significant role in the definition of the CJM habitat. The figure 6 from Bertrand et al. (2004) shows that the variation of salinity in the distribution area is not wide enough to present a discriminant value. Dioses (in press) presents three patterns of habitat related to temperature, salinity and oxygen that we synthesized in the figure 14. It shows that the CJM has a preferendum for salinities between 34.9‰ and 35.1‰ that appears to be less prioritary than temperature preferendum (between 15º and 20º and above all oxygen (waters with DO< 1 ml/l are considered inaccessible to the CJM).

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[3] Bertrand, A., Ballón, M., Castillo, R., Chaigneau, A., Fablet, R., Grados, D., Gutierrez, M., Habasque, J., Josse, E., Quiroz, Z., Roudault, G., Vargas, G., 2013. Routine acoustic data as new tool for a 3D vision of the abiotic and biotic components of marine ecosystems and their interactions. 4th workshop on the Peruvian fishery of Chilean jack mackerel, Lima, 26 June-2nd July, 2013

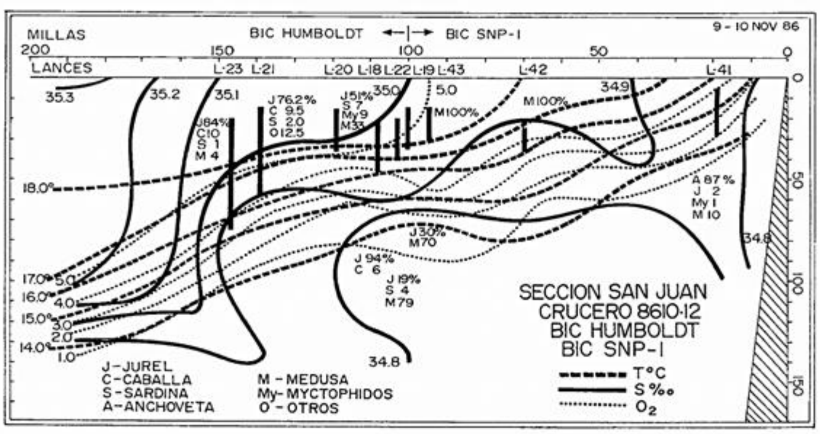

Figure 14. Vertical distribution of Jack mackerel *T. murphyi* spawning schools in relation to oceanographic parameters of temperature, salinity and oxygen off San Juan (November, 9/10, 1986). (from Dioses et al, 1989).

g. Currents, Eddies. The importance of eddies and gyres in the distribution of the CJm has been described by several authors but no final conclusion have been presented as far as gyres are concerned and more work is to be performed. Nevertheless, these mechanisms of concentration of dispersion of the productivity are likely to play an important role in the distribution of the CJM and especially the spawning success and recruitment. A recent work by Parada et al. (2013[4]) shows clearly the importance of eddies in the retention of larvae and thus the success of spawning (figure 15)

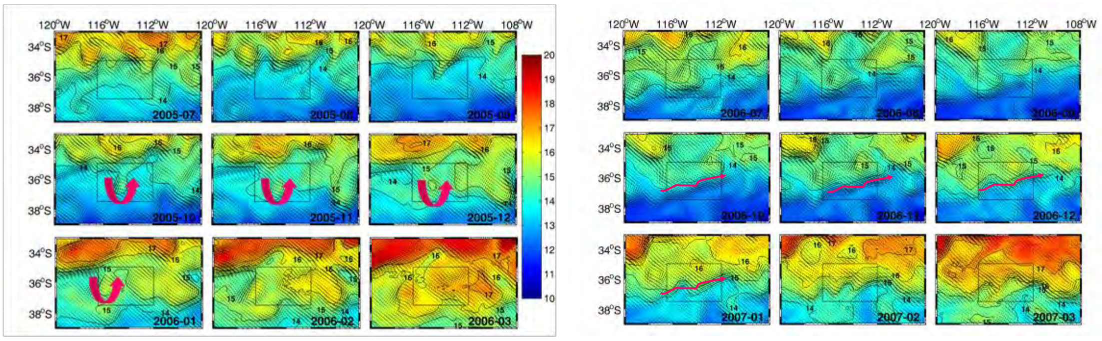

Figure 15. Description of the circulation conditions during high retention years (left) and low retention years (right). From Parada et al., 2013

h. Water mass stratification. Special attention was given to these water masses in Peru because of their strong effects on the anchovy population. We can give as an example the figure x showing all these water masses along the coast of Peru. It has been shown later that these water masses indeed had a strong effect on CJM distribution too (Bertrand et al., 2004), although often inverse than the one they have on anchovy. For instance, the CJM is practically never present in the CCW (Coastal cold waters) (figure 16). Nevertheless, due to the plasticity of the CJM, we may hypothesize that if the fish does not occupy particular water masses, this is more likely due to the richness or poorness of these water masses in preys

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[4] Parada, C., Gretchina, A., Vásquez, S., Combes, V., Ernst, B., Sepulveda, A., Di Lorenzo, E., 2013. Expanding the conceptual framework of the spatial population structure and life history of jack mackerel in the southeastern Pacific of Central Chile: Oceanic seamouint región a spotential spawning/nursery area. Comm. SPICES Symposium, 2013.

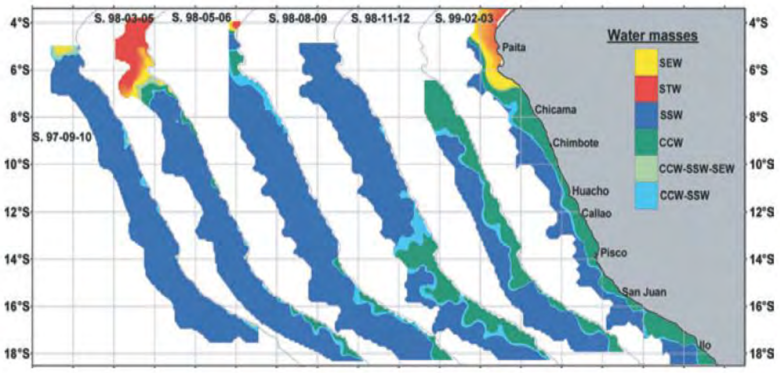

Figure 16. Water masses distribution for the surveys performed along the Peruvian coastline from 1997 to 1999. CCW cold coastal waters; SEW superficial equatorial waters; SSW superficial subtropical waters; STW superficial tropical waters. From Bertrand et al., 2004

It seems that in fact the CJM is more dependent from environmental conditions and particularly the DO concentrations in the 3 dimensions than to given water masses. For instance, Bertrand et al (2004) conclude: "*Jack mackerel were mainly distributed in warm and oxygenated water without a marked preference for one water mass, but with a ubiquitous distribution inside oceanic water masses*". We may hypothesize here that the links between CJM distribution and hydrological characteristics are indirect, the fish following those water masses where the preys (micronekton, Euphausiids, etc.) are present.

Interactions with Chl-a and micronekton. *Trachurus murphyi* is an active predator with a rather high metabolism. Therefore its needs in food are important and it is logical that food availability be a critical factor in its distribution. Alimentation is detailed in chapter 2-F. Relationship with Chlorophyll a has been studied and some results have been given (SNP, 2013[5]). We give for example the Cl-a concentration off Peru during the summers 2012 and 2013 (fig. 17). The most recent works (e.g. SNP, in press; Habasque, pers. Comm..) seem to indicate that the CJM is found on the external border of the high Chl-a concentrations. We can cite the report of the 4th workhop organized by the SNP in Peru (Lima, june2013): "*The CJM has always been observed along the external borders of the upwellings, inside a range of 0.13 to 5.0 µg/Lt*".

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[5] SNP, 2013. 4TH S.N.P. WORKSHOP ON DIAGNOSIS ON THE STATUS OF THE SOUTH PACIFIC JACK MACKEREL (*TRACHURUS MURPHYI*) IN THE PERUVIAN FISHERY LIMA, 26 JUNE-2 JULY, 2013.

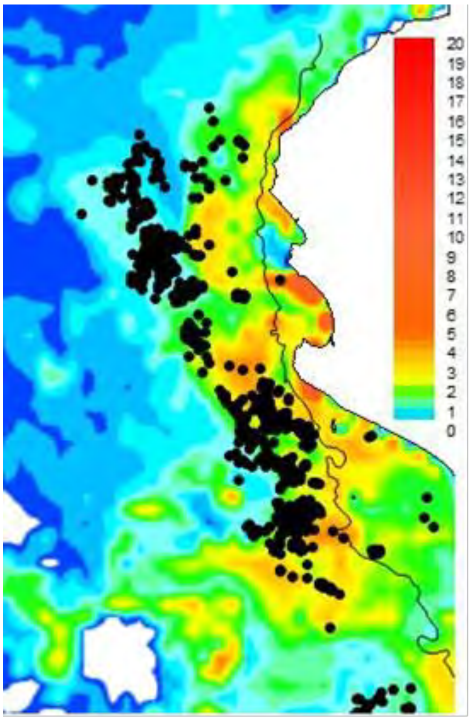


Figure 17. Purse seine sets (black dots) and CHL concentration in the Northern Peru in January 2011. It can be observed that the CJM is mostly concentrated on the external borders of the dense concentrations of Chlorophyll. (from SNP, 2013)

The high degree of consumption of micronekton by the CJM has been put in evidence by Bertrand et al (2006) for instance, who show echograms where the path of a school is marked by the empty areas behind it (figure x), and Bertrand et al. (2004) who show a remarkable case of predation of a micronekton layer by CJM off Chile (see chapter 2)

k. Biological activities. Spawning presents a particular period in the cycle of the CJM, as it seems to be the only moment where the fish is scattered and no catch occur at this moment. It has been shown (see chapter 2-B) that the spawning area is extremely wide and not precisely located. Spawning is related to mixed waters (see Chapter 2), and inside these waters seems more related to the period of the year than to particular hydrological characteristics. Therefore it is difficult to use the spawning area for defining the habitat of the jack mackerel. Contrarily to spawning, migrations are not well understood (lack of tagging surveys), and the knowledge that has been published comes mostly from the analysis of the fisheries.

Conclusion. The habitat of the Chilean Jack mackerel

From all these results and hypotheses, we can define what are the major parameters affecting and defining the habitat (table 1).

Table 1. Limits of tolerance and preferenda of CJM for the main water characteristics in the Southern Pacific Ocean.

parameter	Lower limit	Upper limit	Lower preferendum	Upper preferendum
Oxygen	0.1 ml/l	-	0.2 ml/l	-
temperature	9º	26º	15º	20º
Salinity	<minimum observed	>maximum observed	34.9	35.1
Chl a	0.07mg/m3	26 mg/m3	0.1	?
oxycline	-	30 m	-	40 m

One of the first parameters is the dissolved oxygen (DO). This parameter drives the horizontal as well as the vertical distribution of the CJM. Besides, the DO has forced the CJM to adopt a particular behaviour, and especially concerning its dial and vertical cycles, which are somehow opposite to what is usually known for the *Trachurus* genus: rather scattered and resting by day above the oxycline, in dense schools and feeding by night. Another behavioural consequence of the limiting effect of DO is the inability of the CJM to survive in shallow layers above the oxycline: the CJM hardly can occupy the oxygenated layer above the oxycline when it is shallower than 40 m. Once the necessities in oxygen satisfied, the CJM tends to have a preferendum for waters between 9º to 28º in the whole Pacific Ocean, (15 to 20º in Peru); eventually the preferendum for a given salinity can play a role as a proxy for recognizing water masses.

The second general feature is the subtropical water mass. The “Jack Mackerel Belt” is limited by the cold Antarctic front in the south and the tropical front in the north, which allows to give the isotherms 9º and 28º as overall limits for the CJM domain.

After these two major patterns which show that the CJM presents a great tolerance to the hydrological patterns (except DO), the alimentation becomes the third dominant factor: the CJM is a fish with a rather high metabolism, which means that alimentation is a key factor, and CJM is limited to the zones where the secondary productivity is high, and mostly consisting in Euphausids and Myctophids: this fish is an opportunistic feeder. Chlorophyll is a proxy, knowing that the CJM is not present in the high Chl-a concentration but around the primary productivity fronts.

Other factors are certainly playing some role (especially currents and eddies), but in a secondary level. This is also the case for the migration and spawning cycles of the CJM, which are not rigid enough to define the habitat.

In synthesis we give below in figure 18 what is a preliminary work on defining a conceptual model of habitat (Habasque and Bertrand, pers. comm.)

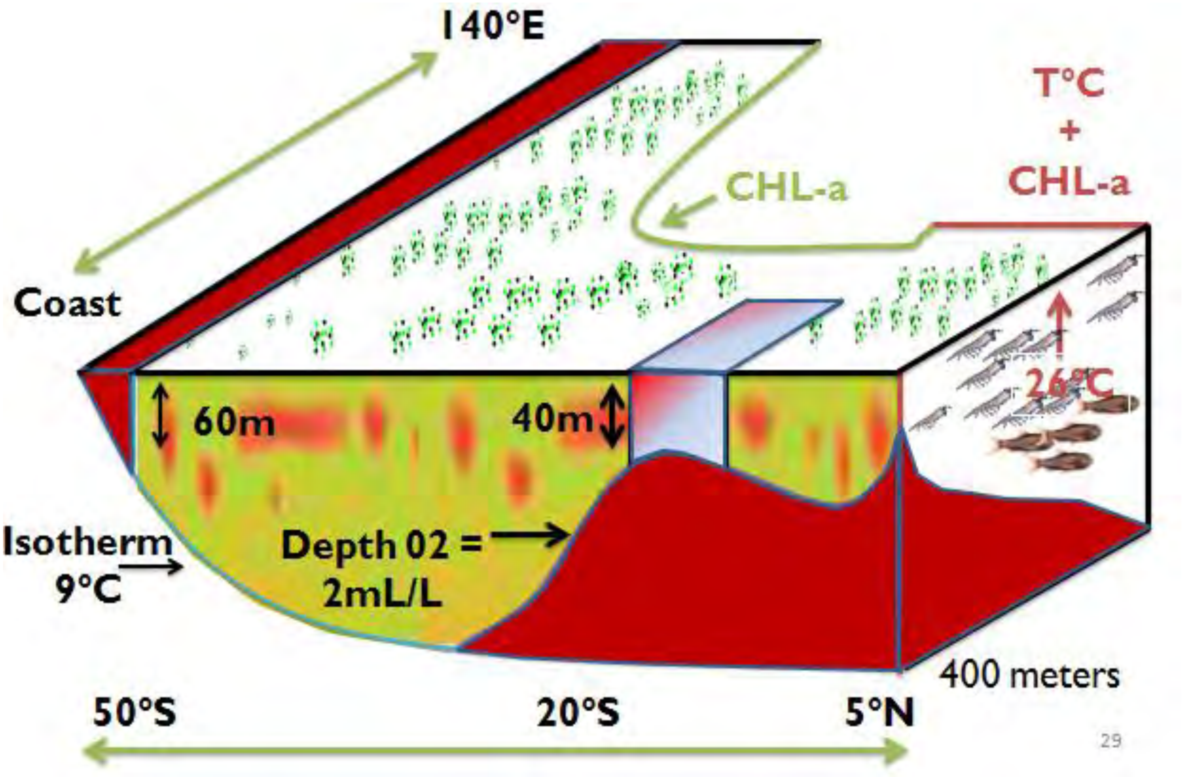


Figure 18. Drawing of a preliminary conceptual model of habitat for the *Trachurus murphyi*. In this model the major limits for the extensoion of the habitat are the temperature (9º being the lower limit, and 26º the upper limit), the productivity (Chlorophyll a concentrations) and the Minimum Oxygen Zone (2 ml/l)

CHAPTER 4-a

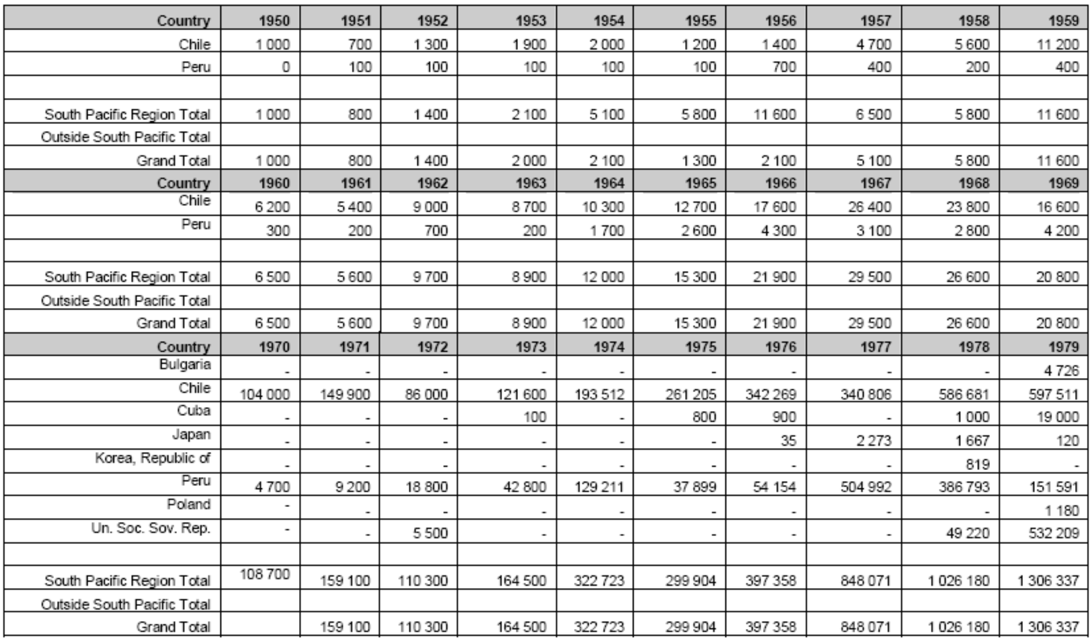
The history of the fishery

1. General description

The fishery on the Chilean Jack Mackerel began in the early 70s with the activities of three countries: Chile, Peru and the USSR plus some Eastern Europe countries. Later, in the late 90s, because of the extension of the population all over the South Pacific Ocean, New Zealand began to exploit it in its EEZ. In 1991 the soviet fishery disappeared and was not immediately replaced by the Federation of Russia, which activity began in the early 2000. At this same period, due to the general decrease of the world catches, countries outside of the south Pacific area found interest in exploiting the CJM, e.g. the European Union, China, etc.

Tables of catches by country and number of countries exploiting the Chilean Jack Mackerel since the mid-20th century have been extracted from the FAO statistics for SPRFMO (Anonymous, 2007[1]), which we present here.

Table 1a. Reported catches (in tons) of CJM by country for FAO area 87 from 1950 to 2004



Country	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
Chile	1 000	700	1 300	1 900	2 000	1 200	1 400	4 700	5 600	11 200
Peru	0	100	100	100	100	100	700	400	200	400
South Pacific Region Total	1 000	800	1 400	2 100	5 100	5 800	11 600	6 500	5 800	11 600
Outside South Pacific Total										
Grand Total	1 000	800	1 400	2 000	2 100	1 300	2 100	5 100	5 800	11 600
Country	**1960**	**1961**	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**
Chile	6 200	5 400	9 000	8 700	10 300	12 700	17 600	26 400	23 800	16 600
Peru	300	200	700	200	1 700	2 600	4 300	3 100	2 800	4 200
South Pacific Region Total	6 500	5 600	9 700	8 900	12 000	15 300	21 900	29 500	26 600	20 800
Outside South Pacific Total										
Grand Total	6 500	5 600	9 700	8 900	12 000	15 300	21 900	29 500	26 600	20 800
Country	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**
Bulgaria	-	-	-	-	-	-	-	-	-	4 726
Chile	104 000	149 900	86 000	121 600	193 512	261 205	342 269	340 806	586 681	597 511
Cuba	-	-	-	100	-	800	900	-	1 000	19 000
Japan	-	-	-	-	-	-	35	2 273	1 667	120
Korea, Republic of	-	-	-	-	-	-	-	-	819	-
Peru	4 700	9 200	18 800	42 800	129 211	37 899	54 154	504 992	386 793	151 591
Poland	-	-	-	-	-	-	-	-	-	1 180
Un. Soc. Sov. Rep.	-	-	5 500	-	-	-	-	-	49 220	532 209
South Pacific Region Total	108 700	159 100	110 300	164 500	322 723	299 904	397 358	848 071	1 026 180	1 306 337
Outside South Pacific Total										
Grand Total		159 100	110 300	164 500	322 723	299 904	397 358	848 071	1 026 180	1 306 337

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[1] Anonymous, 2007. Information describing Chilean Jack Mackerel (*Trachurus murphyi*) fisheries relating to the South Pacific Regional Fisheries Management Organization, Doc. SPRFMO-III-SWG-16, Revised April 2007

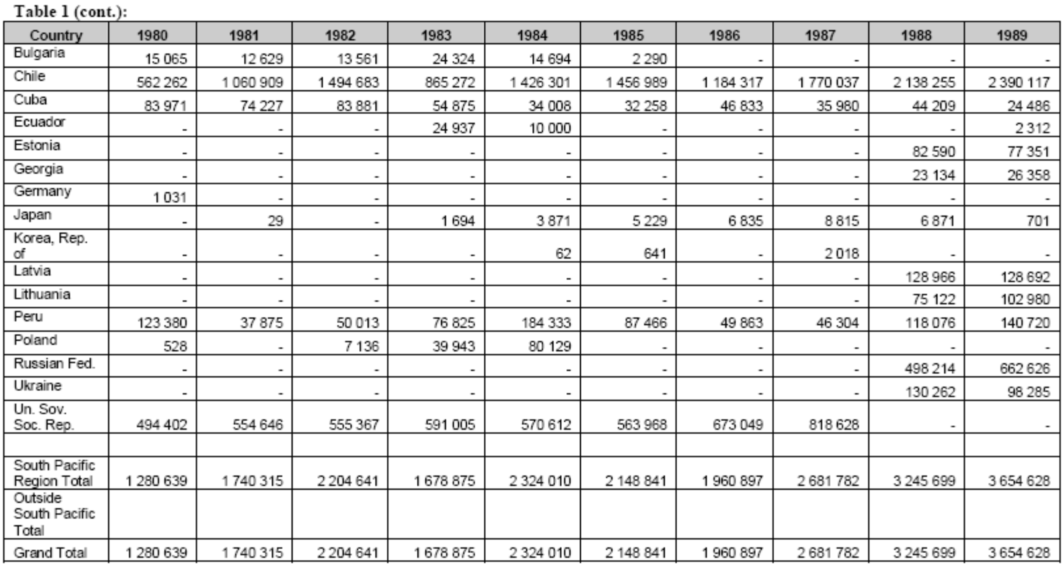


Table 1 (cont.):

Country	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Bulgaria	15 065	12 629	13 561	24 324	14 694	2 290	-	-	-	-
Chile	562 262	1 060 909	1 494 683	865 272	1 426 301	1 456 989	1 184 317	1 770 037	2 138 255	2 390 117
Cuba	83 971	74 227	83 881	54 875	34 008	32 258	46 833	35 980	44 209	24 486
Ecuador	-	-	-	24 937	10 000	-	-	-	-	2 312
Estonia	-	-	-	-	-	-	-	-	82 590	77 351
Georgia	-	-	-	-	-	-	-	-	23 134	26 358
Germany	1 031	-	-	-	-	-	-	-	-	-
Japan	-	29	-	1 694	3 871	5 229	6 835	8 815	6 871	701
Korea, Rep. of	-	-	-	-	62	641	-	2 018	-	-
Latvia	-	-	-	-	-	-	-	-	128 966	128 692
Lithuania	-	-	-	-	-	-	-	-	75 122	102 980
Peru	123 380	37 875	50 013	76 825	184 333	87 466	49 863	46 304	118 076	140 720
Poland	528	-	7 136	39 943	80 129	-	-	-	-	-
Russian Fed.	-	-	-	-	-	-	-	-	498 214	662 626
Ukraine	-	-	-	-	-	-	-	-	130 262	98 285
Un. Sov. Soc. Rep.	494 402	554 646	555 367	591 005	570 612	563 968	673 049	818 628	-	-
South Pacific Region Total	1 280 639	1 740 315	2 204 641	1 678 875	2 324 010	2 148 841	1 960 897	2 681 782	3 245 699	3 654 628
Outside South Pacific Total										
Grand Total	1 280 639	1 740 315	2 204 641	1 678 875	2 324 010	2 148 841	1 960 897	2 681 782	3 245 699	3 654 628

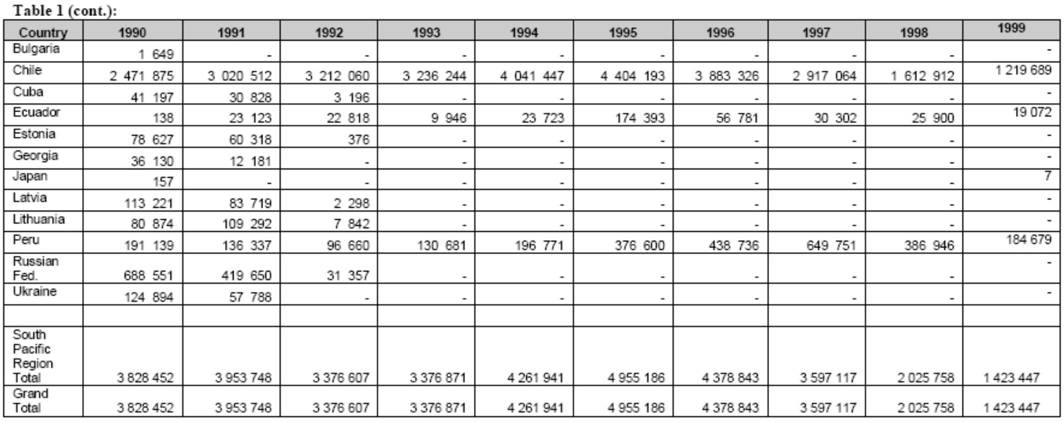
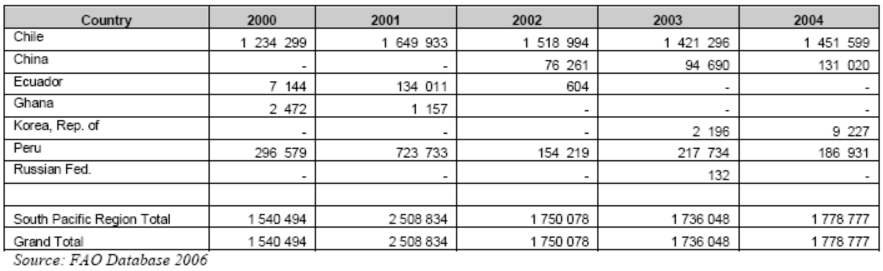


Table 1 (cont.):

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Bulgaria	1 649	-	-	-	-	-	-	-	-	-
Chile	2 471 875	3 020 512	3 212 060	3 236 244	4 041 447	4 404 193	3 883 326	2 917 064	1 612 912	1 219 689
Cuba	41 197	30 828	3 196	-	-	-	-	-	-	-
Ecuador	138	23 123	22 818	9 946	23 723	174 393	56 781	30 302	25 900	19 072
Estonia	78 627	60 318	376	-	-	-	-	-	-	-
Georgia	36 130	12 181	-	-	-	-	-	-	-	-
Japan	157	-	-	-	-	-	-	-	-	7
Latvia	113 221	83 719	2 298	-	-	-	-	-	-	-
Lithuania	80 874	109 292	7 842	-	-	-	-	-	-	-
Peru	191 139	136 337	96 660	130 681	196 771	376 600	438 736	649 751	386 946	184 679
Russian Fed.	688 551	419 650	31 357	-	-	-	-	-	-	-
Ukraine	124 894	57 788	-	-	-	-	-	-	-	-
South Pacific Region Total	3 828 452	3 953 748	3 376 607	3 376 871	4 261 941	4 955 186	4 378 843	3 597 117	2 025 758	1 423 447
Grand Total	3 828 452	3 953 748	3 376 607	3 376 871	4 261 941	4 955 186	4 378 843	3 597 117	2 025 758	1 423 447



Country	2000	2001	2002	2003	2004
Chile	1 234 299	1 649 933	1 518 994	1 421 296	1 451 599
China	-	-	76 261	94 690	131 020
Ecuador	7 144	134 011	604	-	-
Ghana	2 472	1 157	-	-	-
Korea, Rep. of	-	-	-	2 196	9 227
Peru	296 579	723 733	154 219	217 734	186 931
Russian Fed.	-	-	-	132	-
South Pacific Region Total	1 540 494	2 508 834	1 750 078	1 736 048	1 778 777
Grand Total	1 540 494	2 508 834	1 750 078	1 736 048	1 778 777

Source: FAO Database 2006

Table 1b. Number of countries exploiting the jack mackerel, period 1950-2004

YEAR	Nb Countries	YEAR	Nb Countries	YEAR	Nb Countries	YEAR	Nb Countries	YEAR	Nb Countries	YEAR	Nb Countries
1950	2	1960	2	1970	2	1980	7	1990	12	2000	4
1951	2	1961	2	1971	2	1981	6	1991	10	2001	4
1952	2	1962	2	1972	2	1982	5	1992	8	2002	4
1953	2	1963	2	1973	2	1983	7	1993	3	2003	5
1954	2	1964	2	1974	2	1984	8	1994	3	2004	4
1955	2	1965	2	1975	3	1985	7	1995	3	2005	
1956	2	1966	2	1976	4	1986	5	1996	3	2006	
1957	2	1967	2	1977	3	1987	6	1997	3	2007	
1958	2	1968	2	1978	6	1988	10	1998	3	2008	
1959	2	1969	2	1979	7	1989	11	1999	4	2009	

1. History by fishery

a. Soviet Union – Russia

The target researches of jack mackerel in the open South-Eastern Pacific Ocean (outside 200-mile zone of Peru and Chile) were started in 1978 and continued parallel to commercial fishery development in the area. In 1977-1978 the Soviet fleet found commercial aggregations of jack mackerel accessible to trawl fishery. The Soviet research and searching vessels were sampling materials in the area during 1978-1991. The study area is shown in Fig.1. (Nesterov, 2006).

A complete description of the soviet activity was published by Grechina (2009), and we present here some tables that this author elaborated and a map of the different sub-regions identified by the Soviet fishery (figure 1).

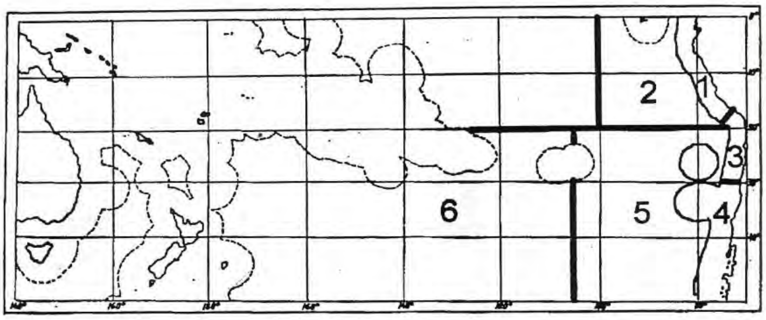


Figure 1. Subdivision of the Southern Pacific Ocean by the Soviet fishery (from Grechina, 2009). (1) Subdivision Peru (inside EEZ); (2) North of South-East Pacific; (3) North Chile (inside EEZ); (4) South Chile (inside EEZ); (5) South of S.E. Pacific; (6) South-West of Southern Pacific.

Generally speaking, the fisheries statistics of the USSR are given in two major subdivisions, South and North of latitude 20ºS (Nesterov, 2006).

The soviet fishery is made exclusively with pelagic trawlers (figure 2).

Figure 2. Examples of pelagic trawlers from the USSR. Note that these two particular trawlers BATM, RTMK-S of 5700 and 9260 t displacement respectively, were also used for exploration and research surveys in the 70s. From Nesterov, 2006

The trawls of the two fishing ships represented on the figure 2 were 120/980m and 120/1120m respectively, with cod-ends of mesh 37 mm without a cover and 34 mm with a cover made of netting with mesh 68 mm. They are representative of the fishing fleet. The annual catch of the fleet is presented in the table 2 (Grechina, 2009)

Table 2. Annual catch of the USSR fleet in the South Pacific Ocean (in 10^3 tons).
From Grechina (2009)

Year	Catch	Year	Catch
1979	539.9	1986	1113.7
1980	642.5	1987	994.8
1981	870.2	1988	1039.7
1982	940.0	1989	1300.2
1983	990.9	1990	1381.8
1984	1349.3	1991	586.6
1985	1074.3	1992	0
Total 1979-1991			12.824.1

The total distribution of the fishing effort during the period 1979-1991 is summarized in the figure 3 and the distribution of the fishing effort is detailed for the years 1986-1991 in figure 4 (Grechina, 2009).

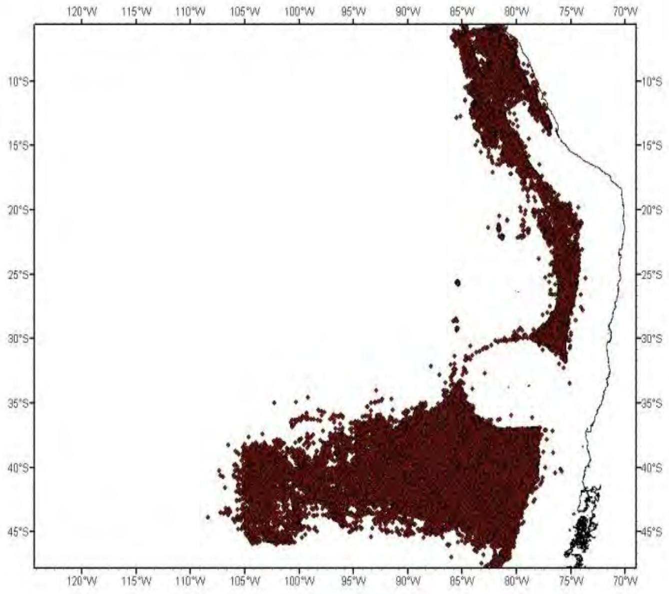


Figure 3. Summarized distribution of the fishing effort of the USSR fleet during the period 1978-1991. Each point represents a trawl set (from Grechina, 2009)

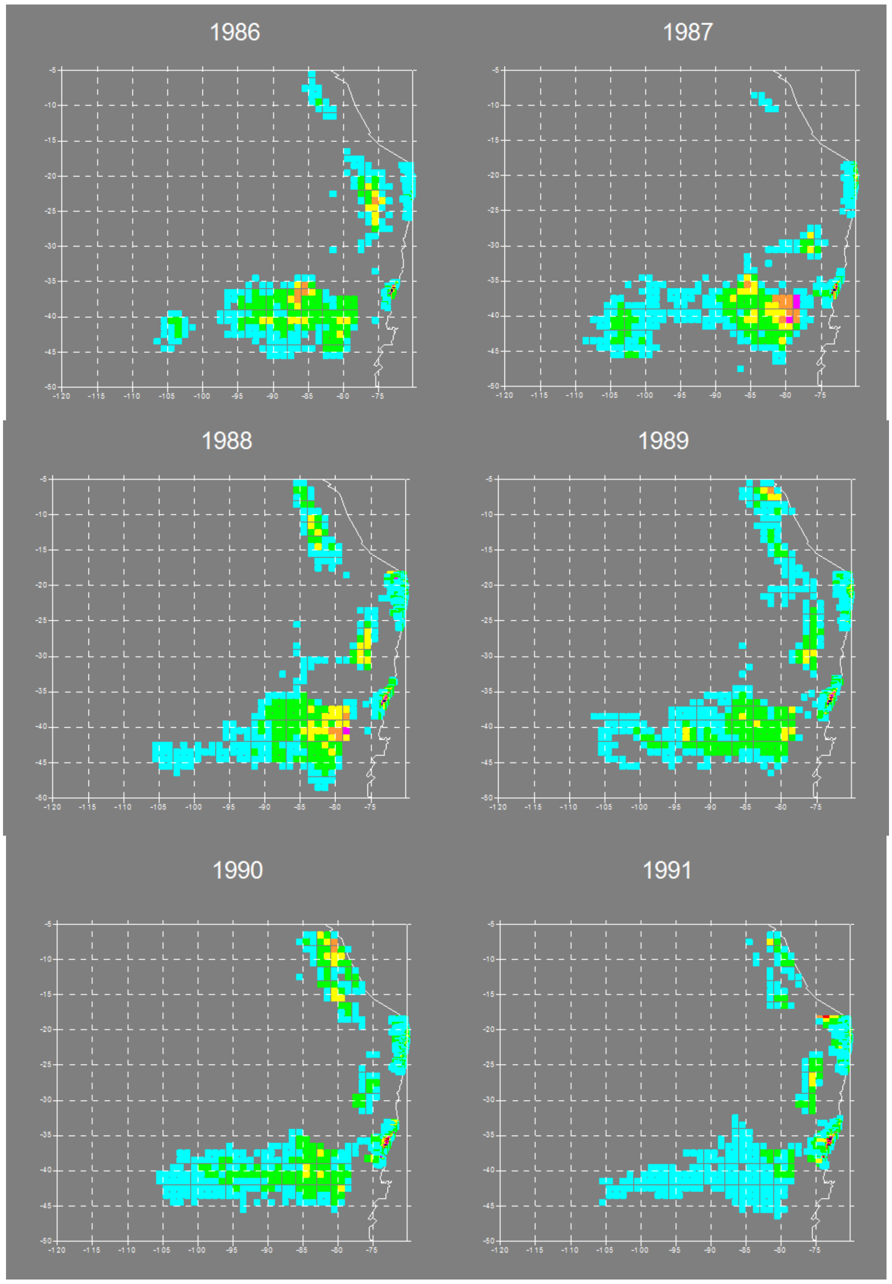


Figure 4. Detailed distribution of the fishing effort of the USSR fleet during the years 1986-1991 (from Grechina, 2009)

Another interesting presentation of the fishing activity was given by Grechina for the years 1986-1991: the monthly distribution of the fishing effort. We extracted from his diagrams the period 1989-1990 that we give in figure 5.

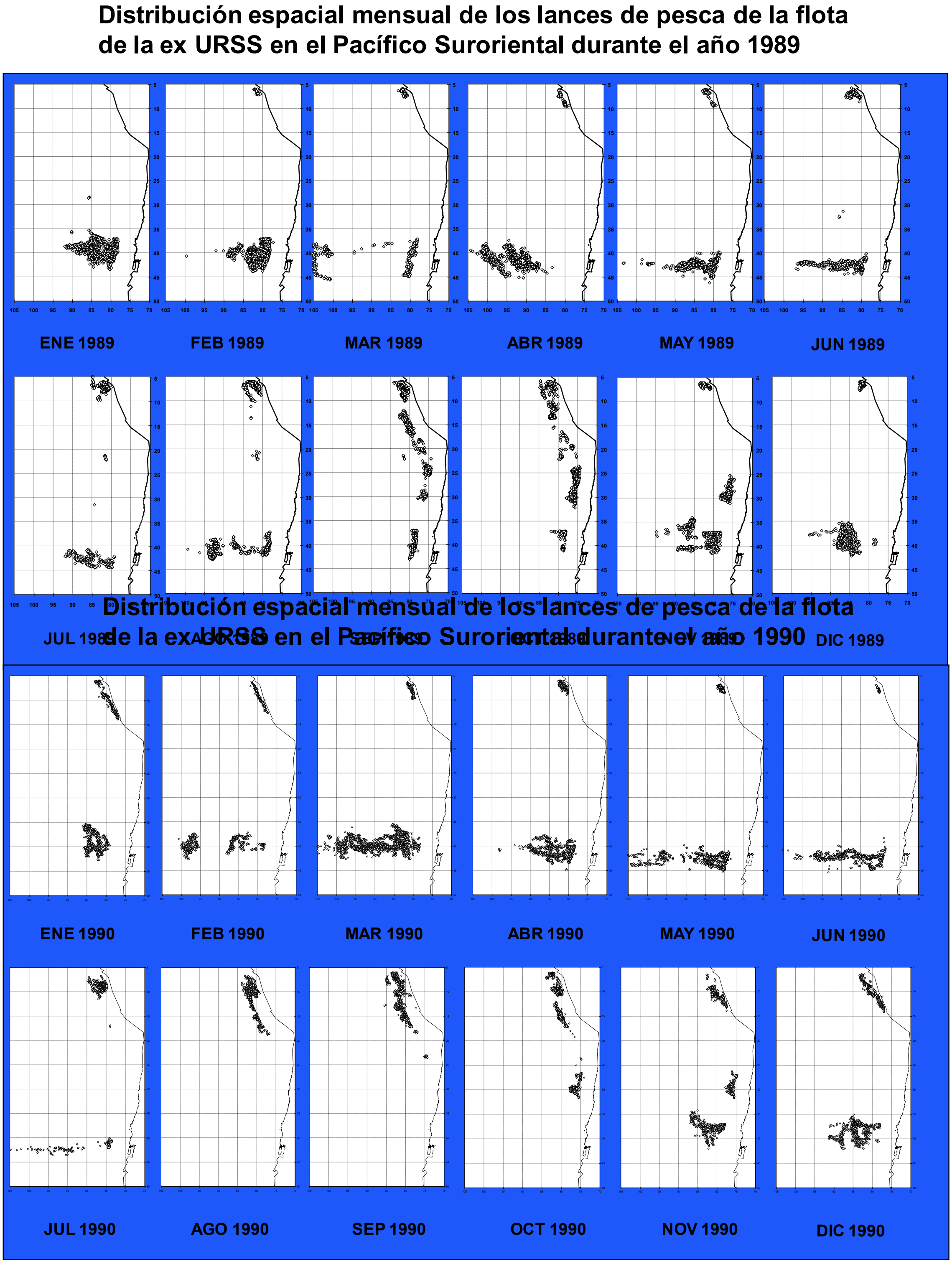


Figure 5. Monthly distribution of the fishing effort of the Soviet fleet from January, 1989 (above, left) to December, 1990 (below, right). From Grechina (2009)

Finally one last interesting point is the extension of the fishing activity towards the west of the South Pacific Ocean, which was clearly demonstrated by Nesterov (2006).

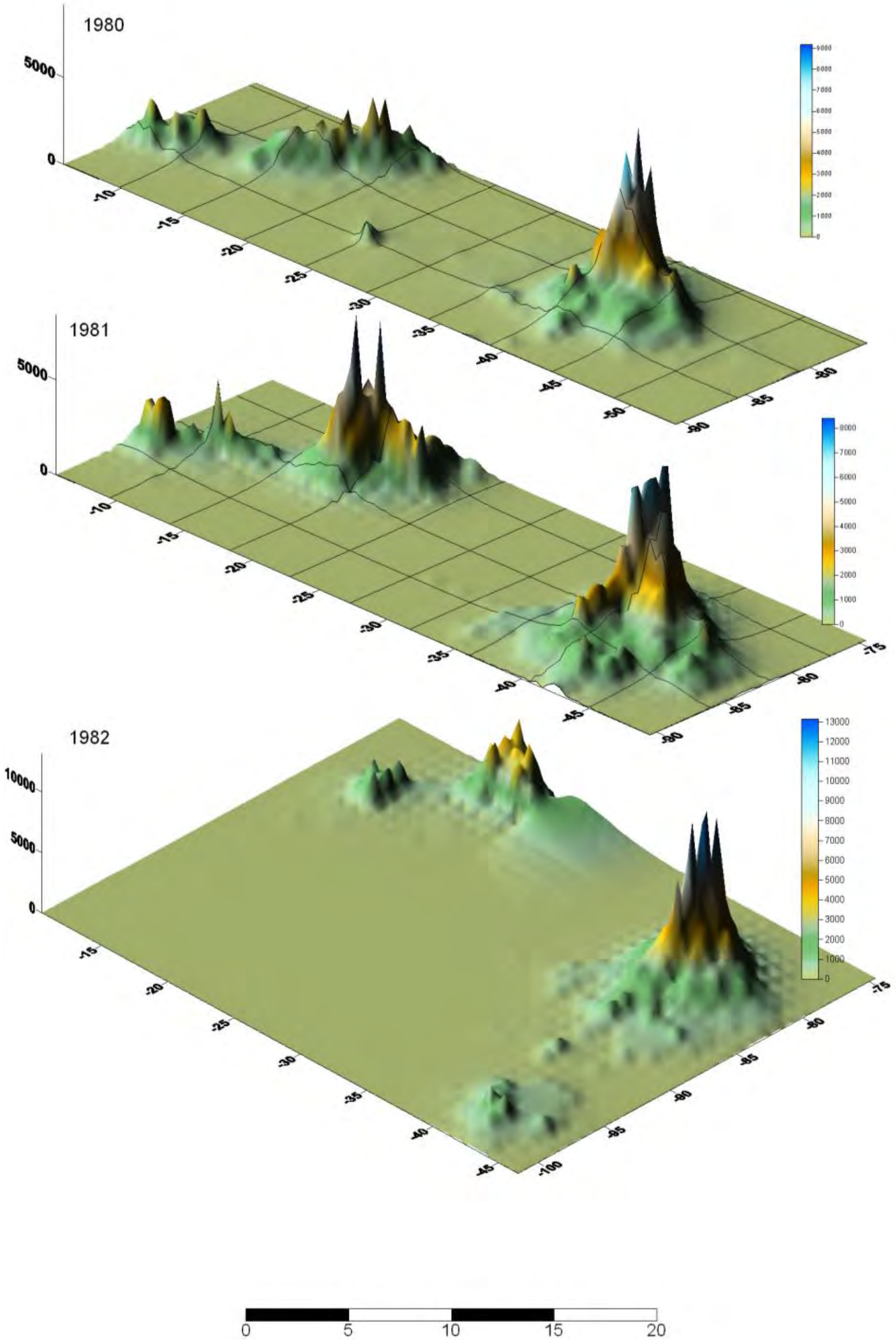


Figure 6. Spatial distribution of the fishing activity (annual catch by 1ºx1º) of the USSR CJM fleet (from Nesterov, 2006)

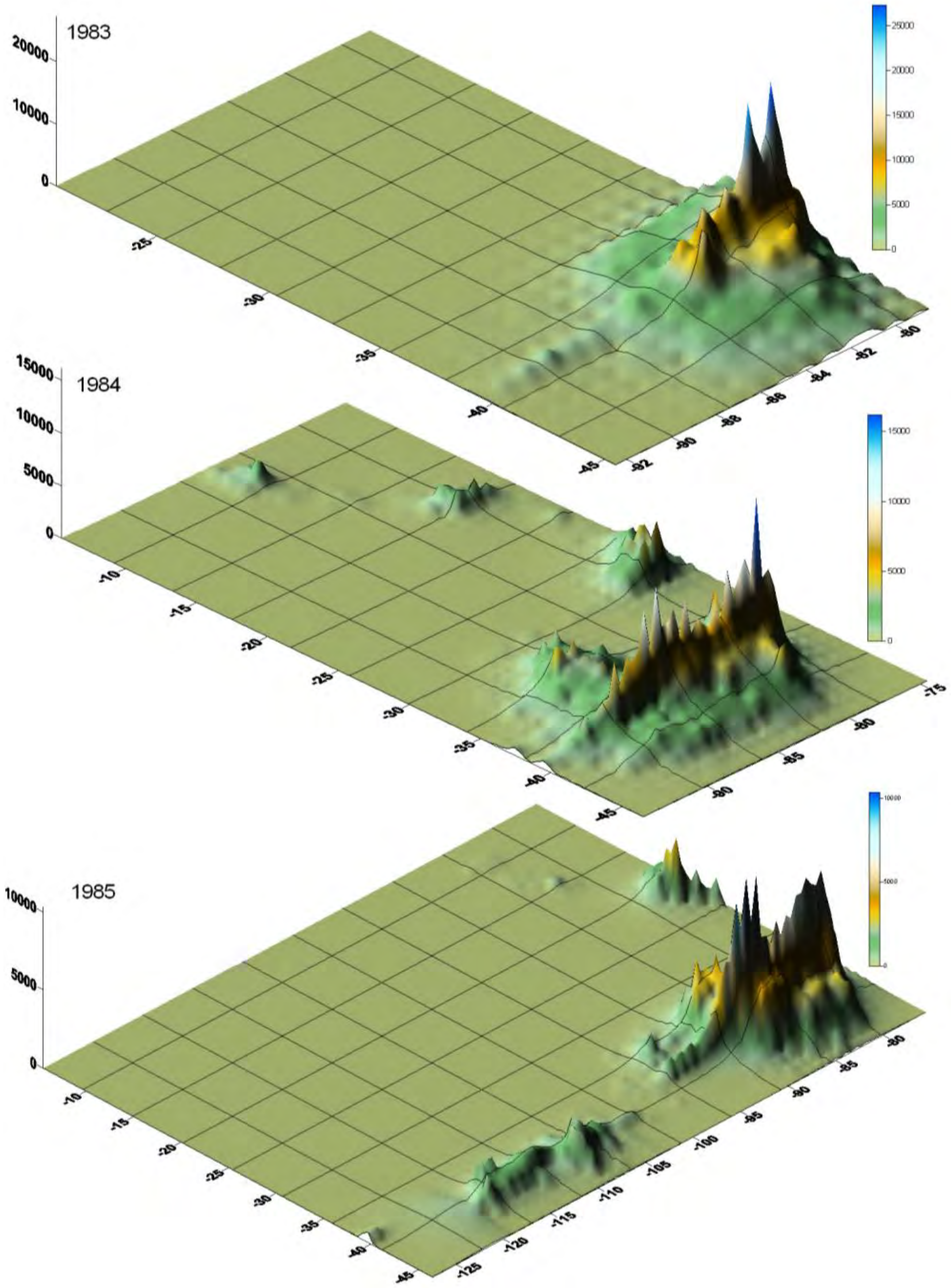


Figure 6 (cont.)

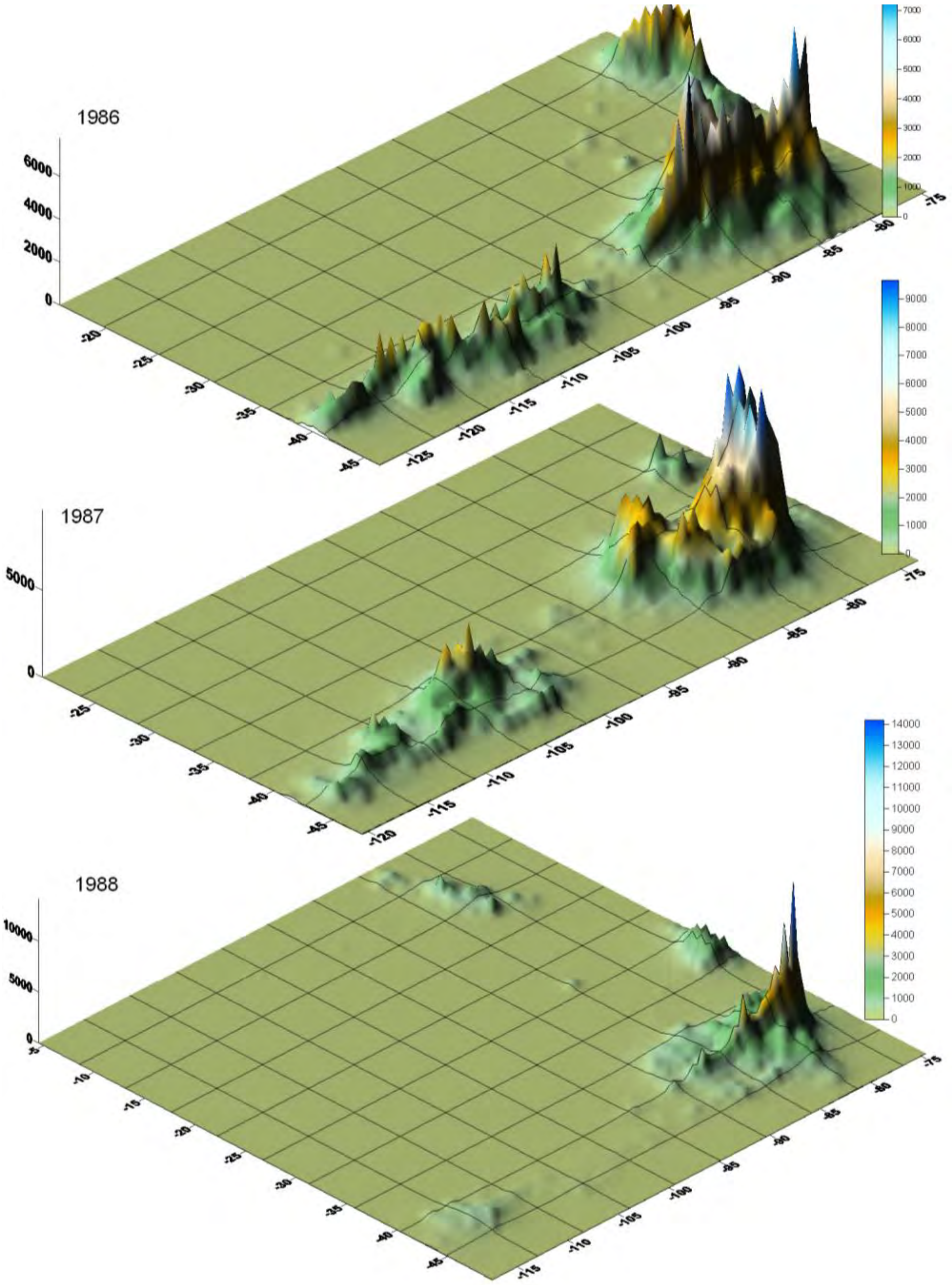


Figure 6 (cont.)

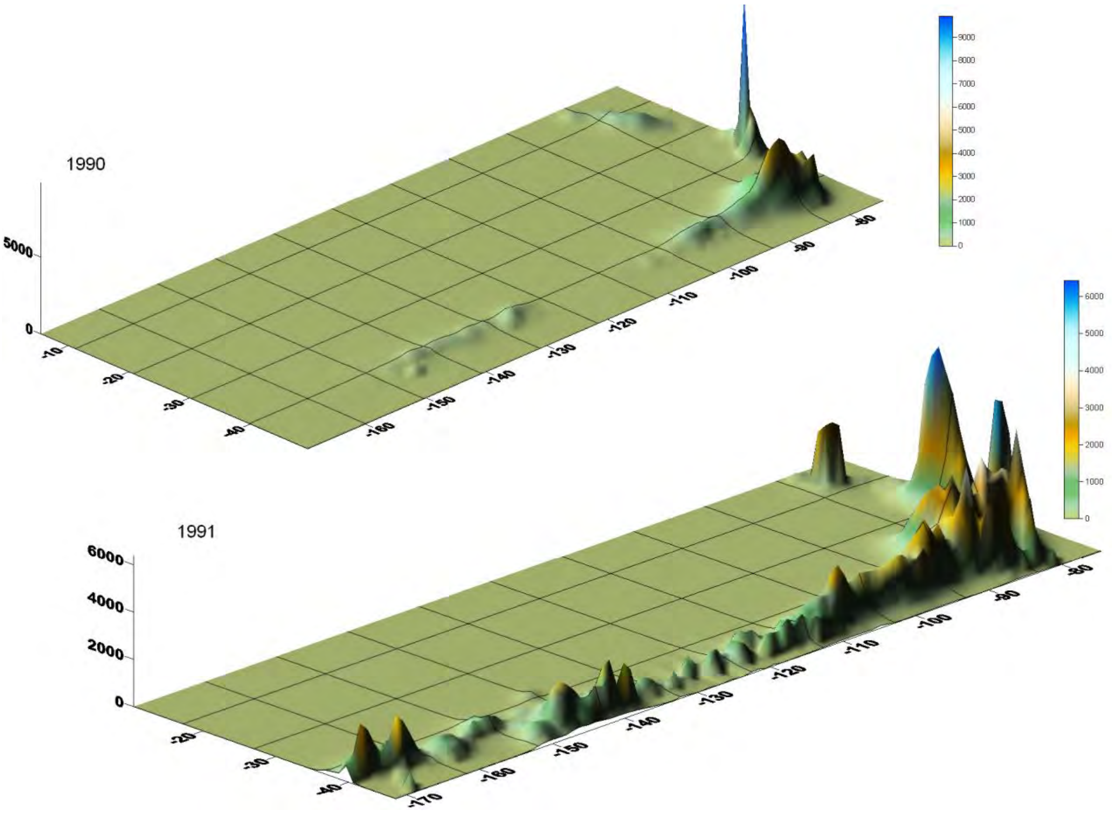


Figure 6 (cont.)

In 1991 for reasons not linked to the jack mackerel situation, the soviet fleet stopped its activities. In total during this period, its contribution to the jack mackerel tonnage landed represented 22% of the total landings (Anon., 2006; cf. FAO world fisheries statistics). Then the Russian Federation began again to exploit the CJM: the first catches have been recorded in 2003 (Anonymous, 2007), but the fisheries never reached the magnitude of the USSR fishery (ref. Catch statistics, SPRFMO, FAO). Moreover fleets from different countries that used to belong to USSR developed independent fishing activities, and nowadays most of the CJM catches are performed by Ukraine.

b. Peru

Peru is the second most important country as far as CJM exploitation is concerned. The fishery is one of the oldest ones in the South Pacific Ocean (table 2) and it reached almost 800 000 tons in the year of highest catch (2001). The important presence of jack mackerel from Paita (5°S) to Mollendo (17°S) including catches of large specimens (more than one meter!!) in the area of Lobos de Tierra was reported in a 1907 description of the Peruvian fishery (Coker, 1908 y 1910). Incidentally this is the first and only time in the history that individuals of such length have been officially reported for any species of the genus *Trachurus*. More recent available landing statistics from the 1960s placed the jack mackerel within the three most important pelagic species for Peru and as the second one after the anchovy since 2000.

The jack mackerel is caught in all the Peruvian EEZ, from the coastline to the 200 NM distance. Some activity is also deployed in the SPRFMO zone. For this area, the Peruvian report (Anonymous, 2012a) details:

The fishing operations were performed off Peru and Chile, starting in a distance of 200 nm and up to 1300 nm from the coast, in the area encompassed between 15º00'S and 41º44'2 S and 86º17'3 W and 101º28'1 W, in areas with a minimum sea surface temperature of 9.5ºC and a maximum of 12.2º with an average of 11.5ºC, and a minimum temperature at the depth of the school (at 70 to 150m) of 9.4ºC and maximum of 12.2ºC. During recent years the Peruvian fleet registered for the capture of jack mackerel in high seas, was constituted by 88 to 92 vessels, from which 79 correspond to purse seiners with an average holding capacity of 491 m^3*, 7 trawlers with an average holding capacity of 3 897* m^3 *and 6 multipurpose vessels (purse seine/trawler) with an average holding capacity of 1691* m^3 *(table 4).*

Table 4. Peruvian fleet registered to develop fishing effort in the SPRFMO area during the period 2010-2012 (from Anonymous, 2012)

Year	Number of vessels	Fishing Gear Types	Holding capacity average (m^3)
2010	79	Purse seine	491
	8	Trawl	5 945
	5	Purse seine/Trawl	1 828
2011	79	Purse seine	491
	4	Trawl	3 885
	5	Purse seine/Trawl	1 828
2012	79	Purse seine	491
	7	Trawl	3 897
	6	Purse seine/Trawl	1 691

Inside the EEZ the catch is mostly done using purse seine. The table 4 gives the catch statistics for the Peruvian waters from 1990 to 2011 in the three subdivisions North, Centre and South of the country.

Inside the EEZ, the species is exploited by the industrial fishery as well as the artisanal fishery. Two gears are used: purse seine and trawl. Two important syntheses were produced on the Peruvian fishery in 2009 and 2012 (Anonymous, 2009[2]; Anonymous, 2012[3a and b]) from which some material is extracted for this paragraph. Historical catch records show that there were regular catches of jack mackerel off Peru since 1939 (Fig. 29), although these did not exceed the 10 tons per year until the 1950s. In the 1950s catches were in the order of a few hundred tons per year, and in 1963 catches almost reached two thousand tons. In 1974 catches increased to more than 100 thousand tons and to more than 500 thousand ton in 1977. After 1977 the annual catches were kept between 100 and 400 thousand tons, except for the maximum recorded 720 thousand tons in 2001. The annual landings of jack mackerel in the period 2002 – 2011 show a clear decreasing trend since 2007, with a minimum in 2010 due to the low availability of jack mackerel. However, the increase of jack mackerel catches during

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[2] Anonymous, 2009. Jaqck mackerel fisheries (*Trachurus murphyi*) on Peruvian Sea. Contribution to the Jack mackerel assessment methods workshop, SPRFMO, Lima, 4-8 May, 2009.

[3] Anonymous, 2012a. Peru. Report of the fishing activities of the Peruvian fleet in the area of the South Pacific Regional Fisheries management Organization (SPRFMO), 2012. SPRFMO, 11th meeting of the Science Working Group, Lima, Peru, 15-19 October, 2012, SWG-11-08.

2011 has partially reversed the decreasing trend observed in recent years. In 2012 the industrial fleet has reported almost 119 thousand tons (Table 5).

Table 5. Annual catches of *Trachurus murphyi* by the Peruvian fleet, 1939-2011 (from Anonymous, 2012) (*)Provisional data for 2011 and 2012

year	Purse seine	Trawl	year	Purse seine	Trawl	year	Purse seine	Trawl
1939	10		1964	1718		1989	57516	83204
1940	34		1965	2561		1990	90544	100595
1941	46		1966	4271		1991	92212	44125
1942	15		1967	3071		1992	96660	
1943	13		1968	2790		1993	130681	
1944	23		1969	4176		1994	196771	
1945	17		1970	4711		1995	376600	
1946	43		1971	9189		1996	438736	
1947	59		1972	18782		1997	649751	
1948	44		1973	42781		1998	386946	
1949	48		1974	129211		1999	184679	
1950	30		1975	37899		2000	296579	
1951	89		1976	54154		2001	723733	
1952	81		1977	504992		2002	154219	
1953	69		1978	386793		2003	217734	
1954	62		1979	151591		2004	187369	
1955	138		1980	123380		2005	80663	
1956	673		1981	37875		2006	277568	
1957	366		1982	50013		2007	254426	
1958	173		1983	43433	33392	2008	169537	
1959	448		1984	54607	129726	2009	25912	
1960	281		1985	40717	46749	2010	300	
1961	174		1986	37006	12857	2011*	257241	
1962	666		1987	31588	14716	2012*	119335	
1963	1954		1988	72420	45656			

Since 1998, the distribution of the catches is mainly concentrated in the center-south region (table 6) and the annual catches fluctuated at a lower level than the previous period, with the exception of 2001 when the catch was 775 thousand tons. In the period 1970–2012 there was a strong seasonality in the jack mackerel catches with best catches in summer and spring. The last years the best catches were concentrated mostly in summer.

Table 6. Jack mackerel purse seine catch by regions (in tons) during 1990-2011 (from Anonymous, 2012[4])

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
NORTH	181.908	127.837	88.449	118.110	190.013	365.767	273.515	629.509	368.191	173.888	257.715
CENTER	7.528	7.808	4.298	3.480	5.899	9.164	129.817	19.093	6.840	8.238	34.139
SOUTH	1.704	692	3.914	9.091	859	1.669	35.404	1.149	11.914	2.553	4.724
TOTAL	191.139	136.337	96.660	130.681	196.771	376.600	438.736	649.751	386.946	184.679	296.579
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
NORTH	258.812	1.022	385	-	1.175	64.618	7.134	90	100	270	101.308
CENTER	433.446	122.803	92.668	151.452	27.683	189.790	178.397	70.322	25.312	30	155.761
SOUTH	31.475	30.394	124.683	35.916	51.806	23.160	68.895	99.125	500	-	172
TOTAL	723.733	154.219	217.735	187.368	80.663	277.568	254.426	169.537	25.912	300	257.241

As we can observe through these tables, the fishery quasi collapsed in the late 2000, with a catch of 200 tons in 2010. This is related to the movements of CJM in the area (figure 8).

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[4] Anonymous, 2012b. Situation of the Peruvian stock of jack mackerel (Northern Stock) and the Peruvian fishery in national juridiction waters. Peru National report nº 2, SPRFMO, SWG-11-08a, Lima, 15-19 October 2012.

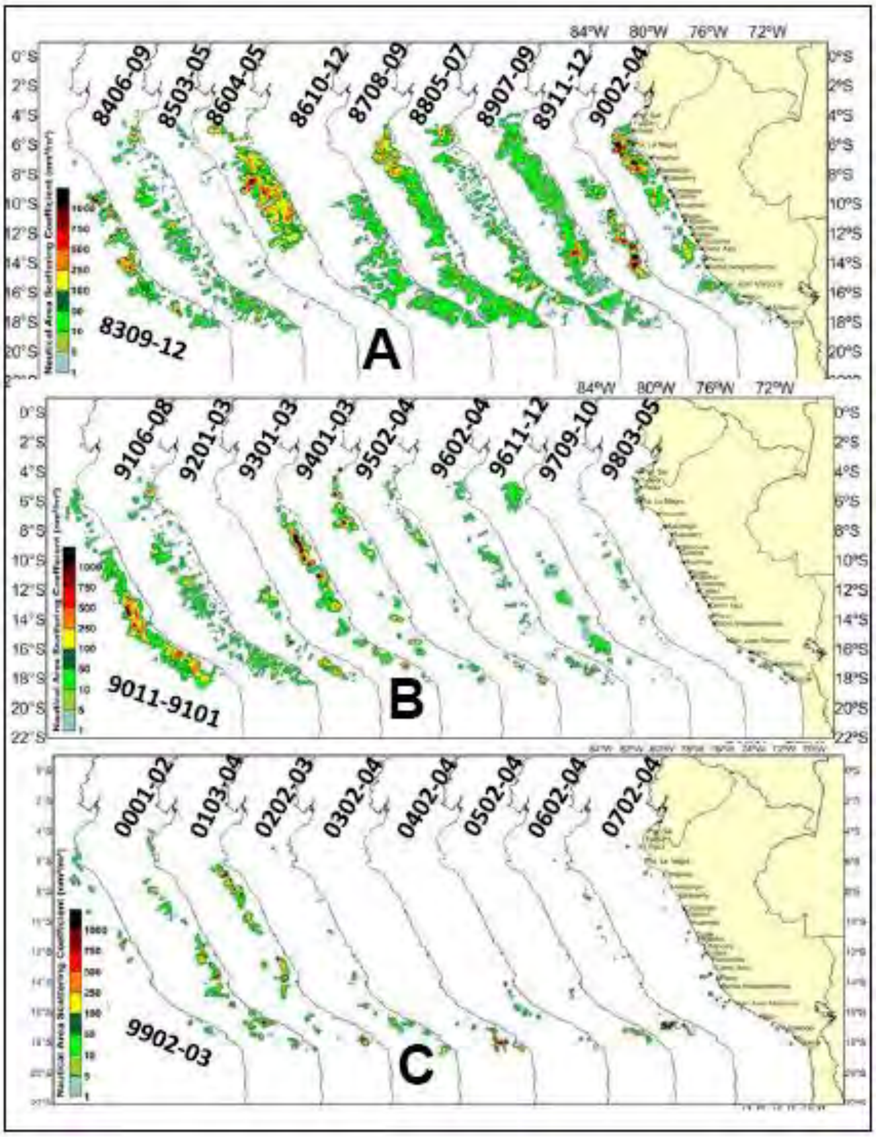


Figure 8. Distribution and abundance of jack mackerel off Peru as obtained from acoustic stock assessment surveys, 1983-2007 (from Anonymous, 2012b)

In 2011 the catches increased again to values closer to the modal value of catches, thanks to the entrance of CJM in the Peruvian waters, joined to the recruitment in the fishery of a year class born in 2007-2008.

The fishery.

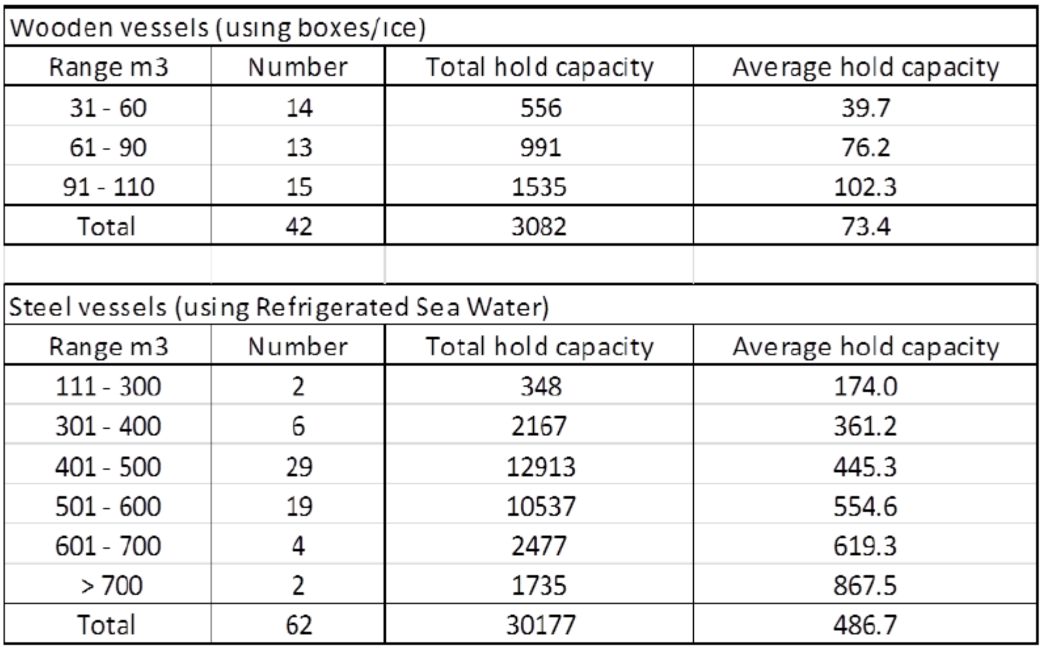
Before 2002, around 500 vessels out of the 1200 that were part of the industrial purse seine fleet directed their fishing effort to jack mackerel, mainly during the closed anchovy fishing seasons. Since 1974, the majority had fishing nets and fishing systems that allowed them to indistinctly fish for one or the other of the above mentioned pelagic species. However, during 2002 the Supreme Decree (D.S. 001-2002 of 06-09-2002) established that jack mackerel and chub mackerel could only be caught and used for direct human consumption, causing a drastic modification of the 'jack mackerel' fleet and the reduction of the total catches of this species since it was not allowed to catch it or use it for the production of fish oil or fish meal. Furthermore, this new regulation promoted the development of an industrial fleet with refrigerated sea water system in addition to other characteristics specific for fishing for direct human consumption.

Characteristics of the purse seine fleet

The Peruvian purse seiner fleet dedicated to jack mackerel mostly operates in the coastal area along the Peruvian coast, mostly within the first 100 nm from the coastline. In 2006 the operative industrial fleet authorized to fish for jack mackerel in the Peruvian waters comprised 511 vessels, of which 53 were steel vessels and 458 wooden vessels. The total holding capacity of the whole fleet was 50 587 m3, with 21 695 m3 for the steel fleet and 28 892 for the wooden fleet

As part of a process of optimization, in 2011 the fleet authorized to fish for jack mackerel in Peruvian waters was reduced to 104 vessels, of which 62 were steel and 42 wooden vessels. The total hold capacity of the whole fleet is 33 359 m3, with 30 177 m3 corresponding to the industrial steel fleet and 3 082 to the wooden fleet. (Table 7).

Table 7. Structure of the industrial fleet authorized to fish jack mackerel in 2011 (from Anonymous, 2012b)



Wooden vessels (using boxes/ice)

Range m3	Number	Total hold capacity	Average hold capacity
31 - 60	14	556	39.7
61 - 90	13	991	76.2
91 - 110	15	1535	102.3
Total	42	3082	73.4

Steel vessels (using Refrigerated Sea Water)

Range m3	Number	Total hold capacity	Average hold capacity
111 - 300	2	348	174.0
301 - 400	6	2167	361.2
401 - 500	29	12913	445.3
501 - 600	19	10537	554.6
601 - 700	4	2477	619.3
> 700	2	1735	867.5
Total	62	30177	486.7

The number of purse seiners that actually fished for jack mackerel during the period 1970 – 2011 is plotted in Fig. 9. The maximum was in the 1990s with around 700 vessels, but then declined and remained relatively constant below 100 since 2002.

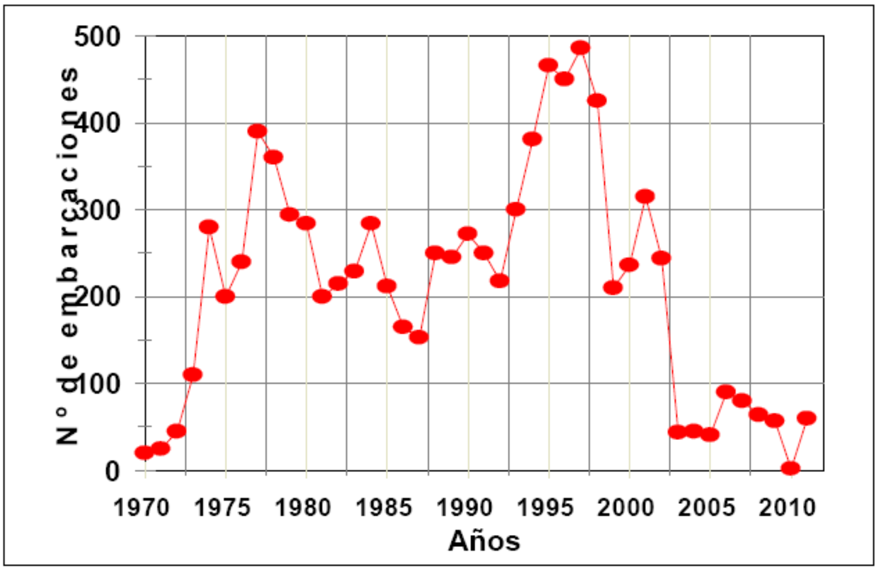


Figure 9. Number of Peruvian vessels for jack mackerel fishery during 1979-2011 (from Anonymous, 2012b)

c. Chile

(An important synthesis was produced in 2006 by the Chilean scientists, and the figures and part of the text below comes from this document[5]) Chile is the most important country involved in the CJM fishery. Its activity is developed inside as well as outside its EEZ (table 8), exclusively with a purse seiner fishery (fig. 10).

Figure 10. A Chilean purse seiner in operation in the South-East Pacific Ocean

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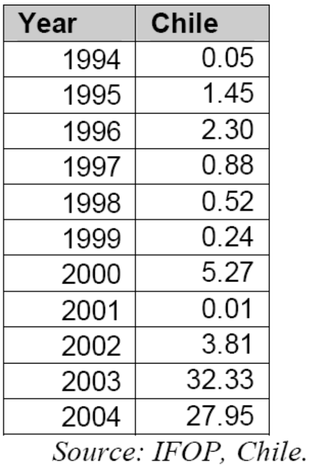
[5] Anonymous, 2006. Chilean Jack Mackerel Report. SPRFMO, Hobart, 20067.

Table 8. Percentage of the CJM catch in FAO Area 87 taken outside its EEZ and inside the proposed SPRFMO area by year, 1994-2004



Year	Chile
1994	0.05
1995	1.45
1996	2.30
1997	0.88
1998	0.52
1999	0.24
2000	5.27
2001	0.01
2002	3.81
2003	32.33
2004	27.95

Source: IFOP, Chile.

After some records of catches since the 1950s, the Chilean jack mackerel fishery started in northern Chile in the 1960s as an alternative to anchovy. Starting in 1975 and up to 1984, Chilean landings of jack mackerel grew steadily at values that went from 200 thousand tons to 1 million tons (t) (Figure 4). From the mid-1980s onwards, the fishing area in the center-south area became the main fishing field in Chile. From 1985 up to 1995, Chilean landings showed a sustained increase and reached a national maximum of 4.4 million tons in 1995. Jack mackerel catches began to decrease in 1996 and dropped sharply as of 1997.

Jack mackerel is exploited by the Chilean fleet mainly in two fishing areas: in the north (roughly the area extending from Chile's northern border and parallel 26º 03'S) and the center-south area (i.e. between parallels 32º 10'S and 43º 30'S). The fleet operating in the latter area operates both in Chile's exclusive economic zone (EEZ) as well as in its projection on to the high seas. Less significant fishing activities are carried out in the area between Caldera and Coquimbo (26º 03'S - 32º 10'S). Records for that area in the period 1988 - 1996 show average annual landings of 140 thousand tons.

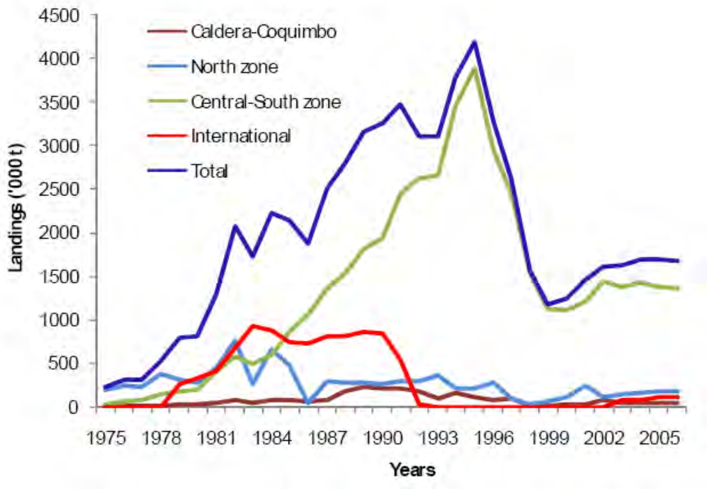


Figure 10. Jack mackerel landings of Chilean fleets by area, 1975-2006. The international (mostly soviet) fleet catches are given as a comparison (source SERNAPESCA)

Since the beginning of the CJM fishery, Chile has developed the most important fishing activity, its contribution being above 60 % during the period of activity of the Soviet fleet until 1990, and above 80 % since this year (figure 11)

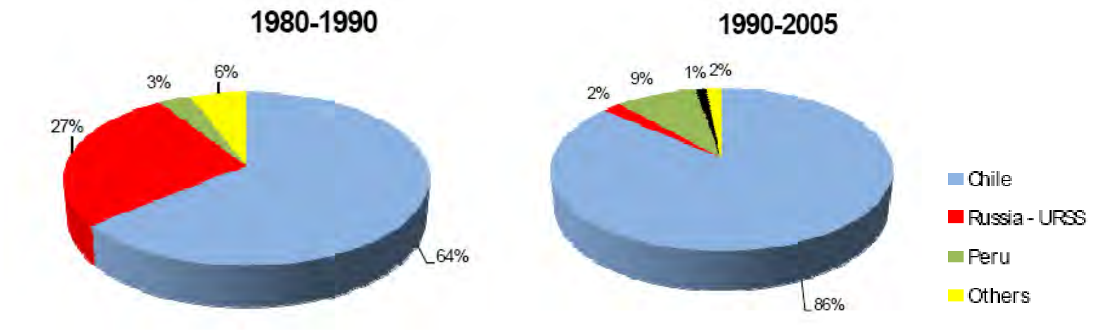


Figure 11. Ratio of Chilean Jack Mackerel catches reported in FAO statistical area 87 (South East pacific) by country, 1980-2005 (source FAO)

In the 1980s important changes occurred in the abundance and distribution of the CJM, which main area of distribution shifted towards the South-West, followed by the fishery (fig. 12); the high abundance recorded during the 1980s and 1990s induced the fishery to adapt by the use of larger vessels and bigger haul capacity (figure 13).

Regarding changes in fishing effort, the increased abundance in Chile's center-south area fishery encouraged the growth of the fleet in the early 1980s. Thus, bigger and better equipped ships began to participate in the fishery. The fleet's significant growth is shown in Figure 13, which also shows its decrease as of 1997 due to fishery regulations. This became even more pronounced in 2001 because of the application of Maximum Allowable Catch limit per ship owner (MACL). In the latter period, increased average hold size is accounted for by the paralysation and/or replacement of the smaller ships.

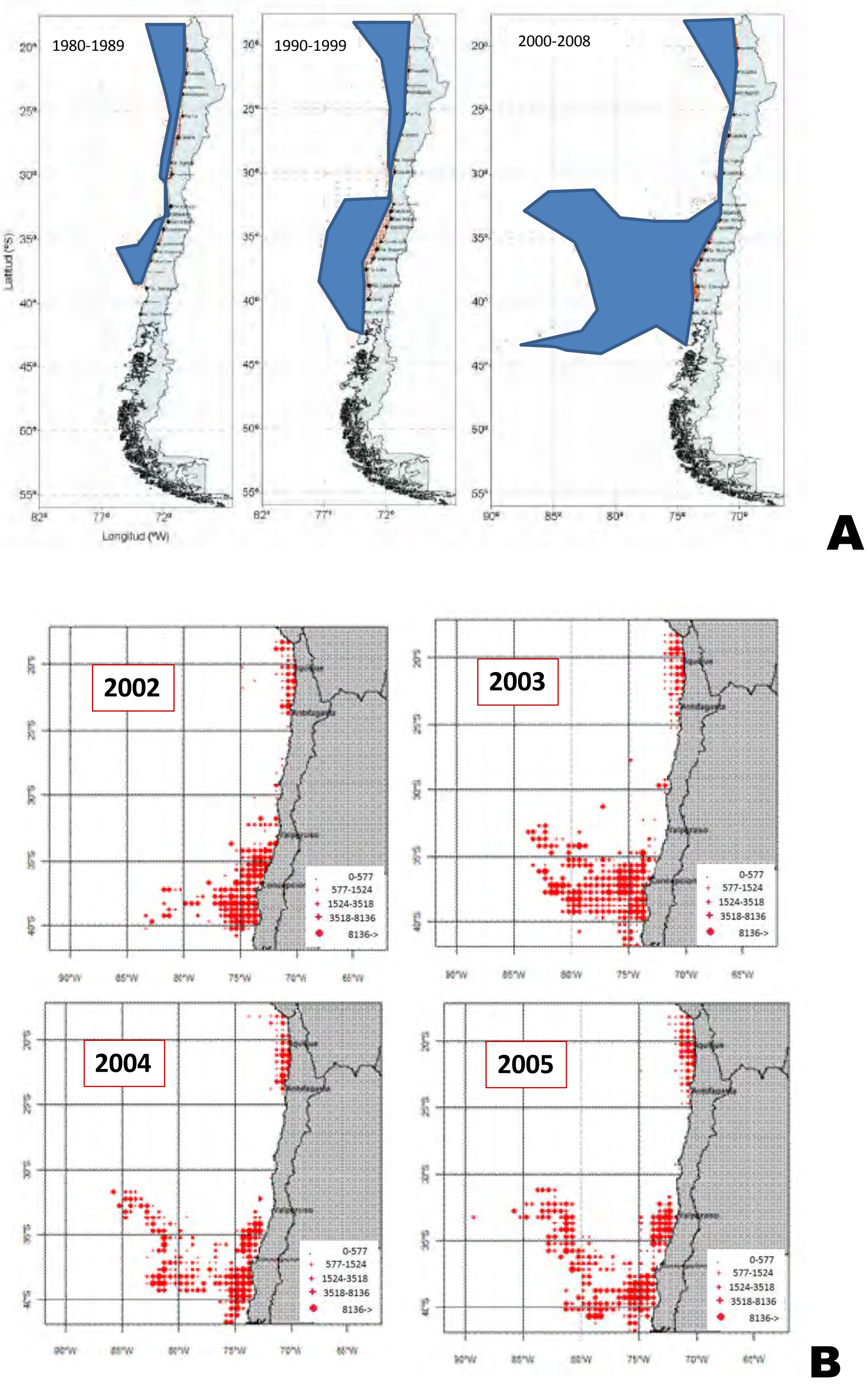


Figure 12. Time-space distribution of jack mackerel catches
by the Chilean industrial purse-seine fleet: A, synthesis on period 1980-2008 (from Canales, 2008), showing the extension towards the west of the fishing/exploration area of the Chilean fishery; B: detailed evolution of catches distribution from 2002 to 2005 (source IFOP)

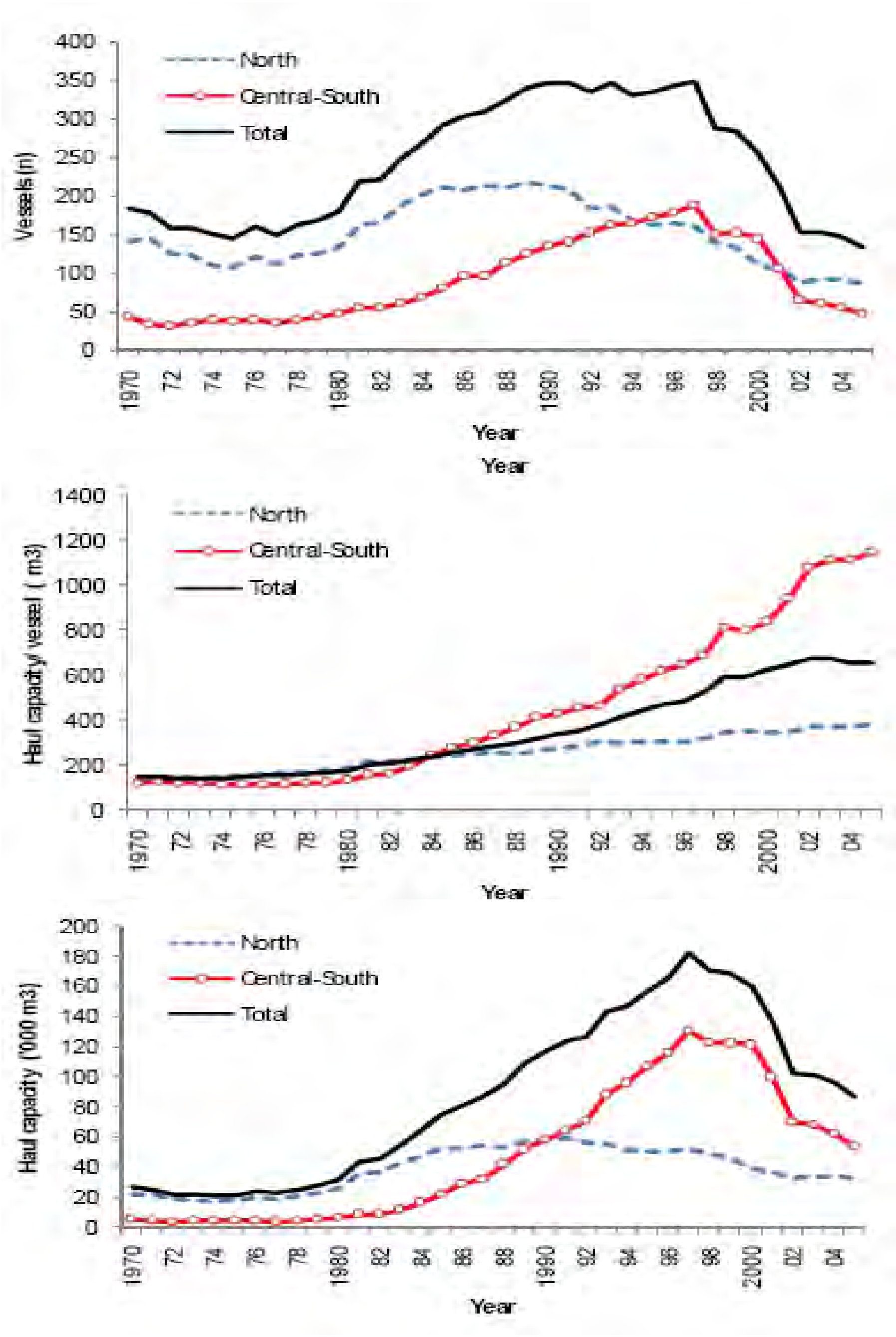
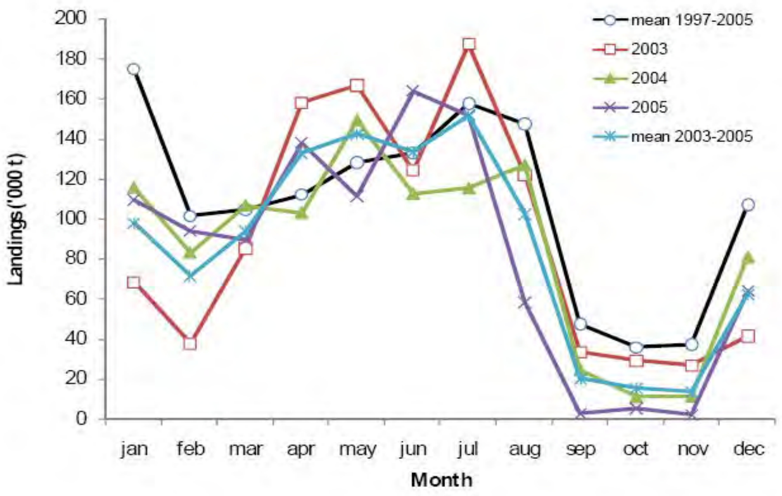


Figure 13. Evolution of the Chilean fleet in the North and Centre-South areas, 1970-2005 (source: IFOP)

Jack mackerel exploitation beyond the first 100 nautical miles from the coast started in 1992 and, by the mid 1990s the incidence of catches recorded between the 100 n.m. and 200 n.m. area was higher than 30%. In the period 2002 - 2003 this extended to catches recorded outside the EEZ, including even up to 700 n.m. off the coast.

The Chilean fishery suffers a high seasonal cycle, and almost all the catches are performed during the austral winter (April-September).



Source: IFOP

Figure 14. Seasonal landings of Jack Mackerel in the 35ºS-40ºS zone

In the recent years, the fishing effort has dramatically decreased, due to the decrease of the CJM population in Chilean waters and offshore adjacent area. The Chilean Report to SPRFMO in 2012 details the fishing effort: "*Over the last five years, the size of the industrial purse seine fleet catching jack mackerel in the SPRFMO area and the Chilean EEZ has decreased 23%, reducing its number from 126 vessels in 2008 to 97 in 2012. During this period more than 56% of the fleet, has been represented by vessels with hold capacities under 600 m3. Correspondingly, the number of vessels operating in the SPRFMO area has also exhibited a decreasing trend for the period 2009-2012, particularly in 2012, when as late as July, no more than 9 vessels were registered. The fleet operating in the SPRFMO area has been mainly represented by vessels with hold capacities greater than 900 m3*" (Tables 9 and 107).

Table 9. Number of industrial vessels catching jack mackerel in the Chilean EEZ and the SPRFMO area between 2009 and July 2012. Data area assembled by year and hold capacity (2011* and 2012* are preliminary data). From anonymous, 2012[6]

Hold capacity (m3.)	2008	2009	2010	2011*	2012*
0-300	8	8	3	0	0
300-600	65	65	68	63	60
600-900	9	10	7	10	8
900-1200	19	19	17	12	6
1200-1500	10	10	10	11	9
1500-1800	10	11	11	12	9
1800-2100	5	6	6	5	5
Total	**126**	**129**	**122**	**113**	**97**

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[6] Anonymous, 2012. Annual national report, SPRFMO – Science Working Group: Jack Mackerel fishery in Chile. 11th Meeting of the Science Working Group, SWG-11-07, Lima, September, 2012

Table 10. Number of industrial vessels catching jack mackerel in the SPRFMO area between 2009 and July 2012. Data area assembled by year and hold capacity (2011* and 2012* are preliminary data). From anonymous, 2012)

Hold capacity (m3.)	2009	2010	2011*	2012*
0-300	1	0	0	0
300-600	16	0	0	0
600-900	5	4	4	0
900-1200	17	12	5	2
1200-1500	10	8	8	1
1500-1800	12	12	10	3
1800-2100	6	6	5	3
Total	**67**	**42**	**32**	**9**

The catches during the last years is detailed in the table 11.

Table 11. Yearly jack mackerel catch in the Chilean EEZ and the SPRFMO area with purse seine nets for the period 2007-july 2012 (from Anonymous, 2012)

Years	Chilean Jack mackerel (t)		
	Chilean EEZ	SPRFMO area	Total
2007	1,040,167	262,617	1,302,784
2008	376,370	519,738	896,108
2009	491,792	343,135	834,927
2010	355,510	109,298	464,808
2011	193,722	53,573	247,295
2012	213,284	4,138	217,423

d. The European fleet

Fleets from the European Union (from Holland and Poland principally) came recently to the South Pacific for fishing jack mackerel. The fleet is made of a few very large vessels (figure 15) that operate in the same area as the Russian, i.e. between 30ºS and 40ºS, 80ºW-100ºW.

Figure 15. German trawler "KVV 171 Maartje Theadora" operating in the South Pacific Ocean (from Corten, 2008)[7]

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[7] Corten, A., 2008. The fishery for jack mackerel in the Eastern Central Pacific by trawlers from the European Union in 2007. SPRFMO, Chilean Jack Mackerel Workshop, Reñaca, Chile, 2007.

The fleet is much smaller (in number of ships) than the former ones. Corten (2009) gives a description of the development of the EU fishery: “*The fishery for jack mackerel by the EU started in 2005 by a single vessel working for 3 months in the second half of the year. The next year, the same vessel returned and worked for the whole season (March-October), together with an Irish vessel. Following the positive results of this season, the number of vessels increased to eight in 2007. In 2008, this number was kept unchanged, following an agreement by the SPRFMO to freeze fishing effort as of 31 December 2007. The vessels involved in this fishery are large pelagic trawlers, preliminary operating under the flags of Germany, Netherland and Lithuania. The vessels use single boat pelagic trawls that are fishing during night-time”.* After 2009, the number of vessels was reduced as a result of declining catches, and no activity was scheduled for the year 2012. Results from the EU annuals reports to SPRFMO (Corten, 2008; 2009; 2010; Corten and Janusz, 2011; 2012) are synthesized in table 129.

Table 12. Fishing activity of nations (*) from the European Union since the beginning of the CJM fishery in 2005 (Corten, 2012) (*) Nations involved are Germany, Netherland, Lithuania, and Poland

year	Number of vessels	Fishing days	Catch in tons	CPUE (catch/day) in tons
2005	1	44	6179	140
2006	2	239	62137	260
2007	8	401	123523	308
2008	7	423	108174	256
2009	6	436	91336	209
2010	5	274	51398	188
2011	2	32	1814	57

The EU fishery is seasonal (March to December in the years of high activity) and follows the highest concentration of CJM west of the Chilean EEZ at latitudes 25ºS-40ºS. An example of the movements of the fishing activity of EU is given in figure 16 for the year 2006.

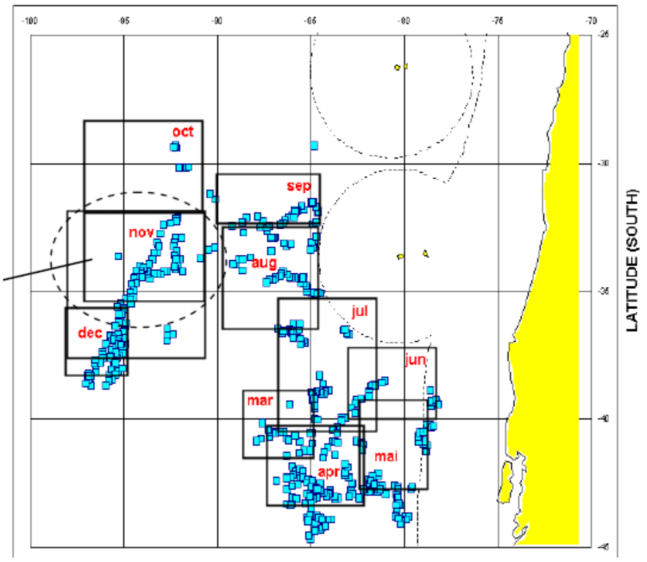


Figure 16. Monthly areas of operation of the Dutch fleet that caught Jack Mackerel during 2005 (from Corten, 2007)

e. New Zealand

New Zealand developed an opportunistic fishery when the Chilean Jack Mackerel, during its period of largest extension (1995-2005) was present in New Zealand EEZ. No dedicated international fishery was built for catching this fish (figures 17 and 18).

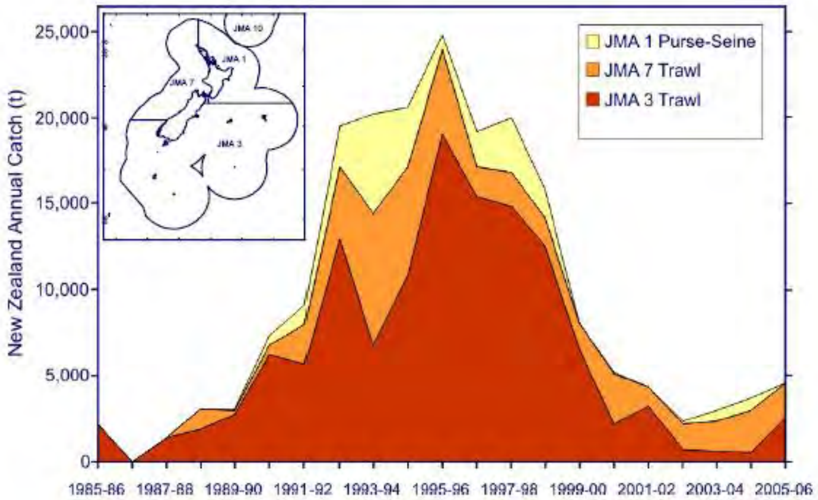


Figure 17. New Zealand estimated catch of *Trachurus murphyi*, for period 1985 to 2006 (from Penney and Taylor, 2008)

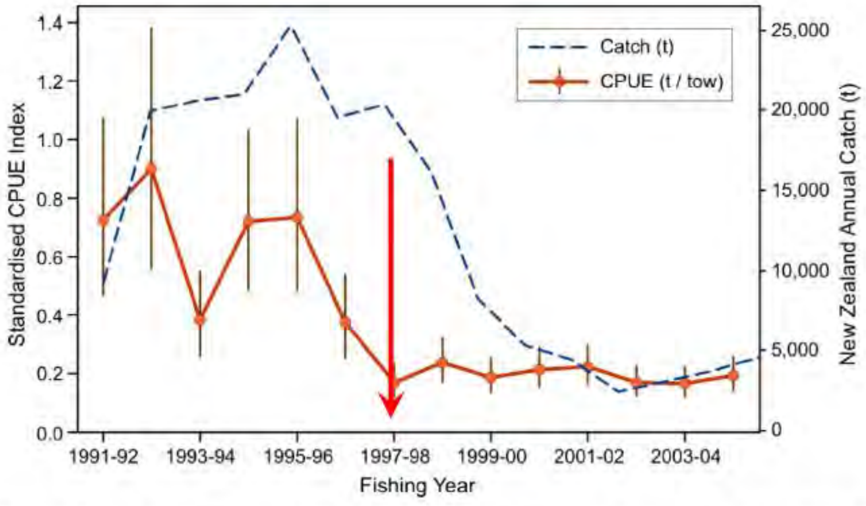


Figure 4. Standardised catch rates of *Trachurus murphyi* (tons per tow) and total catch (t) from 1991–92 to 2004–05 for vessels participating in the New Zealand jack mackerel trawl fishery (adapted from Taylor *et al* 2008).

Figure 18. Standardized catch rates of *Trachurus murphyi* (tons per tow) and total catch (tons) from 1991-1992 to 2004-2005 for vessels participating in the New Zealand jack mackerel trawl fishery (from Taylor et al., 2008 *In* Penney and Taylor, 2008)

During the exploitation of CJM, the NZ fishery used exclusively pelagic trawls inside its EEZ (figure 19).

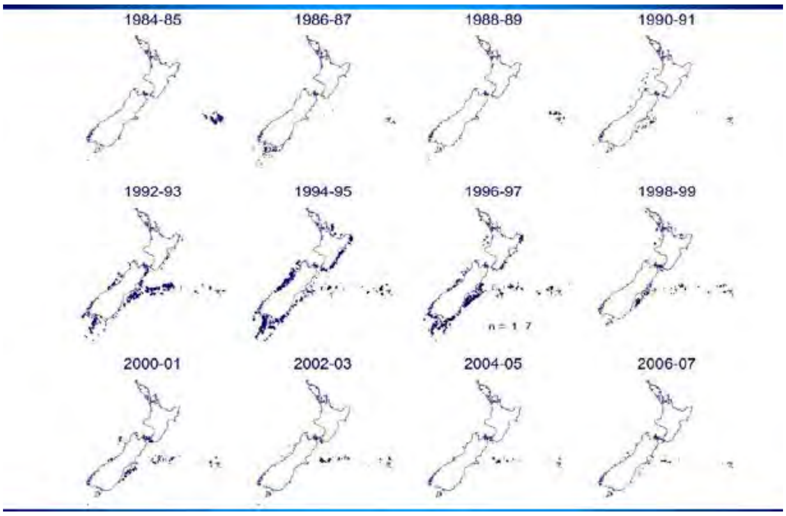


Figure 19. Location of the trawl sets on jack mackerel in the NZ EEZ, during the period 1984-2007 (from Penney, 2008)

f. Other fisheries

The high abundance of Trachurus murphyi during the 1980 and 1990 decades attracted a number of fishing companies that went episodically or permanently to exploit it. These companies were operating under diverse national flags (sometime changing from a country to another), and it is difficult to consider these activities according to the nation that is providing statistics. Moreover, countries that were included in the Soviet Union until the early 1990s became autonomous fishing countries, while on the contrary countries that entered in the European Union were considered as EU fishery. The (non exhaustive) list of countries that transmit or transmitted statistics to FAO and SPRFMO include

- Countries of the South Pacific region with national and international industrial fisheries: Chile, Ecuador, Peru, New Zealand, Australia.
- Countries of the South Pacific region without national or international industrial fisheries: fisheries Cooke islands, Vanuatu, Colombia
- Countries outside the South Pacific region with international industrial fisheries: USSR then Federation of Russia, Bulgaria, Poland, Estonia, Latvia, Lithuania, Germany, Ukrania, Georgia, Cuba, China, Korea, Japan, Taiwan, Viet-Nam.
- Countries of the European Union: Germany, Netherland, Poland, Lithuania.

Once described the major countries (Chile, Russia, Peru, New Zealand, EU), the other countries can be considered as minor participants. Nevertheless it is worth observing the great interest demonstrated by these international actors when the CJM presented a high potential of exploitation. Since the strong decrease in the late 1990s, this interest has dropped, and the example of the EU fishery is representative. But it is clear that as soon as the population recovers, these participants will change their policies and it is quite likely that the fishing pressure from these countries will increase rapidly.

Chapter 4

Fisheries regulation

Fisheries regulations concerning the Chilean jack Mackerel fishery still are depending on national legislations, and ther is no standardization of regulation. In particular, each country uses a specific mesh size for the gears that depends more on the national regulation for the whole fisheries than on a sound application to the case of jack mackerel.

The table 1 gives some information on the national dimensions of mesh size applied to the CJM.

Table 1. Dimension of the mesh size used in the CJM fisheries

Country	**Mesh size**	**reference**
Chile	50 mm (seine) and 60 mm (trawl)	D. Queirolo, UCV (pers. comm.)
EU	50 mm (trawl)	CRR 266, ICES, 2004
Australia	40 mm	G. Geen, Small Pelagic Fisheries Advisory Committee, (pers. comm.)
Norway	42 and 45 mm	B. Isaksen, IMR, Bergen (pers. comm.)
Peru	38 mm (seine) and 76 mm (trawl	Resol. Minister. Nº 209-2001-PE
Russia	76 mm (trawl)	

There are very few works dedicated on net selectivity in the particular case of the CJM, and most of the information gathered in this chapter comes from a selectivity experiment achieved in Peru in 1979 – 1980 by Tadanobu Machii and Yukio Nose (Tokyo University of Fisheries) for trawls. This work was published in a special issue of the Boletin de IMARPE in 1987. The characteristics of the CJM studied are given in the figure 1

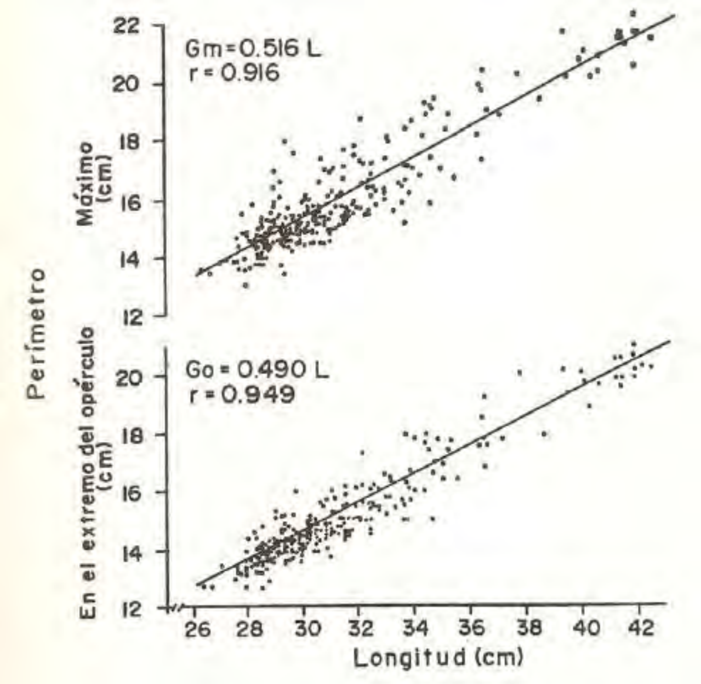


Figure 1. Relationships between the fish length and the maximum body perimeter for Trachurus murphyi (from Tadanobu Machii and Yukio Nose, 1987)

The results of the study are gathered in the table 2.

Table 2. Results of the study achieved in 1987: minimum length (Longitud minima), appropriate mesh size (M), dangerous size (M') and mean length (Longitud media), measured for the four seasons.

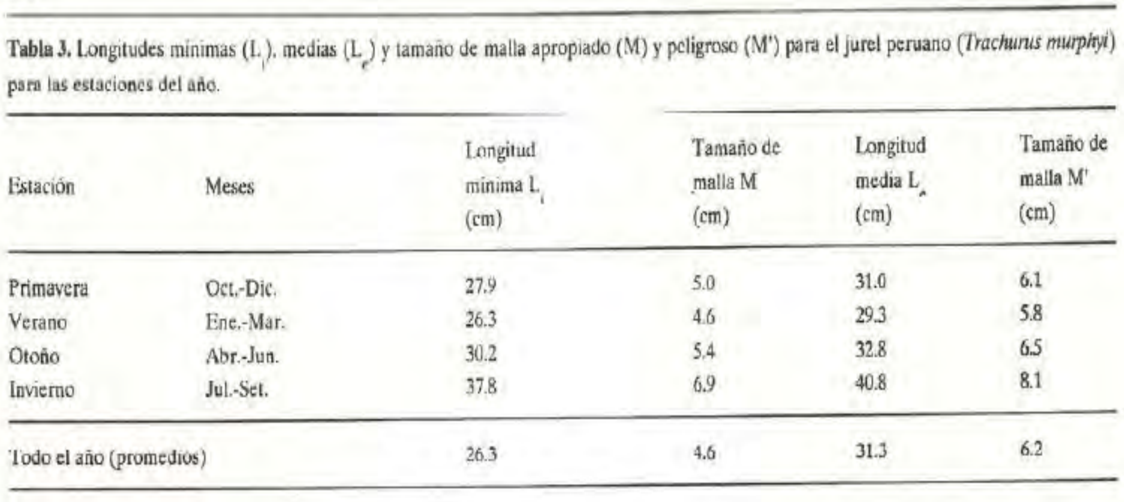
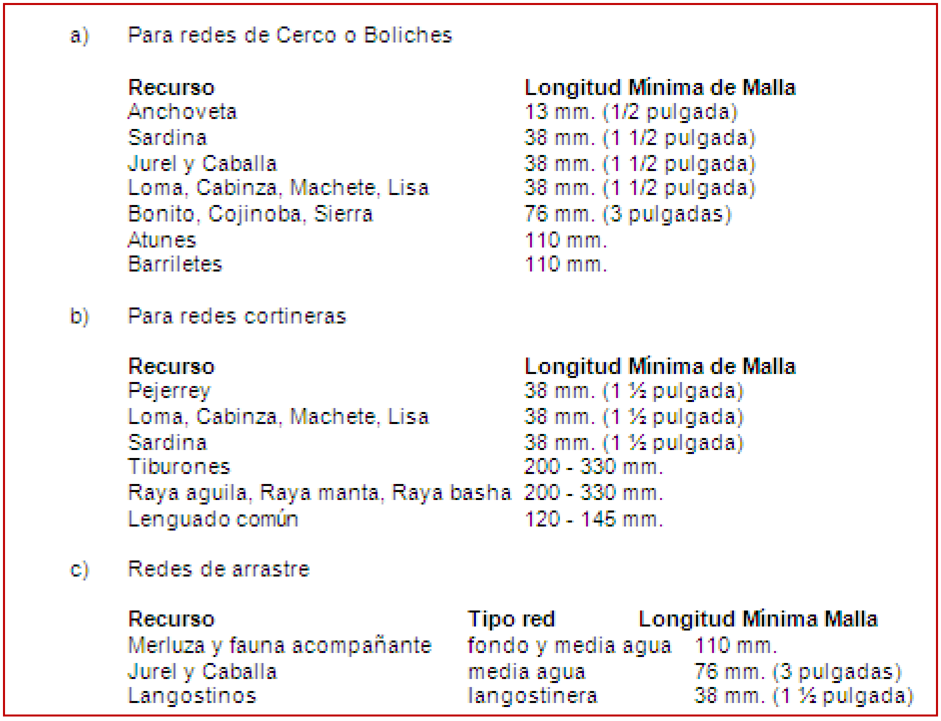


Tabla 3. Longitudes mínimas (L_i), medias (L_c) y tamaño de malla apropiado (M) y peligroso (M') para el jurel peruano (*Trachurus murphyi*) para las estaciones del año.

Estación	Meses	Longitud mínima L_i (cm)	Tamaño de malla M (cm)	Longitud media L_c (cm)	Tamaño de malla M' (cm)
Primavera	Oct.-Dic.	27.9	5.0	31.0	6.1
Verano	Ene.-Mar.	26.3	4.6	29.3	5.8
Otoño	Abr.-Jun.	30.2	5.4	32.8	6.5
Invierno	Jul.-Set.	37.8	6.9	40.8	8.1
Todo el año (promedios)		26.3	4.6	31.3	6.2

From this series of analyzes, a regulation was decided in Peru (**Resolución Ministerial N°209-2001-PE)** for the main exploited species, that is presented in table 3.

Table 3.Detail of Article 5, Annex 1 of the official Peruvian regulation establishing minimum mesh sizes for fisheries operations in the Peruvian sea for the principal gears. Note that concerning the CJM the minimum sizes are 38 mm for purse seine and 76 mm for trawls.



a) Para redes de Cerco o Boliches

Recurso	**Longitud Mínima de Malla**
Anchoveta	13 mm. (1/2 pulgada)
Sardina	38 mm. (1 1/2 pulgada)
Jurel y Caballa	38 mm. (1 1/2 pulgada)
Loma, Cabinza, Machete, Lisa	38 mm. (1 1/2 pulgada)
Bonito, Cojinoba, Sierra	76 mm. (3 pulgadas)
Atunes	110 mm.
Barriletes	110 mm.

b) Para redes cortineras

Recurso	**Longitud Mínima de Malla**
Pejerrey	38 mm. (1 ½ pulgada)
Loma, Cabinza, Machete, Lisa	38 mm. (1 ½ pulgada)
Sardina	38 mm. (1 ½ pulgada)
Tiburones	200 - 330 mm.
Raya aguila, Raya manta, Raya basha	200 - 330 mm.
Lenguado común	120 - 145 mm.

c) Redes de arrastre

Recurso	**Tipo red**	**Longitud Mínima Malla**
Merluza y fauna acompañante	fondo y media agua	110 mm.
Jurel y Caballa	media agua	76 mm. (3 pulgadas)
Langostinos	langostinera	38 mm. (1 ½ pulgada)

This example shows that the regulation and mesh sizes used at present have not been optimized for the CJM fisheries of the 21st Century, and that a general and common regulation should be recommended by the SPRFMO for the different fisheries. This obviously requires that a bibliographical analysis be completed and experiments be achieved. In a second step, the effectiveness of applying regulation for this particular fishery should be considered (fig 2).

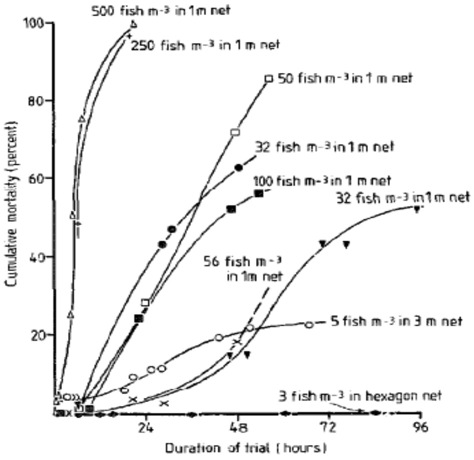


Fig. 4. Cumulative percentage mortality observed during crowding

Figure 2. Cumulative percentage mortality observed during crowding (from Lockwood et al., 1988)

Whatever the efficiency of defining a particular dimension for the CJM optimal mesh size, it is clear that it should be common to all the fisheries.

CHAPTER 4-c

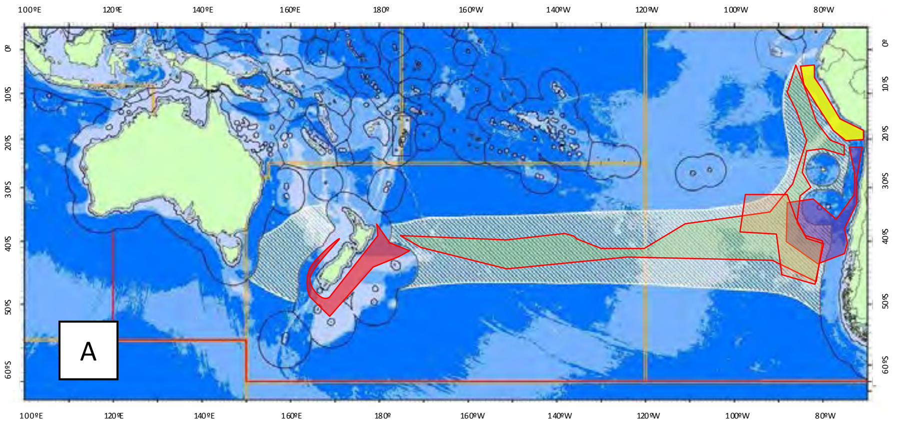
CJM population monitoring

Introduction

Due to its extreme dispersion all over the South Pacific Ocean, the Chilean Jack Mackerel is difficult to survey exhaustively, for two reasons:

1. Apart a series of located acoustic surveys, the only data available so far covering the whole fishery are the fishing statistics, including some biological measurements performed on board. Although the explored area is quite wide and covers probably the bulk of the biomass (figure 1A), catch data alone are not sufficient for studying a fish which recruitment depends more on the climatic conditions that on the actual dimension of the spawning population.

2. It is practically impossible to perform scientific surveys in the whole distribution area, which is far too extended: even though the financial cost of a complete survey would be granted (which is quite unlikely), the delay to survey the complete "Jack Mackerel Belt" would impose too long a time to spend from the beginning of the survey to the end, and the results would not have the same meaning. Nevertheless acoustic surveys are performed in specific areas by the main countries that exploit the CJM (figure 1B).



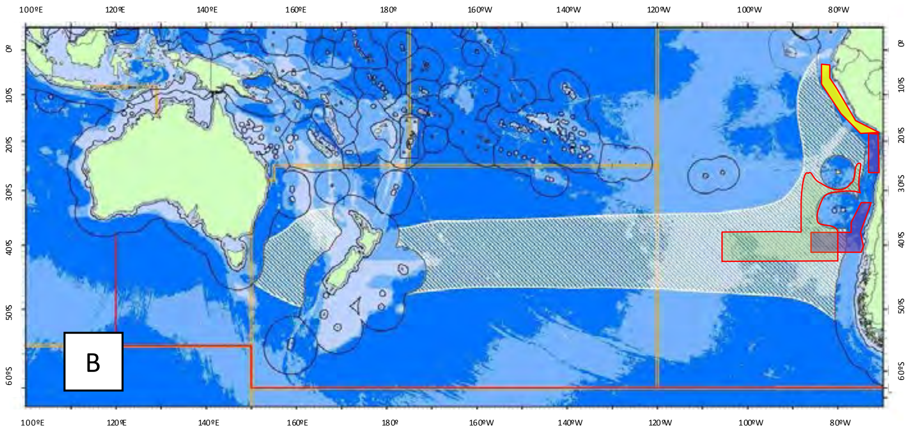


Figure 1. A (above): maximum fishing area of the main fisheries. B (below): Maximum area of acoustic surveys, including Eureka and Rastrillo surveys (for both figures, Peru: yellow; Chile: Purple; USSR/Russia: green; EU: orange; New Zealand: red). In white the Jack mackerel belt.

In conclusion to this observation, the SPRFMO recommended monitoring of the population to be performed: *"The need for monitoring of the whole jack mackerel distribution is required to best understand and manage regardless of alternative stock structure hypotheses. The group* ***recommended*** *that measures to support monitoring be given high priority".* (SWG-JM-Report, SPRFMO, Lima, 15-19 October, 2012).

Monitoring can be performed by a series of methods, but the more efficient ones are acoustic monitoring and monitoring of the fishing activities with observers aboard. There are mostly two methods for performing acoustic monitoring: with scientific acoustic surveys and using acoustic data from fishing vessels.

1. **Scientific acoustic surveys**. Three countries have performed acoustic surveys on CJM: Chile, Peru and Russia. The three of them use similar equipments (scientific echo sounder SIMRAD EK500 then EK600) and protocol, which make the comparison between the results possible once known the respective values of target strength applied by the different laboratories (Simmonds and MacLennan, 2005).

    a. **Chile** has performed acoustic surveys especially dedicated to *Trachurus murphyi* aboard the R/V Abate Molina and other vessels since 1981, with interruptions from 1996 to 2005 in the North (table 1). The surveys are performed and processed by IFOP principally, although some specific acoustic observations have been collected by INPESCA too. IFOP surveys are covering two areas: the North and the Centre-South of the country, mostly inside the EEZ, where the fishery is working. The sampling strategy is based on the behaviour of the CJM and only day data are taken into consideration for mapping the biomass, although acoustic data are collected day and night. The survey design in the south (figure 2) changed in 2003 because of the shift of the concentration areas of the CJM towards the offshore region, both in survey area and inter-transects distances (25 NM until 2002, 50 NM afterwards). In the north Chile (18º20´S - 30º00´S) the sampling strategy was slightly different, being first random during the first years of survey (1981-1982), systematic after 1982. The inter-transect distance, firstly adjusted at 15 NM was later 25 NM, from the coast to 200 NM offshore (figure 3).

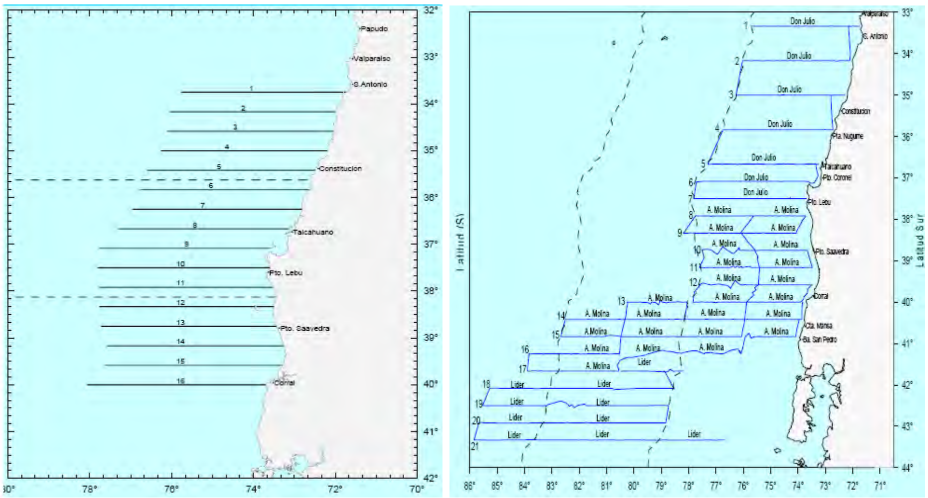


Figure 2. Maps of acoustic surveys in the centre-south Chile, during the periods 1997-2002 (left) and 2003-2007 (right). From Cordova et al., 2008[1]

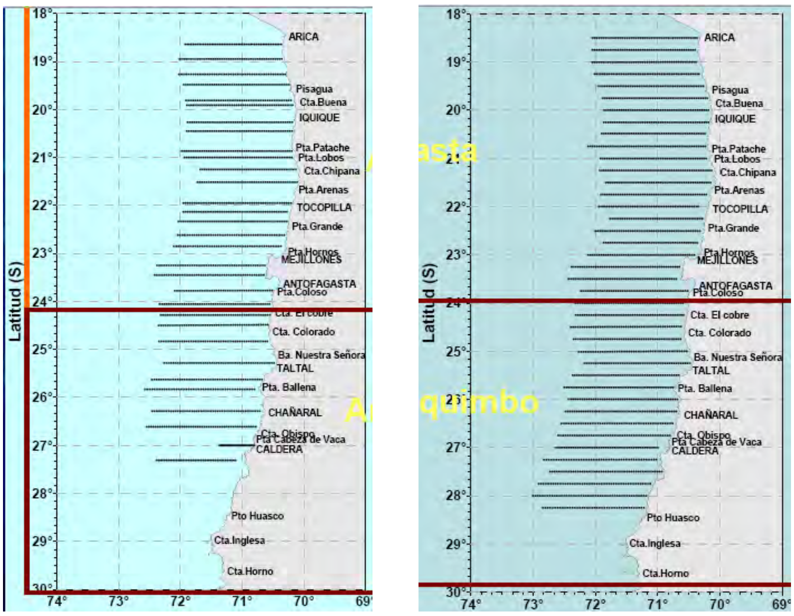


Figure 3. Survey design in Northern Chile in 1981-1982 (left) and 1983-1984 (right). After 1984 the transects are separated by 25 nautical miles instead of 15 ai in this figure. From Castillo and Cordova, 2008[2]

A complete list of the surveys performed on the CJM from 1981to 2006 is given in the table 1 (from Anonymous, 2007[3]). The table details the latitude range of the surveys, the date, number of days at sea, E-W extension of transects from the coastline, number of vessels involved in the surveys.

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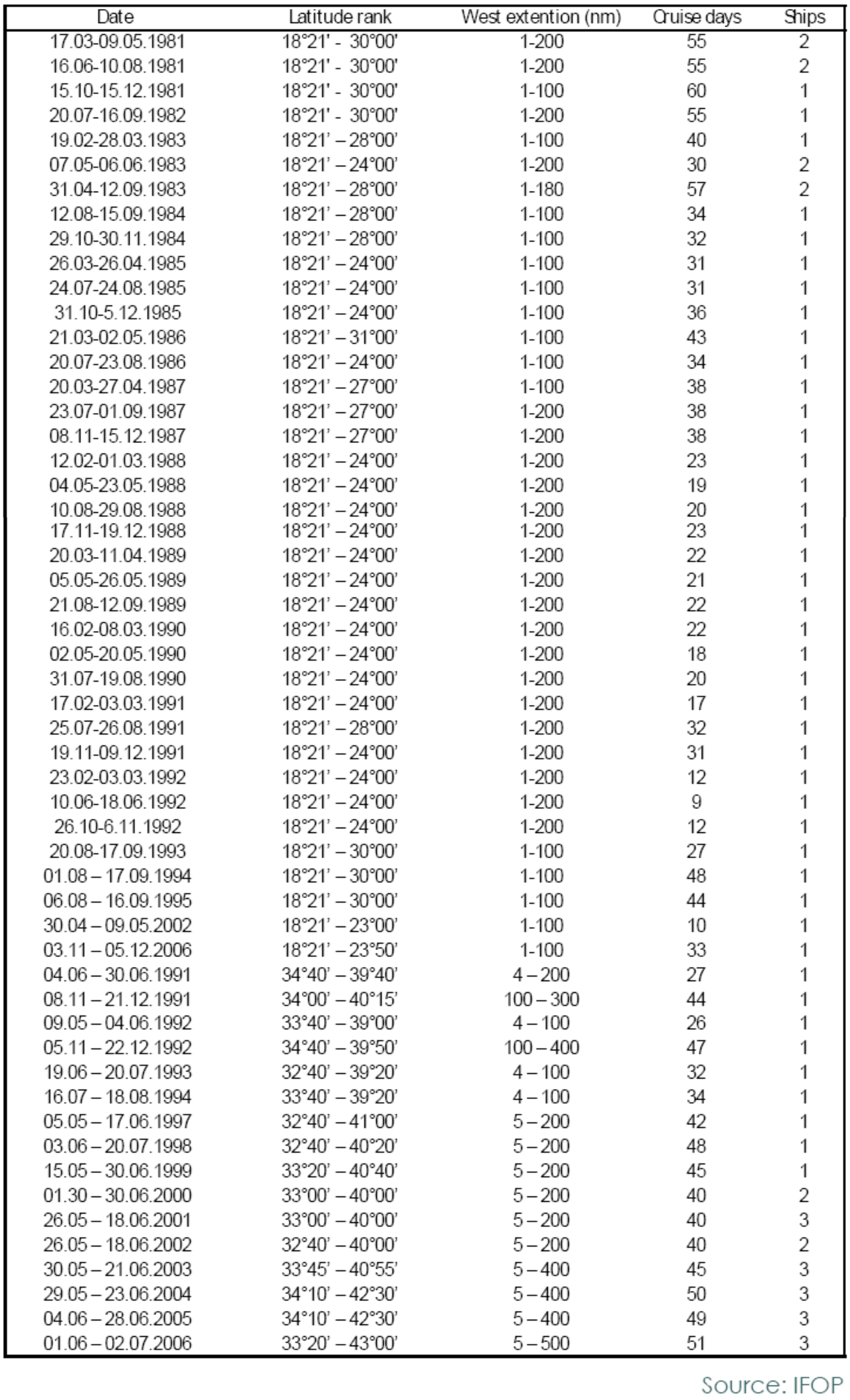
[1] Córdova, J., Bahamonde, R. and Catasti, V., 2008. Evaluaciones hidroacústicas de jurel en la zona centro-sur (33°–42° S) de Chile (1997-2007). IFOP, contribution to the Chilean Jack Mackerel Workshop, SPRFMO, 2008.

[2] Castillo, J. and Córdova, J., 2008. Jack Mackerel (*Trachurus murphyi*) spatial distribution and seasonal acoustic biomass estimated in the north of Chile. 1981 - 1995; 2006-2007. IFOP, contribution to the Chilean Jack Mackerel Workshop, SPRFMO, 2008.

[3] Anonymous, 2007. Research and Management of Chilean jack Nackerel (*Trachurus murphyi*) in the Soouth East Pacific Ocean. Government of Chile, Undersecretariat for fisheries, April, 2007:61 pages

Table 1. Acoustic surveys of Chilean jack mackerel in Chilean EEZ, from 1981 to 2006 (from Anonymous, 2007)



Date	Latitude rank	West extention (nm)	Cruise days	Ships
17.03-09.05.1981	18°21' - 30°00'	1-200	55	2
16.06-10.08.1981	18°21' - 30°00'	1-200	55	2
15.10-15.12.1981	18°21' - 30°00'	1-100	60	1
20.07-16.09.1982	18°21' - 30°00'	1-200	55	1
19.02-28.03.1983	18°21' – 28°00'	1-100	40	1
07.05-06.06.1983	18°21' – 24°00'	1-200	30	2
31.04-12.09.1983	18°21' – 28°00'	1-180	57	2
12.08-15.09.1984	18°21' – 28°00'	1-100	34	1
29.10-30.11.1984	18°21' – 28°00'	1-100	32	1
26.03-26.04.1985	18°21' – 24°00'	1-100	31	1
24.07-24.08.1985	18°21' – 24°00'	1-100	31	1
31.10-5.12.1985	18°21' – 24°00'	1-100	36	1
21.03-02.05.1986	18°21' – 31°00'	1-100	43	1
20.07-23.08.1986	18°21' – 24°00'	1-100	34	1
20.03-27.04.1987	18°21' – 27°00'	1-100	38	1
23.07-01.09.1987	18°21' – 27°00'	1-200	38	1
08.11-15.12.1987	18°21' – 27°00'	1-200	38	1
12.02-01.03.1988	18°21' – 24°00'	1-200	23	1
04.05-23.05.1988	18°21' – 24°00'	1-200	19	1
10.08-29.08.1988	18°21' – 24°00'	1-200	20	1
17.11-19.12.1988	18°21' – 24°00'	1-200	23	1
20.03-11.04.1989	18°21' – 24°00'	1-200	22	1
05.05-26.05.1989	18°21' – 24°00'	1-200	21	1
21.08-12.09.1989	18°21' – 24°00'	1-200	22	1
16.02-08.03.1990	18°21' – 24°00'	1-200	22	1
02.05-20.05.1990	18°21' – 24°00'	1-200	18	1
31.07-19.08.1990	18°21' – 24°00'	1-200	20	1
17.02-03.03.1991	18°21' – 24°00'	1-200	17	1
25.07-26.08.1991	18°21' – 28°00'	1-200	32	1
19.11-09.12.1991	18°21' – 24°00'	1-200	31	1
23.02-03.03.1992	18°21' – 24°00'	1-200	12	1
10.06-18.06.1992	18°21' – 24°00'	1-200	9	1
26.10-6.11.1992	18°21' – 24°00'	1-200	12	1
20.08-17.09.1993	18°21' – 30°00'	1-100	27	1
01.08 – 17.09.1994	18°21' – 30°00'	1-100	48	1
06.08 – 16.09.1995	18°21' – 30°00'	1-100	44	1
30.04 – 09.05.2002	18°21' – 23°00'	1-100	10	1
03.11 – 05.12.2006	18°21' – 23°50'	1-100	33	1
04.06 – 30.06.1991	34°40' – 39°40'	4 – 200	27	1
08.11 – 21.12.1991	34°00' – 40°15'	100 – 300	44	1
09.05 – 04.06.1992	33°40' – 39°00'	4 – 100	26	1
05.11 – 22.12.1992	34°40' – 39°50'	100 – 400	47	1
19.06 – 20.07.1993	32°40' – 39°20'	4 – 100	32	1
16.07 – 18.08.1994	33°40' – 39°20'	4 – 100	34	1
05.05 – 17.06.1997	32°40' – 41°00'	5 – 200	42	1
03.06 – 20.07.1998	32°40' – 40°20'	5 – 200	48	1
15.05 – 30.06.1999	33°20' – 40°40'	5 – 200	45	1
01.30 – 30.06.2000	33°00' – 40°00'	5 – 200	40	2
26.05 – 18.06.2001	33°00' – 40°00'	5 – 200	40	3
26.05 – 18.06.2002	32°40' – 40°00'	5 – 200	40	2
30.05 – 21.06.2003	33°45' – 40°55'	5 – 400	45	3
29.05 – 23.06.2004	34°10' – 42°30'	5 – 400	50	3
04.06 – 28.06.2005	34°10' – 42°30'	5 – 400	49	3
01.06 – 02.07.2006	33°20' – 43°00'	5 – 500	51	3

Source: IFOP

The figure 4 shows some results of density distribution of the surveys in the centre-south region from 1997 to 2007 as an example.

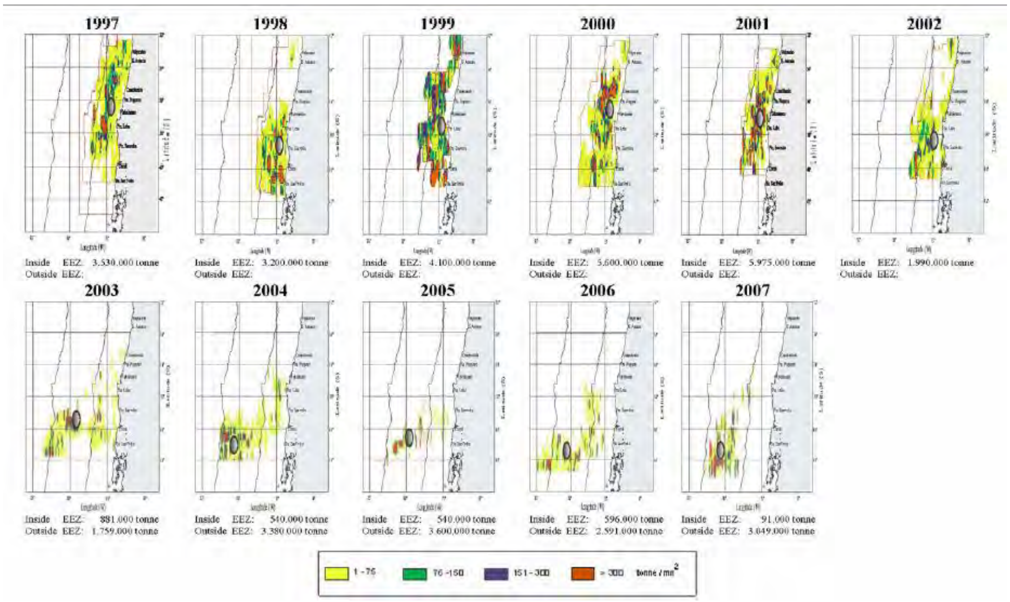


Figure 4. Spatial distribution of the densities of jack mackerel in the region Centre-South of Chile, 1997-2007 (from Cordova et al., 2008)

b. **Peru** began to use acoustic surveys since the 60s (Villanueva, 1971; Valdivia, 1978) and specially focused on anchovies, with the participation of the fishery (Operations EUREKA). In the 70s IMARPE developed an important program of acoustic biomass estimates in co-operation with the FAO the NORAD (1975-1981) with the objective to evaluate the biomass of all the principal species, including jack mackerel (Johannesson & Robles, 1977; Burczynski, 1982; Johannesson & Vilchez, 1981a, 1981b; Venema, 1992). In 1991 the IMARPE team was fully trained and developed several researches in its own (see the numerous nº of the IMARPE Bulletin in this period). Later the Institute developed routine measurements of target strength and calibration (MacLennan, 1998; Gutiérrez & MacLennan, 1998). Estas mediciones se ampliaron a otras especies (*e.g.* Castillo *et al.*, 2009). Since 1997 the Institute operates several echo sounders type EK500 then EK60 aboard its research vessels (R/Vs Humboldt, Olaya, SNPII). In 2003 besides the abundance estimates, the Institute undertook scientific surveys tu study the spatial dynamics and behaviour of the pelagic stocks in coóperation with IRD (Castillo et al 2010). In the particular case of Peru, the acoustic surveys specifically devoted to CJM are very few: the acoustic surveys performed by IMARPE with one or several vessels (R/V Humboldt, Jose Olaya and SNP2) are general surveys, although the targeted species is the anchovy *Engraulis ringens*. If all the species are taken into consideration in the data, the sampling strategy is optimized for the anchovy, which means that not all the habitat of CJM is necessarily covered during a given survey. The survey design has not changed since 1983: transects are oriented perpendicularly to the coastline, spaced each 15 NM, EDSUs are 1 NM long, and the survey is continuous, performed day and night (figure 4).

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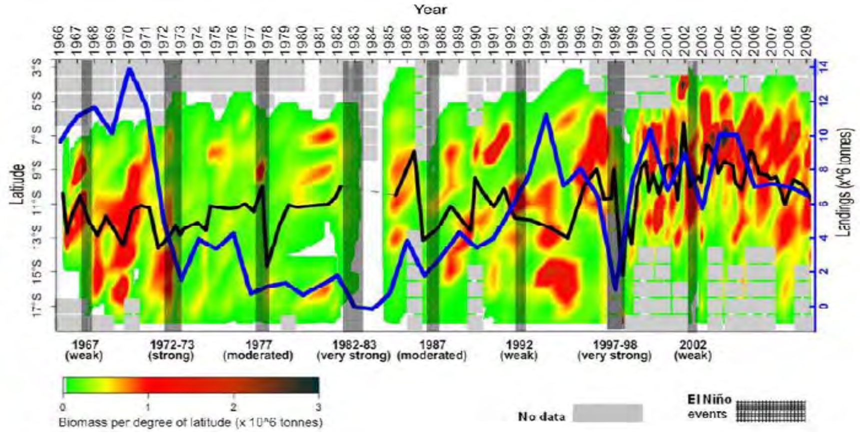

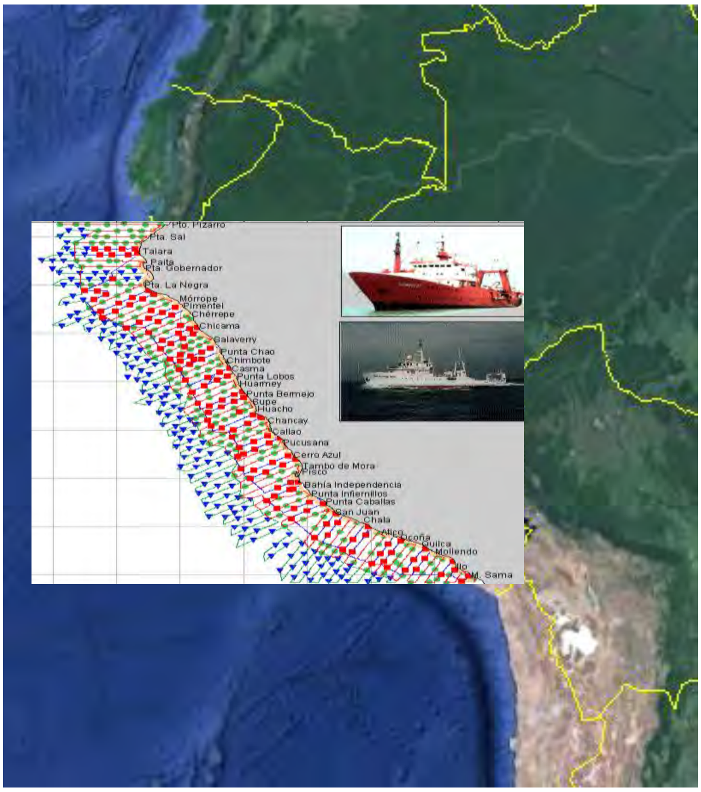

Figure 4. Example of a standard survey in Peru. Transects are separated by 15 NM; fishing samples are collected either regularly (to get biological samples in every region) or each time particularly interesting detections are observed; CTD and plankton stations are performed at predefined points. In this example, the survey was performed simultaneously by two vessels: R/ V Olaya (transects in red) for the inshore area and R/V Humboldt (transects in blue)for the offshore area. Fishing samples are performed by these two vessels plus fishing boats hired for the duration of the survey to sample the coastal area out of range of the two R/V.

c. **Russia** did not perform regular annual acoustic surveys, but sent the R/V Atlantida during the period September, 2002 to January, 2003. During this period the research vessel performed a series of acoustic surveys all over the densest areas of distribution of the CJM (fig. 5 and 6). The R/V Atlantida used an echo sounder SIMRAD EK500 and the same protocol as Chile and Peru (Simmonds and MacLennan, 2005). Another survey was performed by the same vessel in 2009.

It is worth noting that some acoustic surveys were performed before 1991, but in this case they did not give results in biomass estimates or density maps: rather, the work was focused on fish behaviour (e.g. Goncharov et al., 1989).

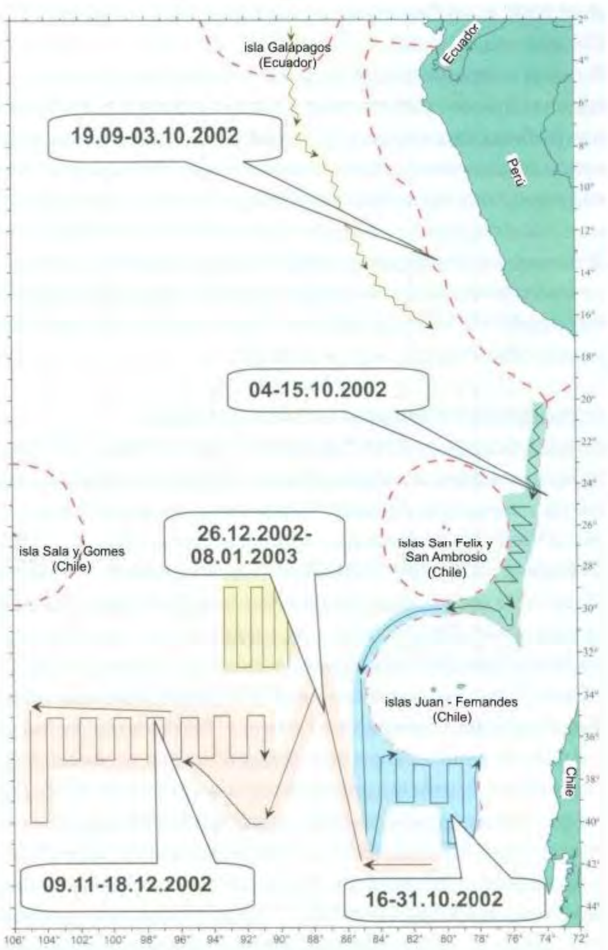

Figure 5. Area and periods of a general survey of the South East Pacific Ocean by R/V Atlantida in September 2002 – january 2003 (from Chukhebov et al., 2004[4])

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[4] Chukhebov, G.E., Kashirin, K.V., Chemishkov, P.P., 2004. ¿Llenará Rusia el vacio? Expediciónb científica de prospección del BIC "Atlantida" a la parte sur-oriental del Oceano pacífico (OPSOr) (traduction in spanish of an article published in the review "Rybnoye khoziaistvo", 2004, nº 2.

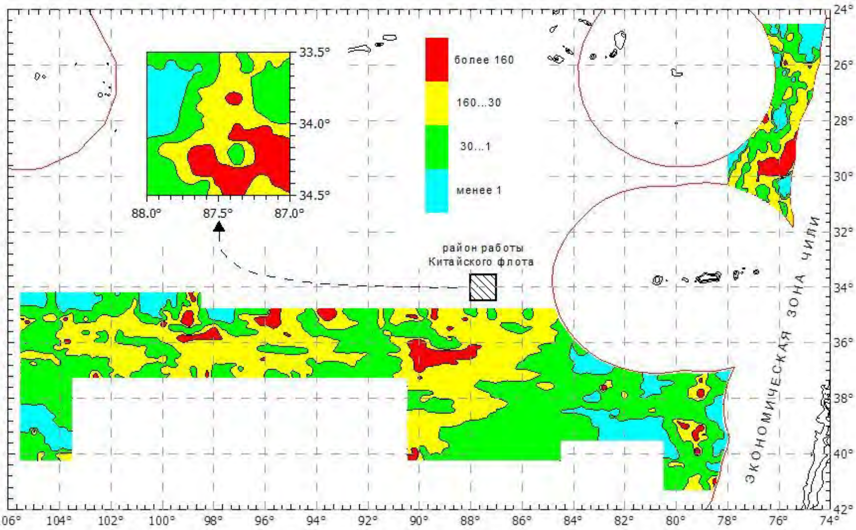

Figure 6. Mapping of the distribution of CJM abundance during the survey of R/V Atlantida

d. **Advantages and limitations of acoustic surveys.** Acoustic surveys performed by research vessels have been done since the invention of the echo-integrator in the late 60s (e.g. Forbes and Nakken, 1972). Since this date a considerable amount of work has been done in order to make the surveys reliable and to provide reliable absolute abundance estimates, including error and bias measurements (see Simmonds and MacLennan, 2005). A scientific survey, if correctly performed, provides a large series of informations: maps of abundance in the prospected area, biomass estimate in this area for each species present, behavioural information on population structure, daily movements, trophic interactions, aggregative behaviour, schooling behaviour, diurnal distribution, migration patterns, etc. (fig. 7).

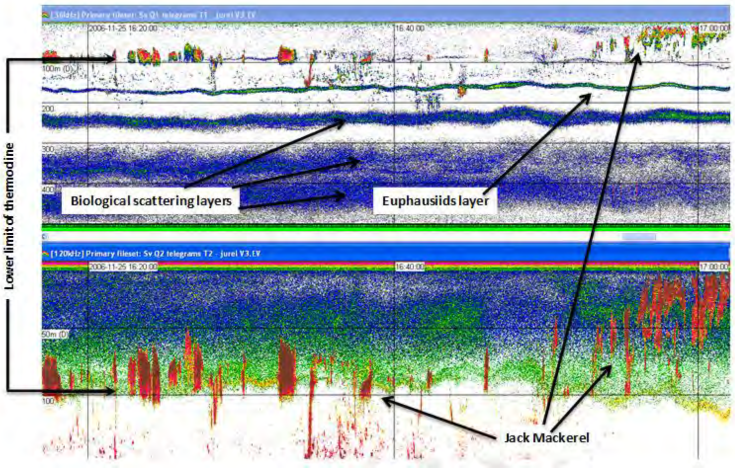

Figure 7. Example of synchronous echograms at 38 kHz (above) and 120 kHz (below) on a CJM concentration. The different parts of the total biomass of the ecosystem can be identified and measured (from Gutierrez et al., 2008)[5].

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[5] Gutiérrez, M., A. Bertrand, M. Ballón, P. Espinoza, A. Alegre and F. Gerlotto, 2008. Distribution changes and interactions of Jack Mackerel off Peru as observed using acoustics (1983-2008). IMARPE, Documento Técnico CDP-12V4-JUNIO2008.

It is admitted that an acoustic survey is the best monitoring method in order to follow the way a population evolves in time and space. The major limitations of acoustic surveys are (1) a limited observation of the population through a “window” represented by the survey area. This is not a major problem when the survey area covers more than the distribution area of the population (e.g. case of anchovies in Peru), but becomes important in cases such as the CJM where the distribution area is much wider than the survey area. In this case the only solution in order to provide biomass estimates is through extrapolation methods using the concept of “potential habitat” (e.g. Zwolinski et al., 2010[6]; Bertrand et al., 2010). (2) The rather slow sampling speed. A research vessels sails at around 10 knots, which means that an area such as the Peruvian shelf is covered in 45 days in a standard survey. This duration is probably the maximum acceptable if one needs to consider that the survey was synoptic: longer durations make the fish and the ecosystem seasonally different between the beginning and the end of the survey: it would be useless to perform an exhaustive survey on the CJM belt, considering that the delay to cover is would be far too long. (3) The cost of a survey is high, because research vessels are involved, with expansive equipments etc. Therefore it may happen that surveys are not scheduled for lacking of funding.

A proposal was submitted to SPRFMO in 2009 to consider the organization of a meeting gathering the main laboratories of the different countries, with the following objectives:

- *To promote the cooperation between scientific institutions and private fishing companies of the SPRFMO area.*
- *To propose to SPRFMO an environmental (multidisciplinary) approach based on acoustic methods for monitoring and study on high seas resources (not only Jack Mackerel).*
- *To define some indicators on ecosystem functioning in different time and spatial scales and trophic levels that might be extracted from echograms.*

Indeed as long as the basic settings and equations are not shared between the laboratories, no real comparison between the results can be done. This has been done in part, and for instance the relative indexes of density (“Target Strength” and aggregation typology have been standardized for Chile and Peru (figures 8 and 9).

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[6] Zwolinski, J.P., Emmet, R.L., Demer, D.A., 2010. Predicting habitat to optimize sampling of Pacific sardine (*Sardinops sagax*).ICES Journal of Marine Science, 2010.

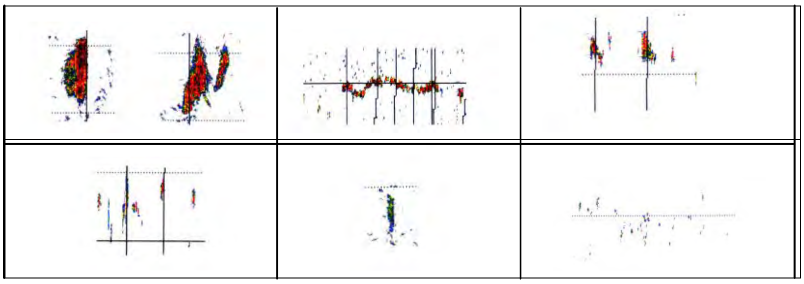

Figure 8. Typology of aggregations for the Chilean Jack Mackerel, defined from acoustic surveys in the centre South of Chile. From up to down and left to right, dense schools, dense layer, medium layer, small layer, individual school, scattered fish. The two first structures (dense schools and dense layers) are those targeted by the fishery (Barbieri et al., xxx)

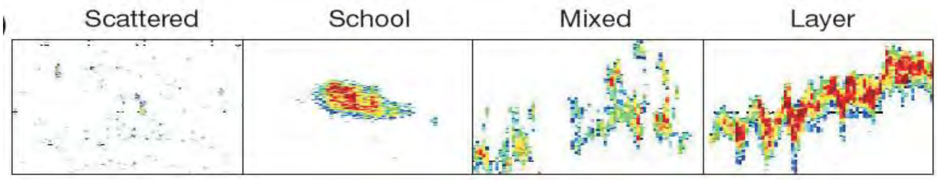

Figure 9. Simplified typology of aggregations for the Chilean jack mackerel defined from the Chilean and Peruvian typologies and applicable to the whole CJM belt (Bertrand et al., 2006). “School” and “layer” are the equivalent to dense school and dense layer in the Chilean tyhpology, and are the target of the fishery.

2. Monitoring survey with fishing vessels.

They have been performed on the CJM in two different ways: either by hiring fishing vessels for scientific purposes; this has been done in Chile (surveys Rastrillo) and in Peru (surveys Eureka); or by collecting their acoustic data during their normal fishing activities.

a. **Eureka and Rastrillo surveys**. In both cases the survey design is prepared by the scientist, and the role of the fishing vessel is similar to that of a research vessel. Nevertheless the sampling strategies are different. Rastrillos define a series of parallel transects, each vessel covering two of them, one westward and one eastward. The result gives a rather conventional acoustic survey, the only difference being that the survey is much wider than usual (up to 20º in longitude) and performed in a short period. Results are also important for biological and ecological sampling, e.g. eggs and larvae, trophic ecology, oceanography, etc. They are particularly important for studies on the spawning of CJM and results in this field are detailed in chapter 2 (figure 10).

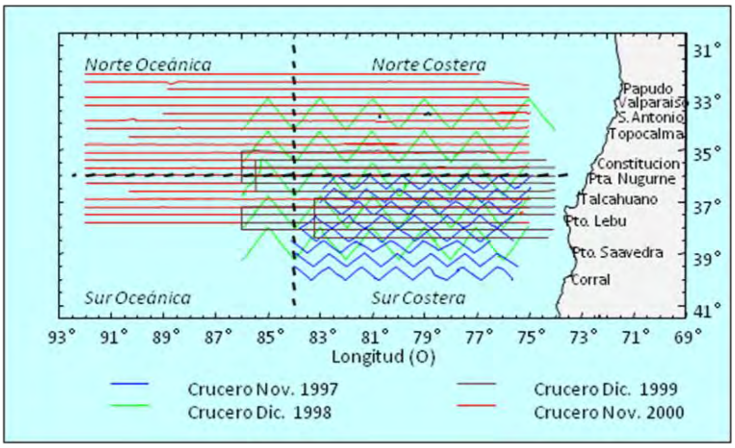

Figure 10. Example of 4 Rastrillo surveys in Chile, from 1997 to 2000. The transect design was zig-zag in 1997 and 1998, conventional parallel surveys after 1998.

The vessels are hired and paid through quotas. Eurekas are performed with several vessels too, but the objective is less to make an ecological observation similar to research surveys than to obtain a map of distribution of a given species, especially anchovies and jack mackerels. Eurekas are organized by the fishing companies under supervision of IMARPE, and they take in charge the choice of the vessels and the sampling design (figure 11). In Rastrillo and Eureka surveys, scientific observers are embarked on all the fishing ships.

Local EUREKA in the fishing grounds using 10 ships from 2 companies (TASA: 8; AUSTRAL: 2)
The sea surface temperature (SST) is indicated

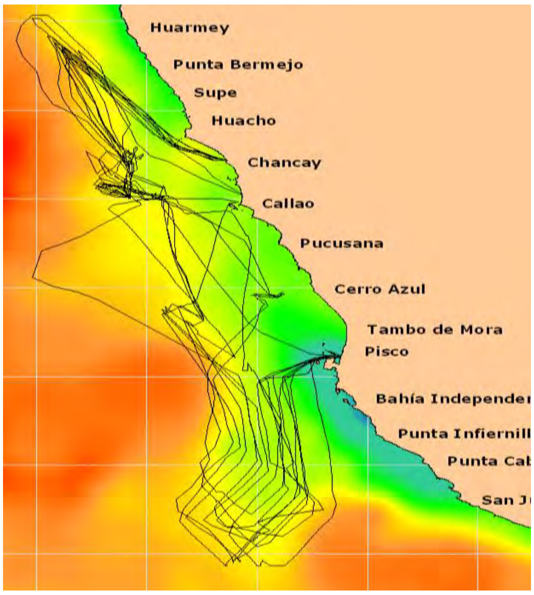

Figure 11. Example of an Eureka survey in Peru (2010), organized by 2 fishing companies (TASA: 8 ships; Austral: 2 ships). Transects are superimposed on the SST map of the region at the period of the Eureka.

b. **Acoustic data from fishing vessels in operation.** In this case there is no major intervention of the scientists aboard during the fishing activity. The acoustic data are collected after the survey and processed in the laboratory, joined with the GPS positioning system. A proposal was submitted to SPRFMO in 2008 by Peru for the use of acoustic data from fishers. The conclusion of SPRFMO at this data was positive:

> *Acoustic indices*
>
> *There was a presentation on the potential use of industry vessels to gather additional acoustic data to that provided by standard scientific surveys (SP-07-JM-SA-08). These data could provide information at times between surveys and in more detail for the times and locations when fishing was occurring. It could also provide information not only on jack mackerel but also on their predators and prey, other species and environmental conditions.*
>
> *There was general support for this proposed use of industry vessels in this way and it was suggested that a more specific proposal be developed for submission to the Science Working Group (SWG) for its consideration.*
>
> *There was also acknowledgement that this proposal, while useful in the future, would not assist with the immediate task of providing advice on the status of jack mackerel this year.* (from Document SP-07-SWG-INF-06, Lima, 2009)

According to this recommendation, contacts were taken with the ICES working group “Fisheries Acoustics Science and Technology” (WGFAST) which presented in 2010 a “*Guideline for Acoustic Data Collection aboard Fishing Vessels operating in the SPRFMO area*” (Karp et al., 2009[7]).

Based upon this guideline, Peru undertook a series of monitoring operation and 4 workshops have been organized to scrutinize the results of acoustic data collected aboard fishing vessels in the Peruvian EEZ (reports of workshops in March, 2011; June, 2011; march, 2012; May, 2013). The conclusions of these workshops were that:

- Acoustic data from selected fishing vessels present the same quality as acoustic data from scientific vessels;
- The number of samples is orders of magnitude higher than those from scientific surveys (figure 12)

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[7] William Karp (NOAA, USA), Rudy Kloser (CSIRO, Australia), Francois Gerlotto (IRD, France), Héctor Peña (IMR, Norway), Mariano Gutiérrez (TASA, Peru), 2009. Guidelines for Acoustic Data Collection aboard Fishing Vessels operating in the SPRFMO area. DRAFT, October 2009

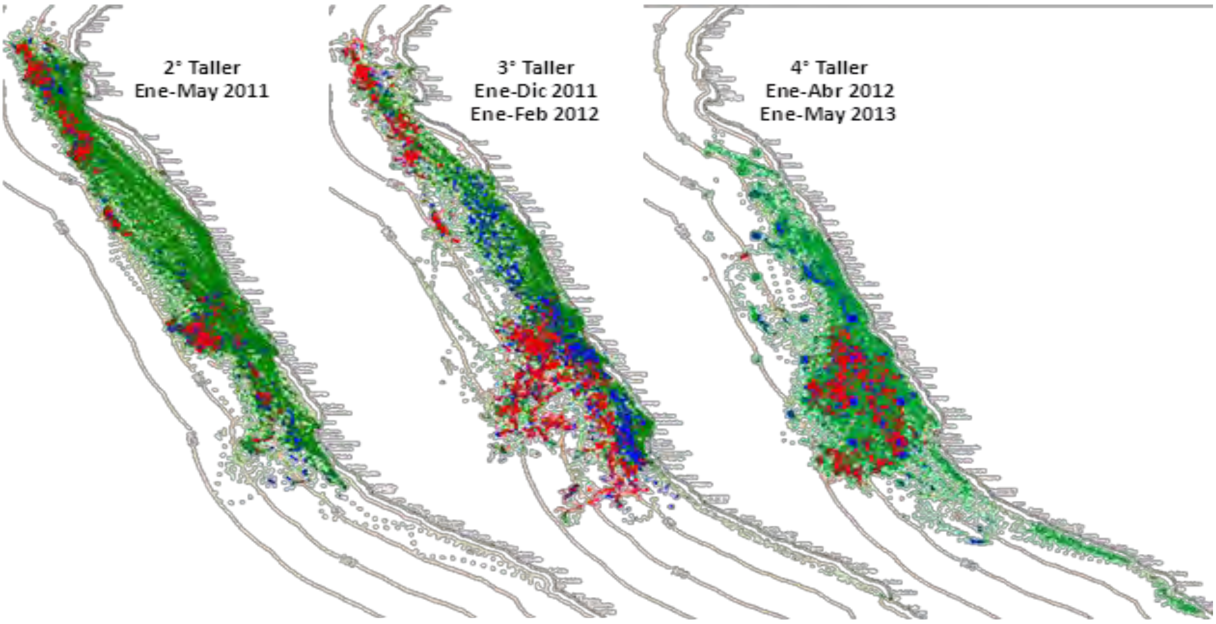

Figure 12. Distribution of fishing operations of the industrial fleet, during years 2011, 2012 and 2013[8]. Red dots display the set actually performed and reported; blue dots correspond to species different than Jack Mackeres and are not used in this report. Green dots display the hourly position of all the vessels as recorded through VMS

- The cost of such activity is low, because many fishing vessels already get scientific (or quasi-scientific) echo sounders: the material costs consist in the purchase of external hard disks to be plugged to the echo sounders and the technical time to process the data is approximately one hour of a technician for one day of survey.
- The fisher sampling strategy has been studied and their exploration route can be modeled as a “Lévy flight” (Bertrand et al., 2005[9]) and is potentially rich in new informations on the fishery (figure 13)

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[8] Sociedad Nacional de Pesquería, Comité de Armadores, Sub-Comité para Asuntos técnicos y científicos, 2011. Taller sobre Diagnóstico de la Situación actual del Recurso Jurel. Facultad de Oceanografía, Pesquería y Ciencias Alimentarias, Universidad Federico Villareal, 2011, 2012, 2013

[9] Bertrand, S., Burgos, J.M., Gerlotto, F., Atiquipa, J., 2005. Lévyt trajectories of Peruvian purse seiners as an indicator of the spatial distribution of anchovies (*Engraulis ringens*). ICES Journal of Marine Science, 62:477-482

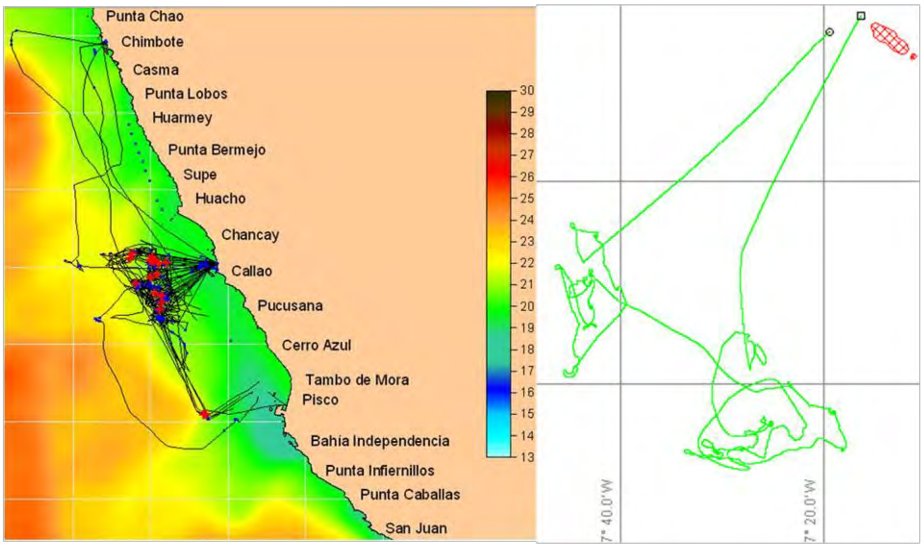


Figure 13. (Left) Route of a series of fishing vessels leaving Callao to the fishing ground. Routes are superimposed on the SST map corresponding to the period of observation. (Right) Details of the route of a single ship. From Gutierrez, xxx

In conclusion, acoustic monitoring provides data on the spatial distribution of fish inside the exploration area, on demographic structure of the population, is easily feasible and provides valuable information. It has the great advantages to sample all the fishing area during all the fishing season, which gives valuable data at almost no cost in areas out of range to scientific acoustic surveys.

c. **Other information obtained through monitoring with fishing vessels.** The fishing vessels are also usable as opportunity platforms, especially when they are hired. These results come from two sources: embarked automatic instruments (e.g. SST, and other sensors) and observers aboard (biological samples from the catch, ecological observations during the trip, etc.). Another important source of information comes from the acoustic data, and particularly the information allowing the description of the MOZ using vertical echo sounders (Bertrand et al., 2010).

The workshops organized by the National Fisheries Society of Peru give good ideas of all that can be obtained through monitoring of the CJM using the fishing fleets: spatio-temporal distribution of the population in the exploration area, relationships between CPUE and abundance, relationships between local hydrology and fish concentration, trophic interactions, growth rate of the exploited cohorts, observation in real time of the recruitment, fish behaviour, fishery behaviour, etc.

Conclusion

The experiments performed in Peru and in Chile showed the richness of monitoring using data from the fishing fleets. The feasibility of such monitoring has been studied, as well as their cost, some protocols have been designed and tested, results have been obtained and analyzed. There is no doubt that this field of research and source of information will in the near future represent a major part of the scientific research on this species (as well as many others in the world), and the recommendation of SPRFMO must be adopted as soon as possible

It remains a series of researches to perform in order to make these monitoring optimal, e.g. develop methods for simple and cheap calibration of the instruments aboard the fishing vessels, development of adapted statistics for analyzing the trajectories of the ships, technical development of automated softwares and methods for data collection and analysis, etc.

Nevertheless as it is, the methodology is already able to provide much more information than expected, and above all informations that cannot be obtained by any other methods.

CHAPTER 5-a

Evolution in Distribution and Abundance

1. Introduction

The distribution, the abundance and their changes have been observed and studied principally from the information provided by the fishery, and in three different areas, from acoustic and eggs & larvae surveys performed by the Soviet Union (1977-1992) then the Federation of Russia since 2003 outside EEZs; by Chile in its EEZ; and by Peru in its EEZ. A few marginal surveys have been performed by other countries, e.g. New Zealand and EU, in the 2000s. A large part of this chapter comes from works published by the scientists of these countries.

Since 2006, the SPRFMO has also encouraged and developed an important scientific work on synthesizing the different results and on developing a population model that allow obtaining a general view of the changes in abundance and in catches during the complete history of the fishery.

2. The spatial distribution.

The general distribution and the maximum habitat have been described in several former chapters. We have observed in Chapter 1-A that the CJM have been observed all around the south Oceans, Pacific, Indian and Atlantic, in periods of widest distributions. More generally it is mostly located in the "Jack Mackerel Belt", which was first defined by Elizarov in 1992 (figure 1)

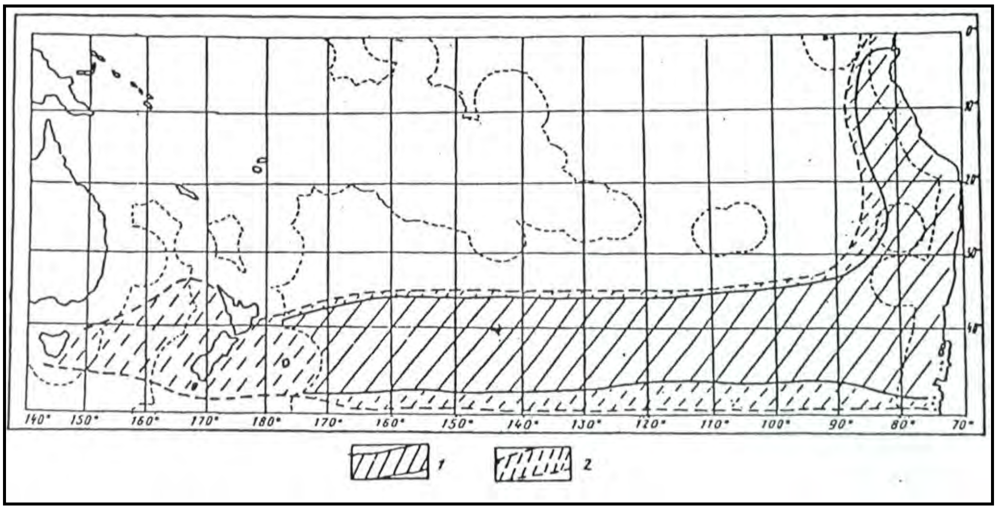


Figure 1. First schema of the Jack Mackerel Belt in the South Pacific. From Elizarov, 1992 (*in* Gretchina, 2009). The two different areas present the average (1) and extreme (2) areas of distribution according to the years.

Depending on the years the distribution can expand or shrink. Gretchina (2009) gives some examples of such changes in the distribution, through the analysis of the fisheries during the period 1992-2008, where a strong decrease of the overall catch was observed (figure 2).

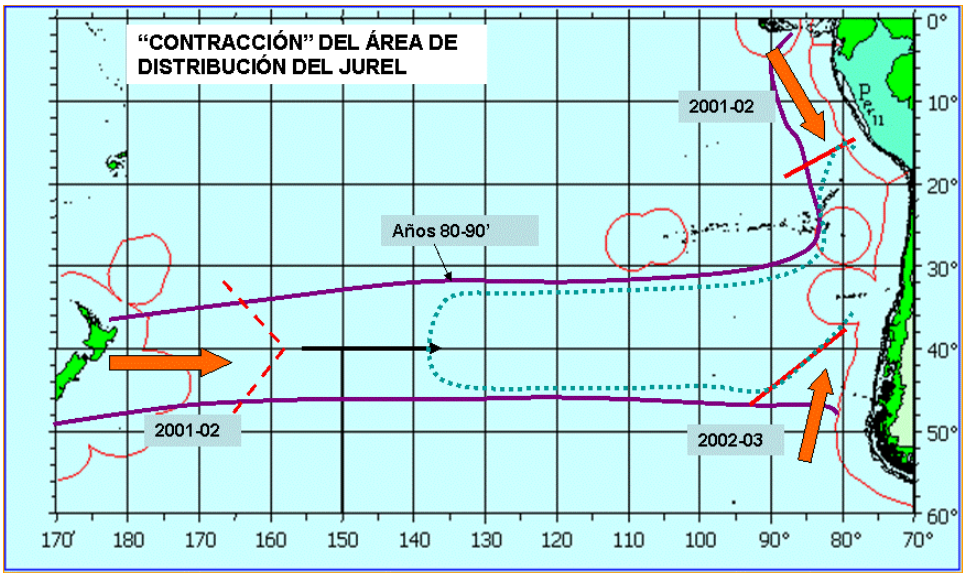


Figure 2. Description of the changes in spatial distribution of the CJM according to the catches. The widest distribution was observed in the 90s. Since the beginning of the 2000s, the distribution area shrank in all its peripheral borders: eastward in New Zealand; southward in Peru; northward and westward in Chile (westward changes are not marked in this figure, but the acoustic observations as well as fisheries showed a marked trend of the population to move outside the 100 miles along the coastline: Cordova et al., 2003; 2004; 2005). From Gretchina, 2009.

Another interesting description of the changes, from a small to a wide area of the distribution was given by Nesterov & Chur (2006) observing the evolution of the catches of the Soviet fleet from 1978 to 1992 (figure 3)

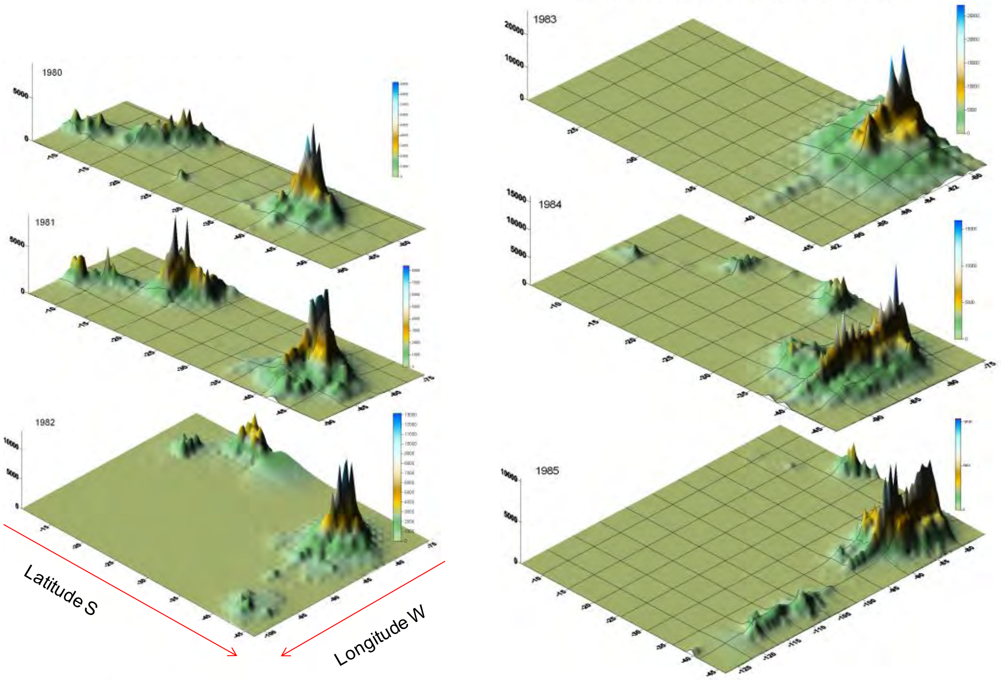


Figure 3a. CJM catch distribution in the South Pacific Ocean in tons by strata 1ºx1º and year for the period 1980-1985. From Nesterov and Chur, 2006.

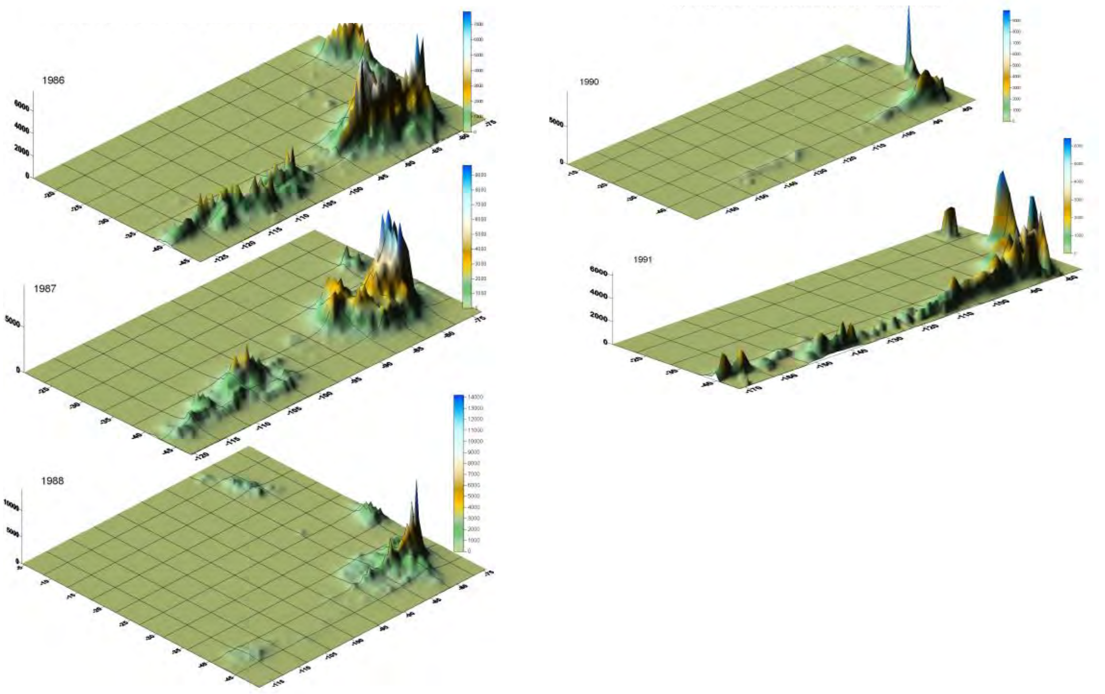


Figure 3b. CJM catch distribution in the South Pacific Ocean in tons by strata 1ºx1º and year for the period 1986-1991. From Nesterov and Chur, 2006.

Assimilate the fishing data to the actual distribution is always a risky hypothesis, but the strength of the signal is so strong that Nesterov and Chur (2006) are probably true in concluding the few following points:

- "*The data on jack mackerel abundance indices distribution in the South-Eastern Pacific Ocean allow to affirm the availability of two stock units of jack mackerel with the conventional boundary at 25°S. The mixed zone between two stocks includes locations to the north and to the south of 25°S. In the Northern subarea this species occurs seasonally at 200 miles off the shore.*

- *In the years with different temperature regimes, jack mackerel distribution in the Northern subarea was different. During intensive El-Nino events jack mackerel may be absent in the open areas (outside 200-mile zone). In the Southern subarea El-Nino events have no considerable effect on jack mackerel spatial distribution*".

These authors analyze also the distribution by year-class that will be considered later.

3. The spatial distribution by year class

From the fishery and in part the acoustic and egg-and-larvae surveys, a good description of the distribution of larvae, juveniles and adults has been obtained and described by various authors. For the larvae and juveniles, a complete analysis of the literature has been presented in chapter 2-C. We will present some of the synthetic results here.

The catch distribution by year class has been synthesized by Nesterov and Chur (2006). The authors detail the catches of the Soviet fleet from 1978 to 1991. They describe the evolution of year-class 1981-1982 during the 9 first years of its life (figure 4).

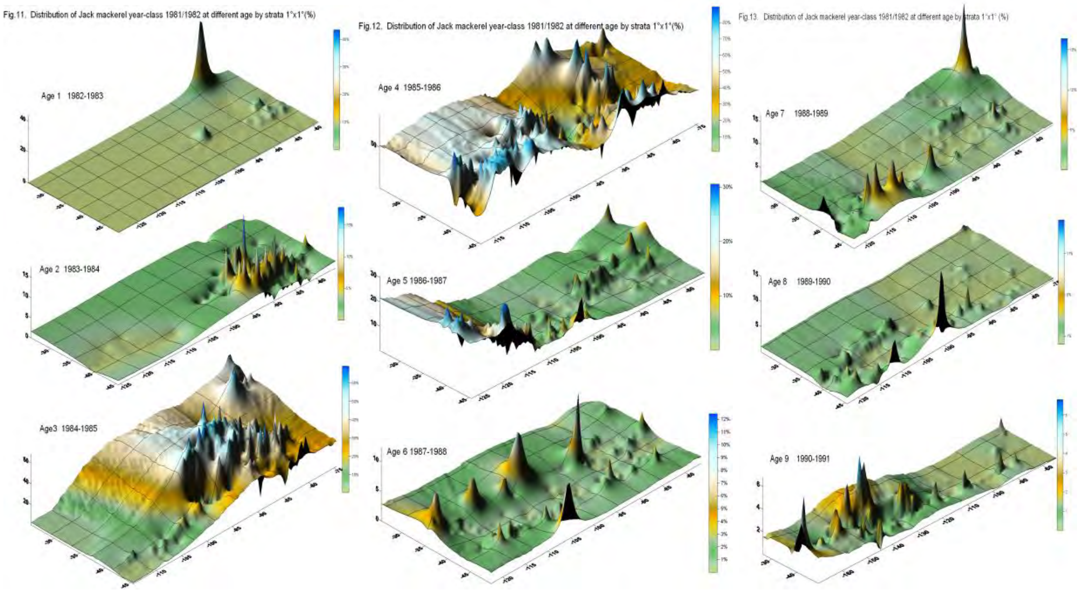


Figure 4. Distribution of catch for the year-class 1981-1982 from age 1 to age 9 in the south-east Pacific Ocean (from Nesterov and Chuz, 2006). Axes x (longitudes W) and y (latitudes S) in degrees, axis z (total catch per square 1ºx1º) in tons

This figure is particularly interesting as it concerns one of the most abundant generations that the fishery could observe continuously during 10 years. Most of the juveniles (age 1) are observed along the coastline at latitude 20ºS. Then at age 2 the class is mostly caught from the coastline of centre-south Chile to the open ocean until 95ºW, between 35º-45ºS. Age 3 covers both the NE zone (20ºS) and the centre-south region (75ºW to 95ºW and 35ºS to 45ºS). During the following years (ages 4 to 8) the distribution of the generation seems to scatter, covering a wide area, from the coastline of Chile up to 150ºW. Finally age 9 concentrates more westward, and the bulk of the abundance is centered on the rectangle 120ºW-150ºW and 40ºS-45ºS.

It is difficult to know whether this case is particular due to the huge biomass of this class or represents the typical case; also, the information close to the coast is not presented (the work refers to the Soviet fishery), therefore the relationships with the coastal concentrations in Peru and Chile are not described. Nevertheless it gives a general background for studying the movements of the fish.

4. The biomass

Due to the extremely wide area of distribution, acoustic surveys, which are the safest way to evaluate a biomass, cannot cover exhaustively the distribution area. Some areas have been covered by this method, mostly in Chile and Peru (figure 4), but if they can give correct estimates of local abundance, extrapolating to the whole area does not make any sense.

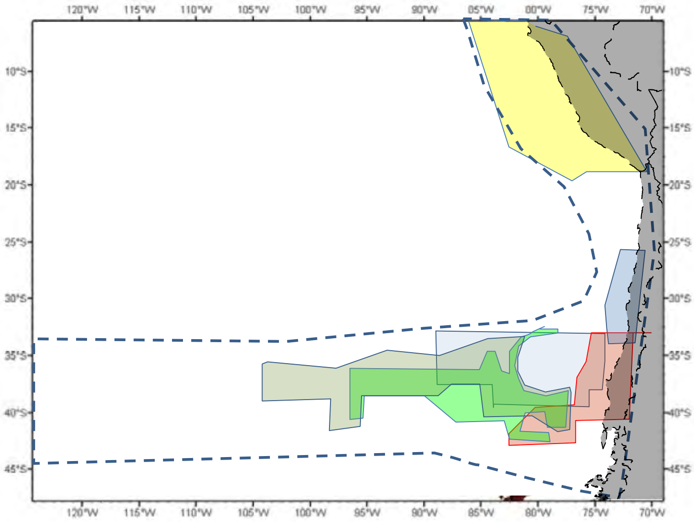


Figure 4. Areas of scientific surveys performed by research vessels from Peru, Chile (*), Russia and international fisheries (EU etc.). Dotted lines: the Jack Mackerel Belt (from national reports from the different countries to SPRFMO, 2006-2010. (*) The Chilean research was performed by the R/V Abate Molina for acoustic surveys in the north and centre-south of the Chile, and by hired fishing vessels for the offshore area during operations “Rastrillo” (see chapter 4.).

Due to this poor coverage, it has been preferred to evaluate the total abundance from VPA models using catch data (see SPRFMO web site www.southpacificrfmo.org for more details). The model is run annually during each scientific meeting of the SPRFMO. Results are presented in figure 5. They show that the overall biomass of CJM in the Southern Pacific Ocean reached up to 33 million tons during the second half of the 80s, after an increase from 12 million tons (1975) evaluated for the first years of the fishery, and followed by a dramatic drop during the 90s to around 3 million tons in the late 2000s (details on the model and its hypotheses can be found in *9th-SWG-Report-Final-Adopted-28Oct2010-corrected.pdf*).

We always may suspect the validity of such simulations, considering the extreme variability of the recruitment is in the CJM population which is not usually well taken into account in models. Nevertheless this exercise showed the magnitude of the overall biomass of the CJM. We found interesting to put on the same figure the value of the total catch (from SPRFMO calculations). It appears clearly that, even though the catch was considerable in the early 90s, i.e. just before the collapse of the population, it was not in condition to produce such a collapse, as catches did not overpass the 15% of the biomass, which is usually considered as a safe proportion. Therefore, if the outputs of the model represent the true situation, the natural variability of the population should be the first responsible of such dramatic drop-off.

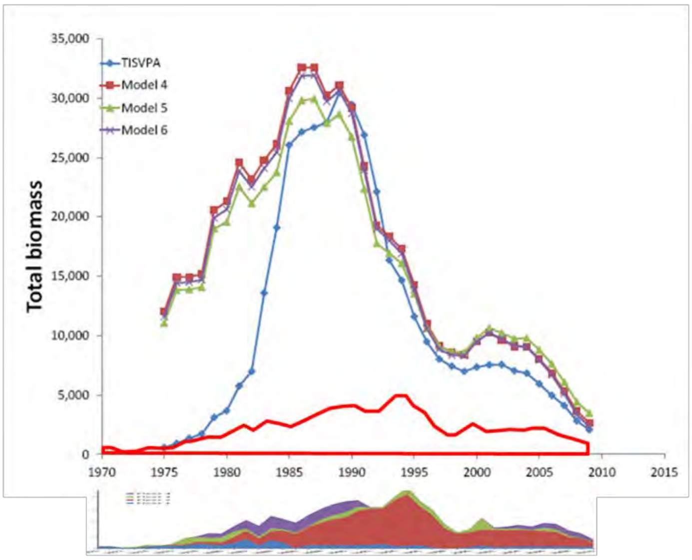


Figure 5. Above: results of simulation through VPA modeling of the overall biomass of the Chilean Jack Mackerel in the South Pacific Ocean (in thousand tons). The drawing represents the results of different hypotheses used for the modeling (see 9th-SWG-Report-Final-Adopted-28Oct2010-corrected.pdf for more details on the method). The continuous red line displays the total catch during the same period, detailed below: catches of the main fisheries during the same period, from SPRFMO (same scales).

Models of distribution variability

Gretchina (2009) gave a synthesis of the different cases for the distribution of the CJM along the coast of South America and the open ocean. The author presents two models, one for the Centre-South Chile and open ocean (figure 6), the other for the Peruvian-North Chile part of the population (figure 7). . The model for Centre-South Chile and open ocean shows the existence of a main central area where the fish concentrate in periods of low density and from which they expand during periods of high abundance. The model on the Peruvian-North Chile area shows differences from the one presented in figure 6: the central area is not geographically stable as in the former case, and moves south and north according to the abundance. This is likely due to the strong effect of the El Niño oscillations that are certainly responsible (directly or indirectly) of the changes in biomass.

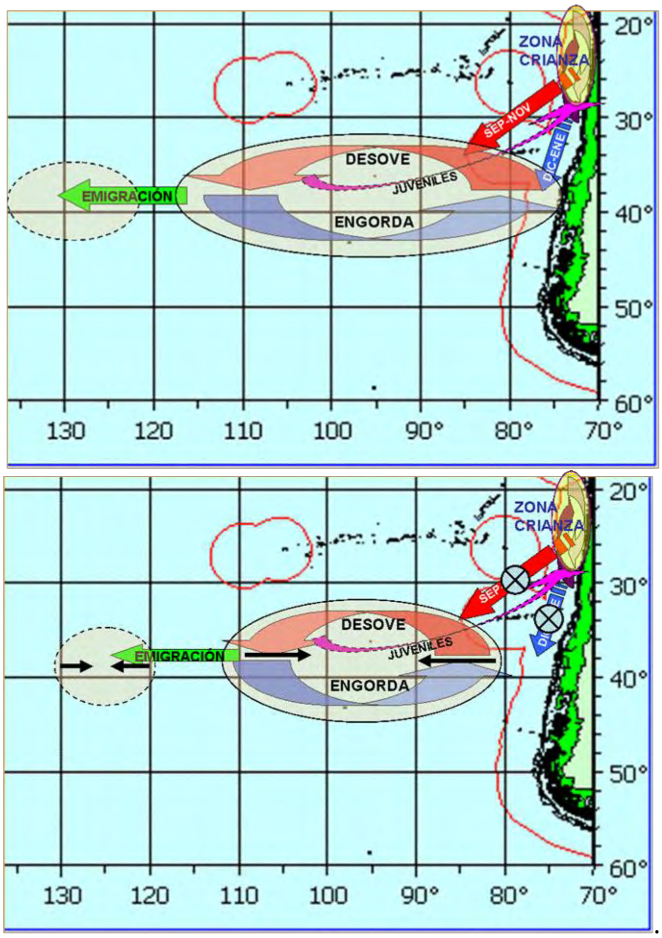


Figure 6. Distribution model of the CJM abundance in the Chilean and oceanic areas. Above: during periods of high abundance; Below: during periods of low abundanceDesove = spawning area; Engorda: feeding areas; Zona de crianza: juveniles and growth areas. From Gretchina, 2009.

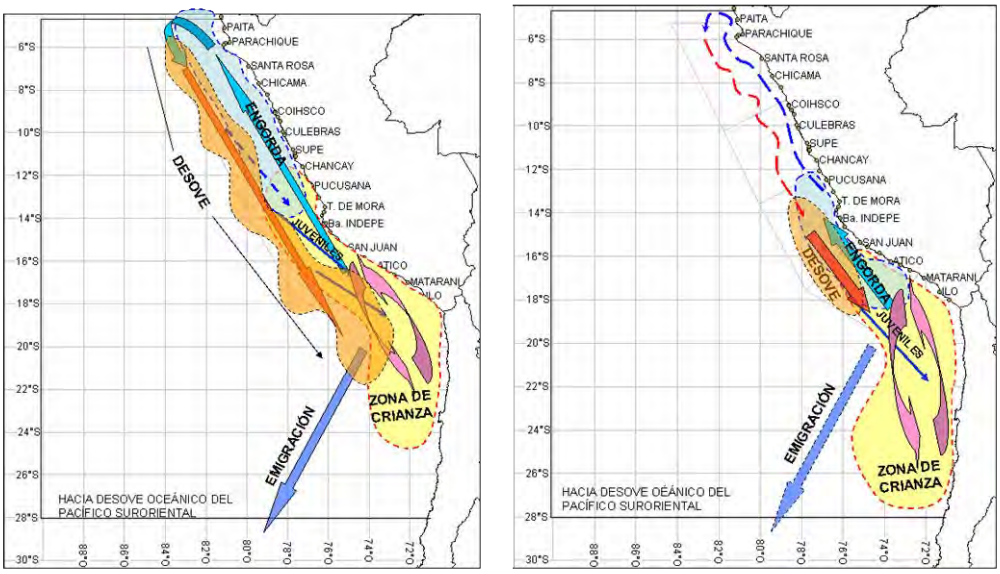


Figure 7. Distribution model of the CJM abundance in the Peruvian and North Chile. Left: during periods of high abundance; right: during periods of low abundance. Desove = spawning area; Engorda: feeding areas; Zona de crianza: juveniles and growth areas. From Gretchina, 2009.

Gretchina (2009) hypothesizes that the two sub-populations present similarities. They share the same juvenile area ("Zona de crianza") centered in the latitudes 18-23º S. Nevertheless the catch data cannot allow confirming this point, because, due to the differences in mesh size regulation (see chapter 4), the Peruvian fishery does not catch the same small fish as the Chilean does, therefore it is difficult to know from these data whether other juvenile concentrations exist in the North. Their relationships with the open ocean are not clear, this is due to a lack of detailed information on this area, unlike the coastal regions, well studied by IFOP and INPESCA in Chile and IMARPE in Peru.

5. The 19-22th parallels

We have already noted that Nesterov and Chur (2006) wrote : "*The data on jack mackerel abundance indices distribution in the South-Eastern Pacific Ocean allow to affirm the availability of two stock units of jack mackerel with the conventional boundary at 25°S. The mixed zone between two stocks includes locations to the north and to the south of 25°S.*". This natural limit between dynamics in the north and in the south of the coastal border of South America is observed in a series of works and results. For instance, the synthesis of results on spawning areas (Gretchina, 1998) shows that there are two major spawning areas, north and south of 25º south (chapter 2). Several factors seem to play a role in the building of this natural limitation. Dioses(2008) observes that this latitude is the one of the limit of the subtropical front (figure 8). Kashirin et al (1994), and Kuznetzof (1994) observe that the Soviet fishery never found important abundances in these latitude close to the coast (keeping in mind that this latitude is also that of the Chilean islands, therefore the Chilean EEZ is extensive in this area and data are not covering all the area). Their observations are presented in the figure 9.

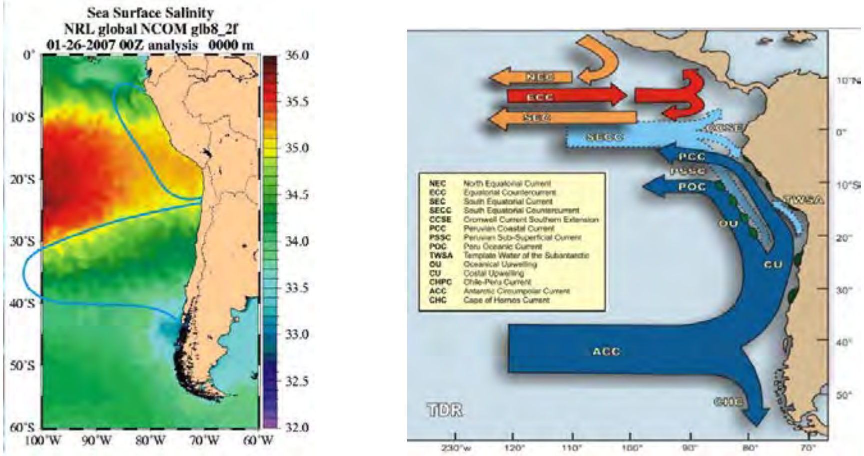


Figure 8. Left: limits of the subtropical front from the distribution of salinity. The blue lines limit the major concentrations of larvae. Right: general current system in the SE Pacific Ocean (from Dioses, 2008)

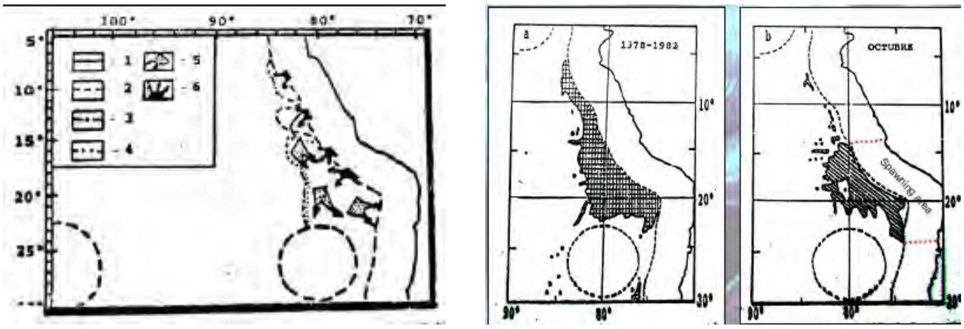


Figure 9. Left: Limits of distribution for the commercial concentrations during the 4 trimestres of the year (1 to 4)Arrows show the direction of the population according to temperature changes (from Kashirin, 1994). Right:Distribution of the commercial concentrations of jack mackerel during the years 1978-1982 (a) and during the month of October (spawning season) for the same years (from Kuznetsov, 1994)

Konchina (1996) presented the catches of the Soviet fleet and showed that the abundance of CJm is the weakest in the 19-22 latitude area (figure 10). This is also visible on the catch statistics for the Chilean harbours, where the Regions III-IV present the lower landings compared to regions I-II (north) and V-IX (see below).

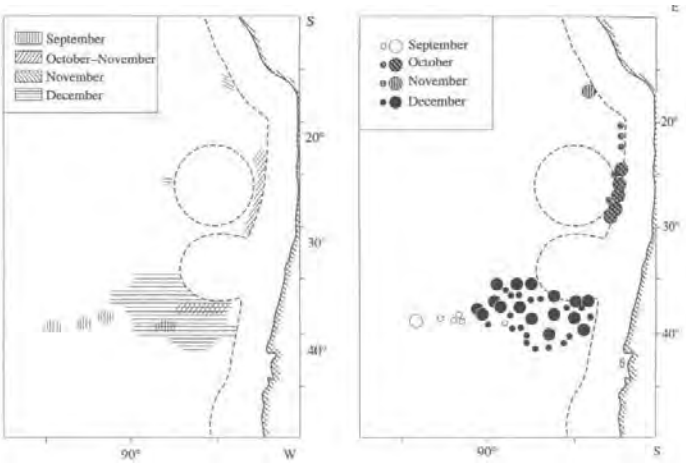


Figure 10. Left: distribution of the CJM in the Eastern pacific in spring 1989; Right: Relative density of the CJM aggregations (tons per hour of trawling) in spring 1989. The diameter of the circles is proportional to the catch (from Konchina, 1996)

It is interesting to note that the subtropical front is moving around 22ºS during the year. We recall that the general structure of the current system shows a movement of the water masses from the south to the north. From this current system Arcos (2001) defined a migration triangle from the main spawning area in centre-south Chile to the coast (fig. 11) where the origin of the juveniles observed in the fishery from 18ºS to 25ºS comes from this hatchery.

Figure 11. Schema of CJM migrations in the Chilean waters. From Arcos, 2001.

This seems in agreement with the general current system as displayed in fig. 8. Nevertheless some arguments presented by Dioses (2008) show that things are more complex and support the idea that the 20-25th parallel could be considered a border between two separate areas, especially as far as spawning is concerned.

Dioses (2008) presented some results and hypotheses to show the reality of the “no CJM zone”) along the 22th parallel. The first point is that CJM spawns rather close to the surface (fig. (12)

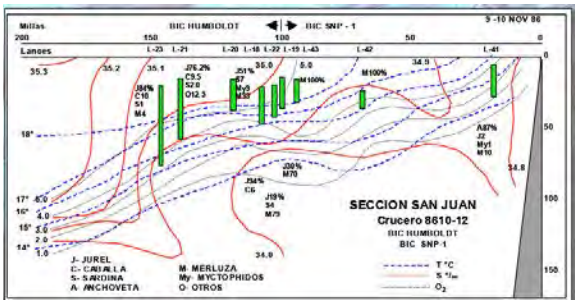
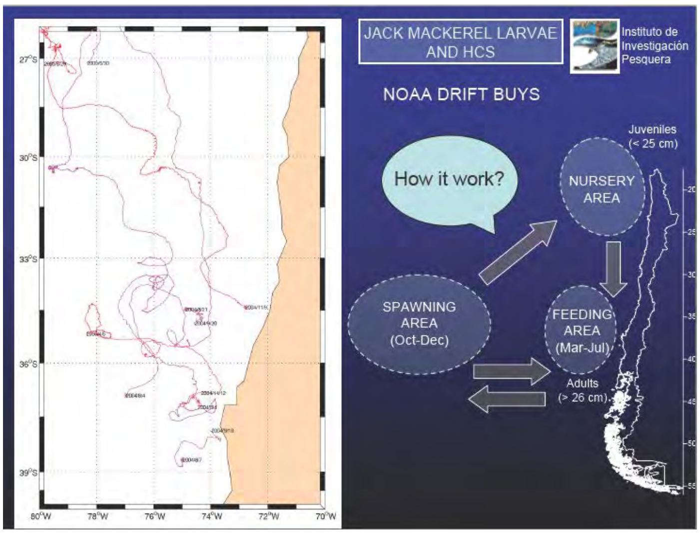


Figure 12. vertical distribution of spawning schools of jack mackerel in Peruvian waters (from Dioses et al., 1989)

The fish, as observed by Bertrand et al (2004) stays above the oxycline. Then in order to accept the “passive” migration of larvae from the main spawning area to the coastline at 20ºS as suggested by Arcos (1998?) we must consider the current system at the surface. Dioses (2008) presents some data on surface current observed from drifting buoys which indicate that the average drift on the surface, through eddies mostly, should not take the larvae to the juvenile area. This point is also considered by Nuñez et al (2008), and no final answer has been given so far (fig. 13 and 14).



JACK MACKEREL LARVAE AND HCS

Instituto de Investigación Pesquera

NOAA DRIFT BUYS

How it work?

SPAWNING AREA (Oct-Dec)

NURSERY AREA

Juveniles (< 25 cm)

FEEDING AREA (Mar-Jul)

Adults (> 26 cm)

Figure 13. Apparent contradiction between the migration model (right) and the surface movement of the sea (left). From Nuñez et al, 2008.

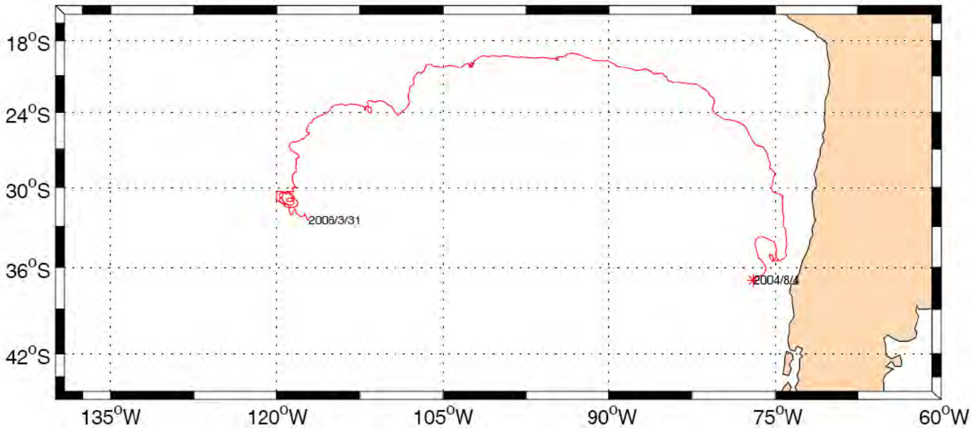


Figure 14. Example of drift of a buoy from 36ºS along the coast of Chile to the open ocean (from Dioses, 2008; Nuñez et al., 2008)

This observation is confirmed by Ashford et al (2012) who use SODA simulation to observe the direction of transport on the sea surface of the SE Pacific Ocean (figure 15).

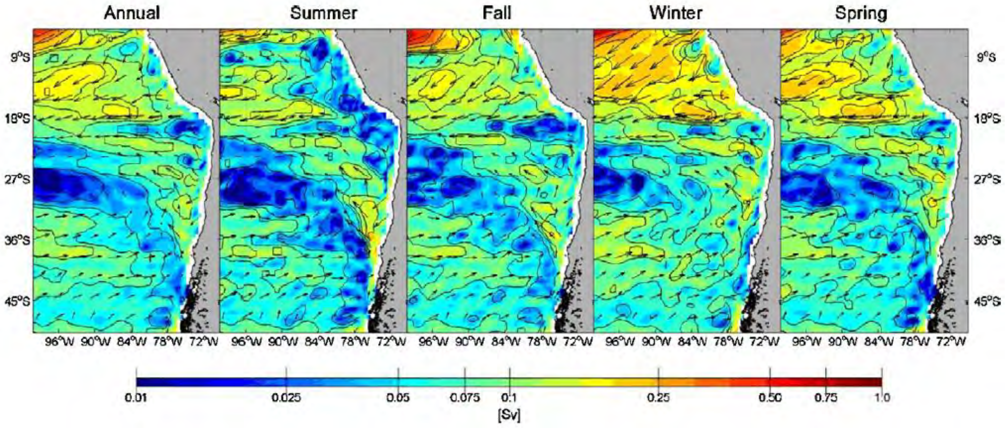


Figure 15. Horizontal transport in the eastern South Pacific ocean during 1958-2005 integrated over the surface 50 m. the annual mean field is shown with mean fields for summer (December-February); fall

(March-May); ans spring (September-November) Means are calculated from monthly current data generated by SODA 2.0.2-3. Color scales and arrows represent the intensity and vectorial field of transport. From Ashford et al., 2011.

Anyway, this potential limit between the north and the south distribution areas of CJM are worth some more research, because several convergent results indicate that this 25º S parallel represents a border in many situations. For instance, Antezana (2008) described the abundance of *Euphausia mucronata*, showing also a minimum abundance at 25ºs and two maxima at 30ºS and 15ºS. The fishery has always been lower in this sector than in the north or the south, since the beginning of the fisheries (e.g. Kusnetsov, 1984; Dioses, 2008: fig. 16)

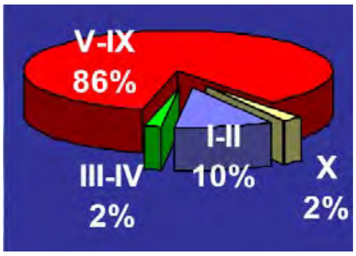


Figure 16. Proportions of catches in the different regions of Chile, from I (north) to X (south) in 2006. Note that regions III-IV have a lower production that in the north (I-II) and in the south (V-IX). From Dioses, 2008

An interesting simulation has been published recently (Brochier et al., 2013) where the effect of the climatic change on larvae retention along the coastline is studied (see also chapter 3, Hydrology). This work shows that retention will decrease and that climatic change is likely to induce a general decrease of recruitment in the populations of the Humboldt current. We can see on the figure 17 that the area from 20ºS to 24ºS is one with the lowest retention capacity.

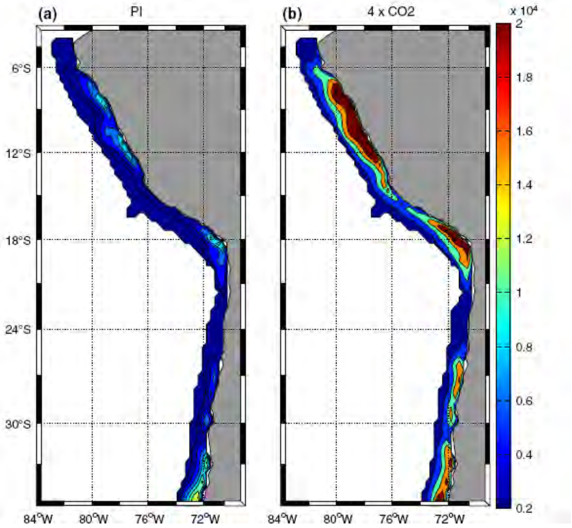


Figure x. Average areas of ichthyoplankton shelf retention for PI and 4 9 CO2 scenarios for simulations UVD30-shelf (see Table 1). Color bar scale: number of retained individuals per grid cell (From Brochier et al., 2013)

Finally one recent hypothesis (Habasque and Bertrand, pers. comm.) is based on the fact that the OMZ is the closest to the surface in this area and frequently present at less than 40 m depth. This height is not sufficient for the CJM to occupy such layers; therefore the OMZ in the 19ºS-22ºS can be considered as a barrier between the north and the south of the CJm overall distribution area, which is only open when the OMZ is pushed below 40 m by oceanographic events e.g. El Niño.

6. The evidences for selecting population hypotheses

As this is a key question, it is not surprising that among the first studies from SPRFMO some considered the structure of populations and tried to extract evidences from the literature. An important work has been done in 2008 (document SPRFMO-VI-SWG-JMSG-02, Reñaca, 30 June-4 July 2008) where a synthesis of all the works that could have an impact on the definition of the proper population structure was produced and synthesized in a table that we reproduce below (table 1) and to which we added comments and some more recent publications.

Table 1. List of results supporting the hypothesis of either a single population or different populations (adapted from SPRFMO, 2008)

Population characteristics	Supporting hyp. of different pop	Supporting hyp. of single pop.	Comments
parasites	Oliva (1999) A central-northern Peru population separated from a Chilean stock (lack of data from southern Peru)		Parasites are not a proof of different populations *per se*, but the demonstration that a given fish has been living in a given place during a given moment
Genetics	Koval (1996) Analysis with allozymes (but grey literature, low nb of loci, no peer review	Poulin et al (2004) FIP-IT96-15 (grey literature) Zhang et al (paper SPRFMO 3). Low sampling, peer review needed	Genetics shows clearly that there is a single recent population in the whole SPO. Thism means that there is a single genetic population, but various “ecological” population can exist
Spawning grounds	Evseenko (1987); Serra (1991); Nesterov et al (2007): two main spawning grounds Peru-central Chile. Santander & Flores (1983); Gorbunova et al (1985); Dioses (pers.comm): presence of spawning activity in Peruvian waters every year. Braun & Valenzuela(1): low egg and larvae density in the northern Chilean waters, increasing towards	Braun & Valenzuela (1): important spatial and interannual changes in egg distribution in northern Chile. Evseenko (1987); Cubillos et al (2008); Nuñez et al (1): spawning of jack mackerel in the main reproductive region from Chilean extended up to 110ºW	The CJM spawning ground is not strictly delimited; eggs and larvae can be found almost everywhere. Existence of major areas, at least 2 of them in periods of large distribution: Peru, central south Chile which can be considered the “source” (80-110ºW); conditions for separate life cycles including spawning are present. Balance: although the main spawning characteristics of CJM allow drawing the two hypotheses, the two-

	southern Iquique Nuñez et al (1); Ruiz et al (1); SSP(2) (1): main spawning ground in Chilean waters 35-40ºS		population hypothesis is more likely.
Abundance distribution	Castillo (1); Gutierrez (1): acoustic biomass concentrated northern to 17ºS and southern 20ºS. Existence of a “no-fish zone” between north and south populations. Soldat et al (1): 3 populations groups in the Central Pacific based on discontinuities of distribution, 105-125; 125-155; 155-175ºW (data 1982-1991, not currently available)	Castillo (1): continuous CJM distribution through the northern coast of Chile before El Niño 83. Cordova et al (1): biomass distribution by acoustic in water masses salinity between Peru and central-south Chile.	Abundance and distribution show a patchy distribution, with 3 major focuses: Peru and northern Chile; “source” central-south Chile; west 110ºW, although there is no discrete distribution, existence of continuous distribution all over the CJM area.
Demographic structures	Soldal et al (1): in the three areas defined from the soviet fishery, there is spawning activity and complete range of ages from juvenile to adults (same remarks as above on data availability). Espinoza et al (1); Ñiquen & Peña (1); Ojeda et al (1); Bernal et al (1): distribution patterns different in Peru and Chilean waters, with larger fish towards the North in Peru and the South in Chile; complete size-age structure in both Peruvian and Chilean waters.	Espinoza et al (1); Ñiquen & Peña (1); Ojeda et al (1); Bernal et al (1): similarity in catch at length composition in N Chile and S Peru; similarity in recruitments since 1998 from S Peru to S Chile; presence of juveniles in N Chile and S Peru	A global vision of demographic structures shows that there is possibility of independent cycles of life until 1998. Description in the litterature of a juvenile area S Peru to N Chile (but contradictory with abundance distribution). No clear idea of demographic and recruitment independence of the different sub-populations.
fisheries	Castillo (1); Cordova et al (1); Gutierrez et al (1): fisheries based on a permanent and large concentration and biomass off Chile and Peru (at least until 1998).	Zhang et al (1); Corten (1): presence of continuous catches by Chinese and EU vessels 878-110ºW); the seasonal movements. INPESCA (2008)(1): the spatial distribution of central-south purse seine fleet shows the continuous distribution and the seasonal patterns	Four separate fisheries have existed until 1998 (Peruvian, Chilean, International, New-Zealand) in 4 separate areas. Since 1998 the coastal fisheries are decreasing; in 2008-2009 the Peruvian has almost disappeared and appeared again in 2011; in 2009 the NZ fishery has almost disappeared; the

		of CJM off central Chile, from coast to areas beyond Chilean EEZ	Chilean fishery is every year more focused on the international sector. Nevertheless in 2011 a new cohort appeared and allowed rather important catches in Peru. It seems that during high abundance periods populations behave separately. The international area is the less affected by the global decrease of the abundances.
Environmental conditions	Gutierrez et al (1); Dioses (pers.comm): differences in water masses between Peru and central-south Chile. Soldat et al (1): existence of permanent eddies in the western areas.	Arcos et al (2001): global influence of El Niño events in distribution patterns.Northern Chile as an important nursery area.	Environmental conditions do not seem to play a role in the discretization of populations (high plasticity of fish in regard to physical conditions)
Trends and Cycle life	Soldat et al (1): in the three areas defined from the soviet fishery, there is spawning activity and complete range of ages from juvenile to adults (same remarks as above on data availability). (paper already presented in line "demographic structures"). Espinoza et al (1); Ñiquen & Peña (1); Ojeda et al (1); Bernal et al (1): complete size/age structure in both Chilean and Peruvian waters.	Penney and Taylor (1): Coincident trends in catches between Chilean and New Zealand areas.	3 major remarks: - There is synchrony in many cases for recruitment and variations in abundance. - There is a complete set of ages in each one of the sub-population areas. - There is a coincident trend in the catches. Here too the conditions for a metapopulation to exist are existing but do not proove this existence.
alimentation		Cordova et al (1): existence of feeding grounds (*for Chilean CJM?*) in Peruvian coastal area.	Here too investigation shows that there is an important plasticity of CJM as far as feeding is concerned. Not a good criterion for population discrimination.

(1) : paper presented at the CJM workshop, 30 June-4 July, Santiago, Chile

(2) (2) SSP: Subsecretatia de Pesca, Government of Chile

7. Conclusion

Almost all the observations produced in the literature agree on a small series of points:

- The unity of *T. murphyi* as a single species in the whole South Pacific ocean, and the extension of the "Jack Mackerel Belt";
- The existence of patches of high density in several areas, and especially in the north Chile, the Peruvian waters, the Centre-South Chile, the open ocean west of C-S Chile, etc.
- The probable existence of at least two separate "groups" (not to say sub-populations) along the coast of south America, approximately north and south of the latitude 20-22ºS;
- The huge variability of the overall biomass that is accompanied by large movements of expansion and reduction at the edges of the distribution area.

Some intriguing questions remain, especially the existence of independent or semi-independent populations, the existence of precisely delimited spawning areas and their respective migrations of larvae, the value of the total biomass, etc. Some of these questions will be explored in the next paragraphs, as several scientists have produced important papers in these fields, through the study of genetics, otholiths, parasites, and proposed some hypotheses on the actual structure of the CJM population.

CHAPTER 5-b

Biological markers

Introduction

The definition of the population structure is needed before to be able to design an assessment model that would be completely adapted to the Chilean Jack Mackerel: depending on the type of structure the species selected, the management would be different (see former chapters).

Due to the wide extension of the stocks in an open area, geographical limits are impossible to define correctly. In such cases one usual way for studying this point is through the use of tagging experiments. Unfortunately several aspects of the biology and the fishery of the CJM are not favorable to such method: the dimension of the stock would need an important international tagging program with a large number of fish tagged; fish are not large enough to receive active tags (acoustic tags, pop-up tags, etc.); and the industrial fishery of this species, in large part used for producing fish meal through industrial processing, does not facilitate the recovery of tags from the catches. Very few tagging experiments were done, e.g. by the Peruvian fisheries in the late 1990s[1] but with no usable results, and none with the purpose of discriminating populations. Some tagging experiments were performed also in North Chile during the 80s (Dioses, 2008, results from Torres, 1986) that are described in chapter 2, migrations.

In such cases there is no other way to discriminate between possible sub-population than using biological markers. A document presenting these methods and suggesting research field for such topics for the CJM was prepared for SPRFMO (Doc. SPRFMO-III-SWG-21, Reñaca, April, 2007). This document had as overall objective "*to determine the stock structure of* *__Trachurus murphyi__* *to inform future fisheries management. The specific objectives are:*

- *To determine methods for separating stocks of* *__Trachurus murphyi__* *for fisheries management purposes*
- *To define the stock structure of* *__Trachurus murphyi__*
- *To define the discrete stock boundaries*
- *To determine mixing rates among relevant stocks*":

The list of methods includes those that have been explored and have results published, and others still to be applied. The main methods already used are genetic tags, microchemistry of otholiths, parasites, morphometry and life history patterns; in addition some biochemical techniques are also suggested to be included.

. This chapter will give the state of the art of the three fields of research on biological markers already applied to the jack mackerel.

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[1] Dioses, T., 1997. Marcación experimental de jurel a bordo del BAF "K-INCA". IMARPE, internal report, 1996.

1. Genetic discrimination of populations

An important synthesis on “population structure of the jack mackerel, *Trachurus murphyi*, in the South Pacific ocean: proposal for discussion for a regional joint research” has been produced by IFOP, Chile, in 2007, for SPRFMO (document SPRFMO-III-SWC-21, Reñaca, 2007). We extract from this document the history of genetic studies until this date.

“*The first study done on jack mackerel (Trachurus murphyi) was in 1986 been also the first time using this technique was applied in Chile on an important fish stock. In this study 25 loci were analyzed, corresponding to 19 enzymes. The polymorphic systems analyzed to differentiate stocks correspond to 4 enzymes (L.glycerol phosphate deshydrogenase, phosphoglucomutase, phosphoglucoisomerase and Esterase). Samples from different locations of the EEZ were analyzed like Chiloé Island (42º34’S; 73º43’W), Iquique (20º12’S; 70º13’W) and Juan Fernandez island (33º30’S; 79º39’W) (Galleguillos and Torres, 1088).*

A second study was done in 1994 and its main goal was the jack mackerel stock structure between 20º12’S-70º13’W and 45º20’S-73º37’W. A total of 23 loci were analyzed consequently with analysis of 15 enzymatic systems. Six polymorphic systems made the comparative study between stocks possible. No difference was found among the samples taken from northern to southern Chile (FIP-IT/94-19).

A third study was done in 1996 employing for the first time molecular techniques based on nuclear DNA. In this study with the PCR-RFLP (Restriction Fragment length polymorphism) techniques the ITS zone of a ribosomal gene was analyzed with a total of 600 pb. 11 restriction enzymes were utilized of which 7 permitted to identify the cutting place in the ITS-2 zone. The samples taken in Mocha Island (38º21’S-73º52’W), Juan Fernandez Island (33º30’S; 79º39’W) and Iquique (20º12’S; 70º13’W) off Chile, and in New Zealand and Tasmania did not show differences in the genotypes that were obtained from the ITS-2 with the PCR-RFLP technique. In addition, the control region DLOOP and the ATCO gene from mtDNA was standardized for future investigations (FIP-IT/96-15)

The fourth and last study was done in 2002 in which samples taken in Talcahuano, San Antonio and Iquique in Chile. The molecular technique employed correspond to mtDNA and msDNA. The results show a lack of genetic structuration in T. murphyi when different haplotypes found in the DLOOP region and 4 loci of the microsatellites are compared (Ojeda and Poulin, 2002). Similar results were obtained in 2004 which include samples taken also off New Zealand (Poulin et al., 2004).”

The document listed also the different methods that could be applied to the CJM population, i.e. allozyme electrophoresis, microsatellite DNA, and molecular markers sequencing for mitochondrial DNA.

From this series of works, two major papers were published, i.e. Poulin et al. (2004), Cárdenas et al. (2009). Both confirm the existence of a single genetic population of CJM in the South Pacific Ocean (figure 1)

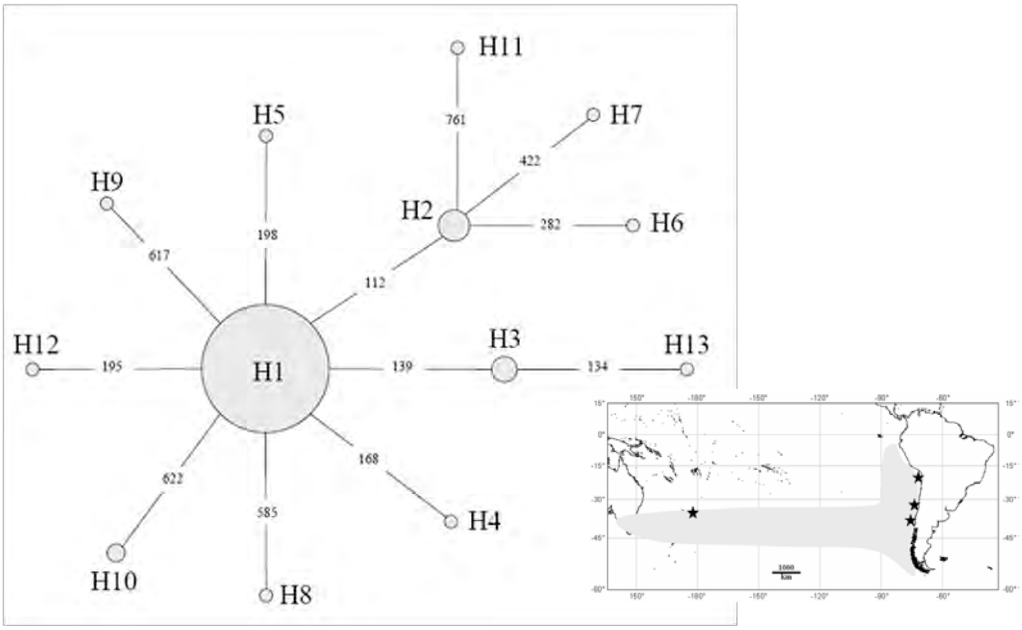

Figure 1. Genetic diversity of the Chilean Jack Mackerel in the South Pacific Ocean (see map for locations of samples) From Poulin et al., 2004).

More recently, a new series of works have been performed by Russian scientists (Afanasiev et al., 201). 2 Sampling was performed on both sides of the Pacific Ocean (figure 2).

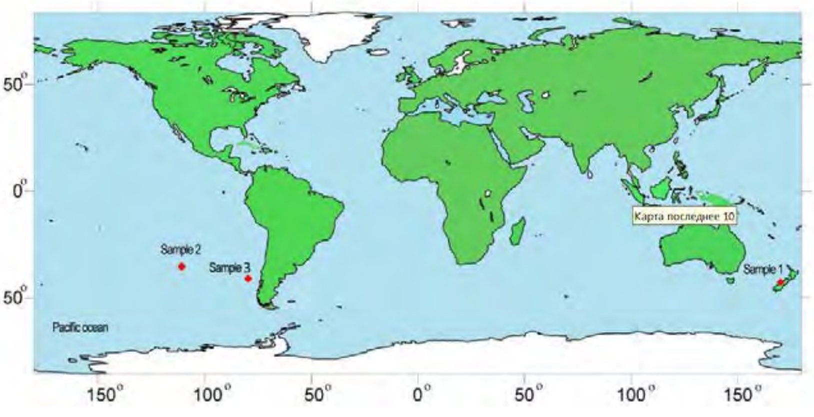

Figure 2. Location of samples for the Russian genetic study (Afanasiev et al., 2012)

The Russian work is still in course and results are likely to be produced soon. The effort was principally focused on the finding of proper loci for a correct representation of the CJM genetic diversity. The choice of the method seemed efficient as the work already allowed to find “*significant differences between localities*” in two of the four loci selected.

The major interest of such work is to go further towards a finer observation of the genetic diversity. Indeed it seems admitted that the CJM forms a single wide global population, but its dimensions should produce some detailed variations from one site to the other, due to their isolation during the rather short time since the fish as expanded all over the Pacific ocean. As the question of the population structure is a priority in research (see this chapter, paragraph 5-E and 5-F), any additional information that could provide more detailed information than the first (seminal) genetic studies would be welcome.

In any case, the major conclusion so far on this topic is that the Chilean Jack Mackerel, as many coastal pelagic fish, suffers a series of expansions and shrinks, during which its genetic diversity is lost, making the overall population a single one. Moreover it is quite likely that exchanges of genetic material between the different areas of distribution is permanent albeit limited, which is the common case for these species (e.g. McQuinn, 1999, for North sea herring; E.U. project HOMSIR on *Trachurus trachurus*; etc.).

2. Otholiths

Otholiths morphology

The detail of otholiths morphology studies applicable to CJM has been written in the document SPRFMO (Doc. SPRFMO-III-SWG-21, Reñaca, April, 2007). We cite here a large part of the relevant paragraph of this document (most of the numerous references cited have been removed and could be found in the original document).

"Variations in morphological characteristics of otholiths have been defined as population-specific and successful stock discrimination by means of otholiths shape analyses were reported for a range of temperate marine fishes. In similar species like Chilean Jack Mackerel, a recent work considering morphological characteristics of otholiths of horse mackerel from the Mediterranean has been done by Turan (2006).

The use of otholiths morphology as indicator in stock separation can be divided in three categories. According to recent studies, the first includes the traditional one-linear measurements of size-related attributes, such as otholiths length and width and distances such as nucleus length and width of hyaline bands of increments also fall within this category. The second category comprises two-dimensional size measurements, such as area, perimeter and different shape indices, including circularity and rectangularity. A third, more recent morphological technique examines the two-dimensional outline of otholiths shape using Fourier analysis".

The use of otholiths morphology has not been used yet for differentiating populations of CJM, and we will not enter in more details for this domain, but a sound proposal has been produced in the document cited to which the reader should refer.

Otholiths biogeochemistry

Although some works have been published (Markwitz et al., 2000) in this domain, this paragraph is mostly based on a paper published by Ashford et al. in 2011. Indeed these authors are the only ones who used the biochemical properties of otholiths for population identification.

The objective of this work was first to evaluate whether otholiths were a consistent tool for evaluating variations in the populations characteristics. The authors defined a series of sampling location (figure 3).

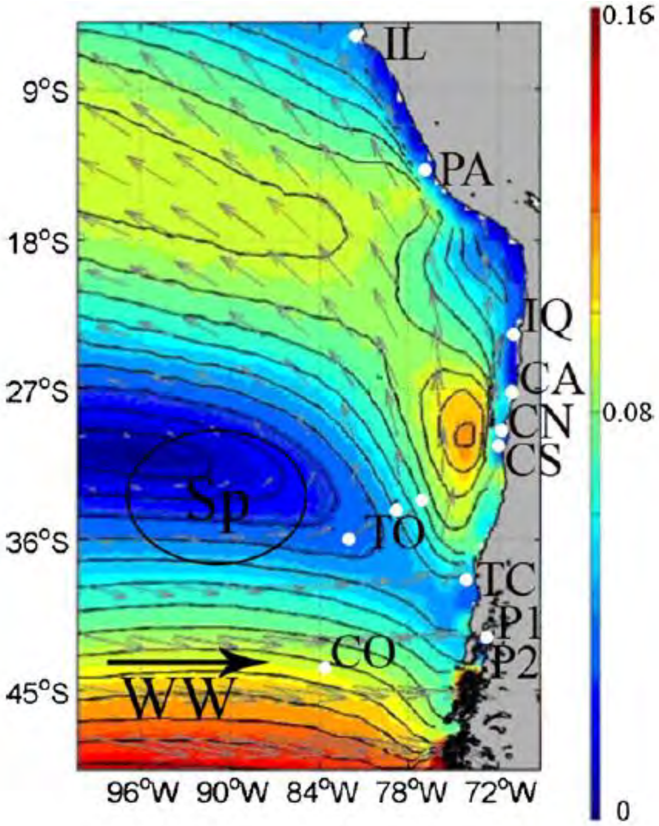

Figure 3. Sampling areas in the SE Pacific, showing mean annual wind fields betzeen 1958 and 2005 based on monthly data generated by the simulation model SODA 2.0.2-3. Color scale and grey arrows represent wind intensity (Nm^{-2}) and direction respectively; black arrowz, West Wind drift. Circles show larvae distribution in November 2004 (redrawn from Nuñex et al., 2008). Sampling areas (white dots) are displayed as following: IL: Isla Lobos de Afuera; PA: Paracas; IQ: Iquique; CA: Caldera; CN: North Coquimbo; CS Coquimbo; TC: Talcahuano coastal; TO: Talcahuano oceanic; P1 and P2: Puerto Montt; CO: Chiloé oceanic. Sampling areas in New Zealand are not shown (from Ashford et al., 2011)

After some description of the material and methods, the authors give some results: first they show the tool is able to differenciate among locations (“*The otholiths chemistry did not lack power to detect spatial differences”)* and for instance that significant differences appear for some of the indicators that they selected, although not always in the same direction. Among their results, one important is the existence of no major differences in neighbour sampling areas (e.g. between two samples taken in Puerto Montt), while on the contrary strong significant differences occur between the coastal and oceanic areas (e.g. between Chiloé oceanic vs. coastal areas of Talcahuano, North Coquimbo, Iquique; or Isla Lobos de Afuera vs. coastal areas of Puerto Montt, Talcahuano, Coquimbo Norte). On the contrary, the data could not find “*a consistent differences marking a population boundary between Chile and Peru (…) There was also no consistent difference between New Zealand and South America*”. This seems to indicate that “*fish at New Zealand were exposed to similar environmental conditions during* *their early stage life as fish at most sampling areas of South America".* Their results were summarized in figure 4.

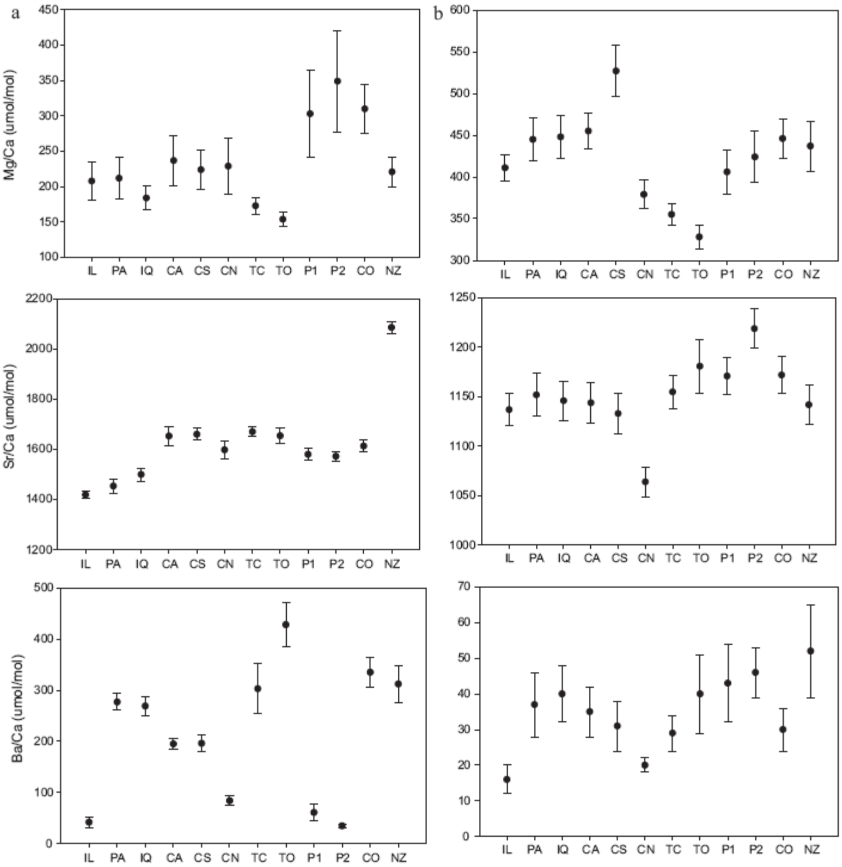

Figure 4. Mean elemental ratio concentrations found in the otoliths of *Trachurus murphyi* from the Southern Pacific Ocean. Bars show standard errors. Data for Mg.Ca^{-1}, Sr.Ca^{-1} and Ba.Ca^{-1} are from otoliths (a) edges and (b) nuclei (from Ashford et al., 2011).

In conclusion, the authors state that "*the chemistry laid down in otholiths nuclei showed considerable spatial heterogeneity*" that should exclude the hypothesis of a single randomly mixing population with fish off New Zealand, Peru and Chile, recruiting from a single spawning area in oceanic waters off Central Chile; but they did not found evidence of "*population boundaries separating discrete, self-sustaining populations off Chile, Peru and New Zealand*", apart a distinct population encountered in North Peru that present marked differences. Although the results show already some essential patterns, e.g. the existence of a different population in the far north of Peru, and some differences due to egg and larvae transports from the surface hydrology, it lacks of a wider overview to draw a conclusive model of population structure. But the instruments, add to genetic results, is probably one of the best ways for obtaining such information.

The most synthetic conclusion of this seminal work is probably that there are no discrete borders between the different spawning and population areas, but that some structuration exists, especially between centre-south Chile and the northern area. Whether the fish in North Chile and South Peru belong to or are creating a separate population should be studied more in details in order to understand clearly these associations and differences. One key pattern could be the hydrological characteristics of the area and especially the transport of superficial water masses (Dioses, 2008) that could induce separate spawning origins of these different groups. In any case it seems demonstrated that the Centre-South Chilean population and the oceanic one come in a large part from the large C-S spawning area. Most of the conclusions of this paper should be cited for it presents convincing results and realistic scenarios. Any constructed hypothesis on the population structure of the CJM should be in agreement with these results.

3. Parasites

Apart its major role in ecosystems, in animal behaviour and even in evolution, the parasitism presents two interesting characteristics for the discrimination of populations: some parasites are extremely selective, at the level of species and even populations in their choice of host; some of them are also very selective in their location, being unable to survive in other waters than their endemic area. Due to these two characteristics, a few parasite species are used as markers for recognizing fish species or populations[2] . We present in figure 1 an example on Trachurus trachurus, showing that the proportions of parasites can help to discriminate between population of this species in the European sea (figure 5).

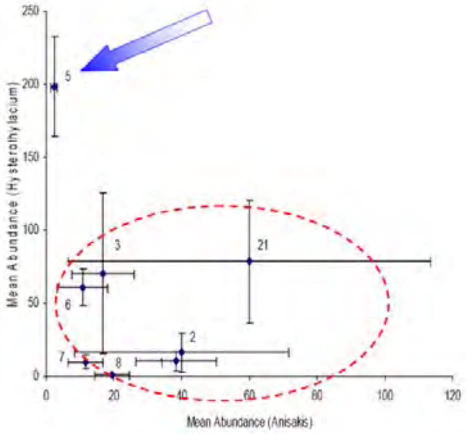

Figure 5. Proportions of contamination by two species of parasites on *Trachurus trachurus* in European waters. The arrow shows one population totally separated from the others by the proportion of *Hysterothylacium* vs. *Anisakis* species of parasites (from Abaunza Martinez, 2008*)[3]

The Chilean Jack mackerel is a-priori a good study case, due to its extreme dispersion in a huge area, its potential distribution in sub-populations, a rather easy access to samples from the

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[2] A few additional references:

MacKenzie, K. and Longshaw, M., 1995. Parasites of the hakes *Merluccius ustralis* and *Merluccius hubbst* in the waters around the Falkland Islands, Southern Chile and Argentina, with an assessment on their potential value as biological tags. Can. J. Fish. Aq. Sci., 52: 213-224

Brown, J:A:, and Colgan, W.P., 1986. Individual and species recognition in centrarchid fishes: evidences and hypotheses. Behav. Ecol. Sociobiol., 19:373-379

Cox., F.E.G. (Ed), 1990. Modern paraqsitology, 3rd Edition. Blackwell Scientific publications, Oxford, UK.

Fréon, P., Cury, P., Shannon, L., Roy, C., 2005. Sustainable exploitation of small pelagic fish stocks challenged by environmental and ecosystem changes: a review. Bulletin of Marine Science, 76(2):385-462, 2005

[3] Abaunza Martinez, P., 2008. Horse mackerel (*Trachurus trachurus*) stock identification research (EU-Project HOMSIR). A multidisciplinary approach using genetic markers and biological tags in horse mackerel (Trachurus trachurus) stock structure analysis. Comm. SPRFMO, 2008.

industrial fisheries all over the South Pacific, and even its co-existence or not with other *Trachurus* species, especially in the western South Pacific (*T. novaezelandiae*, *T. picturatus*, for instance).

Thus, several studies were performed focused on this question: is parasitism able to discriminate populations in the *T. murphyi* species?

A review of these works has been published by the SPRFMO (see SPRFMO JM 2008 Workshop Report – final-6) and as there is no need to repeat a good work already done, we can cite rather extensively its analysis:

"Since the pioneer paper by Herrington et al. (1939), parasites have been successfully used as biological tags in population studies not only in marine and freshwater fish in order to evaluate stock discreteness, migratory movement and habitat (Moser, 1991; MacKenzie and Abaunza, 1998; Oliva 2001; Oliva and Ballon 2002; Oliva et al 2004), but also in molluscs, crustaceans and mammals (Balbuena et al., 1995; González and Kroeck, 2000; Pascual and Hochberg 1996; Thompson and Margolis 1987, Oliva and Sanchez 2005). As pointed out by MacKenzie and Abaunza (2005) the basic principle underlying the use of parasites (both metazoan and protistan) as biological tags is that fish can become infected with a particular parasitic species only when they come within the endemic area of that parasite. The host parasite association implies two kinds of parasites: those specific to the host that in turn represent an evolutionary system; and generalist parasites, close associated with an ecological process. In the first case we have an association in an evolutionary scale that can give important clues about population structure; in the second case we can get information on migratory movements. Other approaches imply that if infected fishes are found outside the endemic area of the parasite, we can infer that these fish had been within that area at some time in their past history (MacKenzie and Abaunza, 2005). In this case it is mandatory to know the exact distribution of that parasite species, a problem not easy to solve.

The use of parasites as biological tags require meeting criteria that are well described and explained by Mckenzie and Abaunza (2005). Parasites have been used successfully to identify the population structure in some marine fishes from Chile like hake Merluccius gayi (George - Nascimento 1996, Oliva and Ballon 2002), Merluccius australis (Gonzalez and Carvajal, 1994), red rockfish Sebastes capensis (Oliva and Gonzalez, 2004), anchovy Engraulis ringens (Valdivia et al, 2007), hoki Macruronus magellanicus (Oliva, 2001) and jack mackerel Trachurus murphyi (George-Nascimento 2000; Aldana et al 1995; Oliva 1999), among others. The problem of local variability in the parasite fauna of anchoveta was clarified by Chavez et al. (2007).

With regard to the jack mackerel, parasitological information is a little confusing because the analytical procedures used by different authors do not follow a common pattern. The most comprehensive studies are those by Oliva (1999) and George-Nascimento (2000). Both studies analyzed metazoan parasites in the jack mackerel along the Chilean and Peruvian coast (Oliva, 1999) and from Iquique to Valdivia (George-Nascimento 2000). The data of Oliva (1999) strong suggest two stocks (Central - Northern Peru and a unique stock along the Chilean coast) based on univariate analyses. George-Nascimento suggests two ecological stocks in Chilean waters: a northern and a southern stocks, based on a multivariate analysis, unfortunately, George-Nascimento (2000) pooled the northern and southern localities and did not analyze a potential latitudinal gradient. Unpublished re-analyses of Oliva's data (1999), based on multivariate analyses using not only parasites as explanatory variable but also fish length, shows that the difference is a function of fish length but not parasites".

Glubokov in his series of documents on "Chilean Jack Mackerel species profile", updated each year for SPRFMO, presents also some general overview of the parasite research on the CHM:

"There is also evidence for a stock in the central south pacific ocean based on reproductive distribution, morphological and parasite information (Evseenko 1987, Duran and Oliva 1983, Romero and Kuroki 1985, Storozhuk et al. 1987, Kalchugin 1992, and Adveyev 1992). However the degree of independence of this stock from the south east pacific ocean stocks remains an open question" (*In* Glubokov, 2008. Information describing Chilean jack mackerel (*Trachurus murphyi*) fisheries relating to the South Pacific Regional Fishery Management Organisation : document SPRFMO-VI-SWG-JMSG-3).

This has also been reviewed by Peruvian scientists who give their own analysis (e.g. Characteristics of the Peruvian stock (Northern stock) of jack mackerel (*Trachurus murphyi*) in the Southeast Pacific and notes on the scientific basis for its differentiation**.** SPRFMO, SWG-11-JM-03, 2012)**:** *"The use of parasites as biological tags for the identification of stocks is very old (McKenzie, 1987). Unfortunately the studies on parasitism on jack mackerel off Peru are very scanty stock. In a recent study Jara (1998) determined the prevalence of helminthes parasites in 100 specimens, but it only allowed a partial comparison with the Peruvian stock since it mostly focused on jack mackerels caught off Chile. More recently, George-Nascimento (2000) undertook a comparative analysis of parasite communities in jack mackerels from different Chilean localities and concluded that there was evidence in favor of the existence of more than one stock of jack mackerel in the Southeastern Pacific".*

One of the last comments comes from Ashrord et al (2011), who write: *"evidence from parasite studies, catch length distributions, biomass concentrations and reproduction suggest Chilean jack mackerel caught off Peru may come from a separate self-recruiting population (Serra, 1991; Anonymous, 2008)"*.

In their study on metapopulation, Gerlotto et al. (2010; 2012) state: *some particular traits that are significantly linked to a given subpopulation are not necessarily the demonstration of different sub-populations: given the ability of fish to move along considerable distances, the fact that a fish present, for instance, a difference in the proportions of parasite species that infest it may just show that it has passed (or is provisionally living) in a region where these parasites are present"*.

Conclusion.

From all these works and reviews, three major conclusion.

- There is a real possibility of obtaining valuable information on stock structure through the analysis of parasites for *T. murphyi,* as the preliminary works show clearly. The recommendation from SPRFMO to undertake a more exhaustive research on this field should be encouraged.
- Nevertheless this is quite a challenge, as some of the population and behavioural characteristics of *T. murphyi* may blur the results, e.g. its ability to move over large distances and therefore to go through areas of specific contamination: the fact that a fish hosts one particular parasite (considering that this parasite domes from a given

> area but can survive this area once contaminating a host) may only indicate that the fish has passed through the contaminating area, not necessarily that it belongs to the population currently living in this area. Statistical analysis must be done with great caution.

In synthesis, the existing results converge towards the conclusion that there are some differences between the three major areas, North (north Chile and Peru), centre-south Chile and open Pacific Ocean west of Chile, as it appears in many works done with other methods. The fact that none of these works give significant result does not forbid noticing this convergence of facts, which mean that there is an urgent need to perform international work and get international consensus on this question.

CHAPTER 5-c.

Demographic structure of the CJM stocks in Chile and Peru

One evidence for the existence of independent or semi-independent sub-populations would be if specific demographic strategies, implying different recruitments, can appear in the different sub-population areas. This question has been studied by a large number of authors and laboratories by comparing the demographic structures of the CJM caught in the different fisheries.

- **Demographic structure for each major fishery**

Chile.

A synthesis has been presented by Bernal et al (2007) at the workshop organised by the SPRFMO[1]. The authors present the methodology (sampling of otholiths for age determination, sampling area, sampling effort, etc.). In Chile, length measurements defined as standard are fork length. Among the main results, some key points.

The mean length of the sample individuals decreased from 32 to 21 cm from years 1976 to 2002, and remained stable afterwards, oscillating between 21 and 23 cm (figure 1).

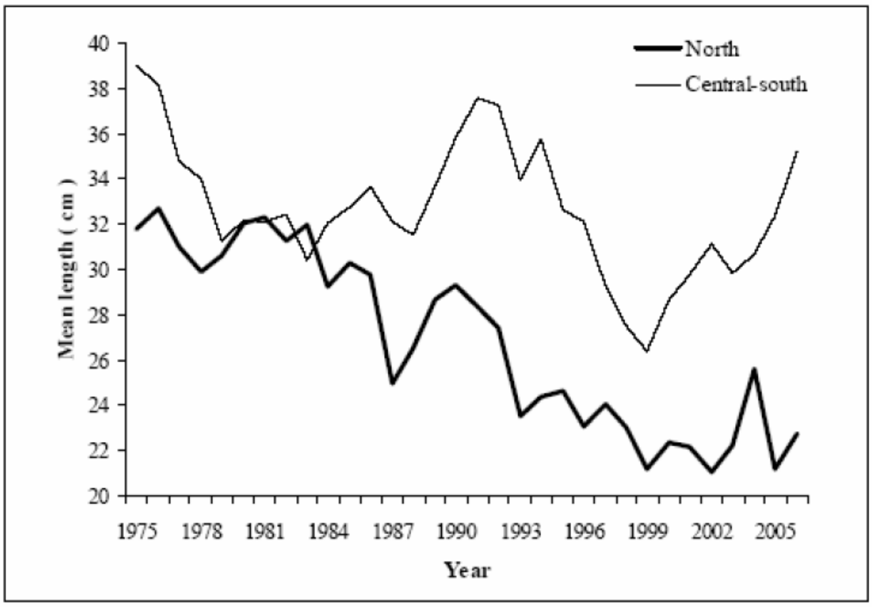

Figure 1. Evolution of the mean length (fork length) of CJM in the Chilean fisheries of North and Centre-South Chile

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[1] Bernal, C., Aranis, A., Martinez, C., Canales, C., 2007. Catch size compositions for jack mackerel (*trachurus murphyi*) off Chile (1975-2006). SPRFMO, Chilean Jack Mackerel Workshop

The two curves plotted on figure 1 represent the mean length for the North and the Centre-South fisheries. We can see that the data from the northern fishery seems to be responsible of this general decrease; since the mid 80s, the mean length in the north dropped compared to the centre-south and remained at lower levels. This is the first observation of a difference between these two areas as far as demographic structure is concerned. Bernal et al. (2007) note also that a strong year class was observed from 1986 to 1991, and some others (although less evident) during the periods 1998-2000; 2000-2004; 2005-2007. This is explained by the authors as a possible relationship between an ENSO event (El Niño) and the occurrence of a strong recruitment (figure 2).

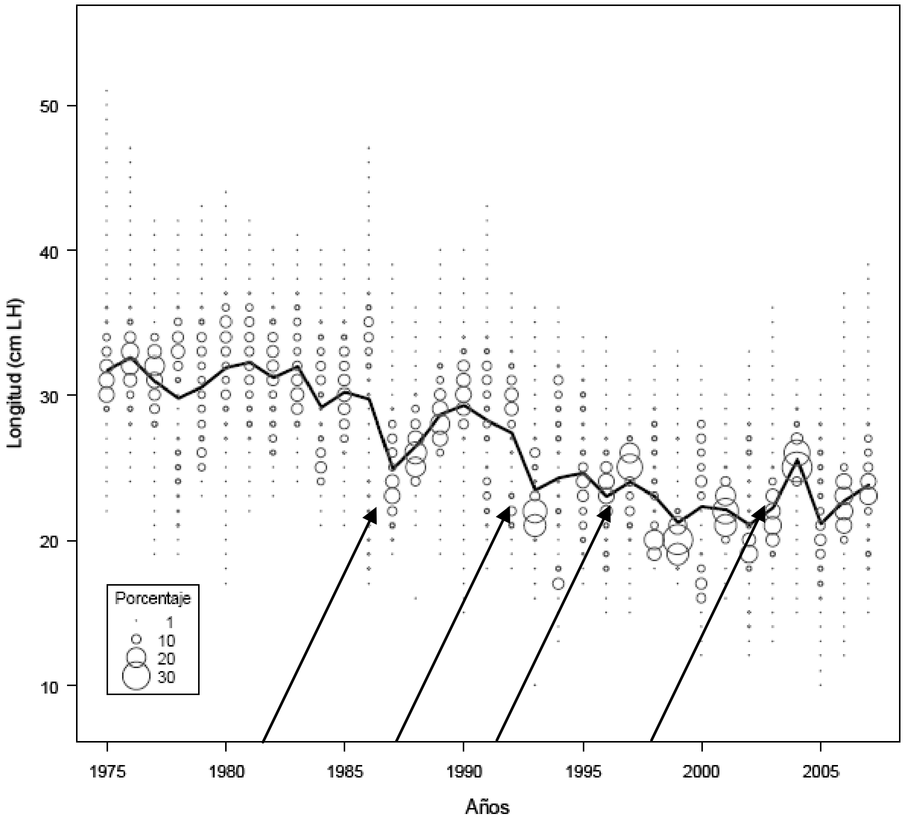

Figure 2. Annual length histograms and mean length of *Trachurus murphyi* in the Chilean fishery: Arrows indicate the cohorts born during the ENSO 1982-3, 1987, 1991 and 1997-8

Grechina (2009) presents a synthesis of these results and a general description of the demographic structure and evolution from the catches of the Chilean fishery in the Centre-South region from 1982 to 2008 (figure 3). This figure shows clearly the high recruitments of some year classes, as indicated before, corresponding to the main ENSO years.

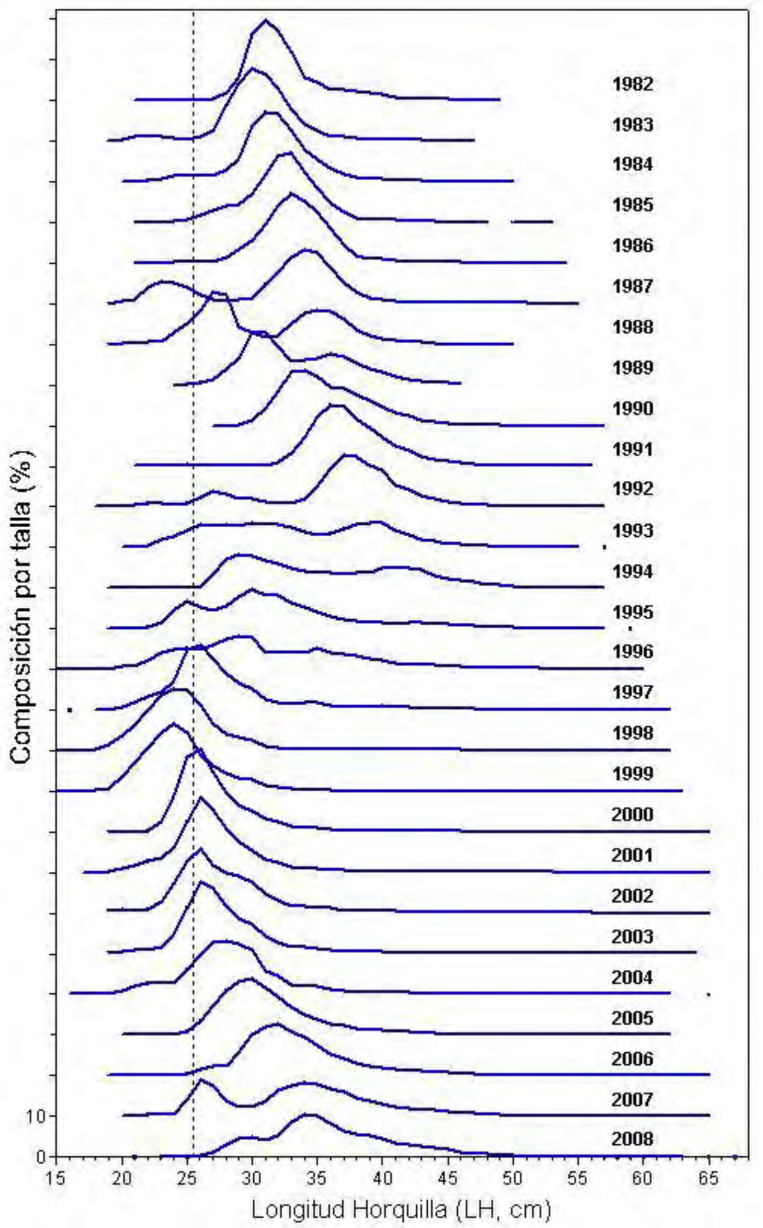

Figure 3. Length frequency of CJM (fork length) in the catches of the Chilean fishery in the Centre-South region, from 1982 to 2008 (from Grechina, 2009)

USSR

The Soviet fishery exploited the whole CJM area in the South Pacific Ocean, from the limits of the Chilean and Peruvian EEZs up to the New Zealand EEZ. They used pelagic trawls, which may produce some bias when comparing with the catches of the Chilean and Peruvian fisheries that operate purse seines, but on the other hand this gear is less affected by the possible differences in schooling behaviour of fish according to their age. The data provided by the fishery are given in fork length. A synthesis has been presented by Grechina (2009) over the period 1978-1991, which is the complete period of activities of the Soviet fleet, and the figures given here come from his work.

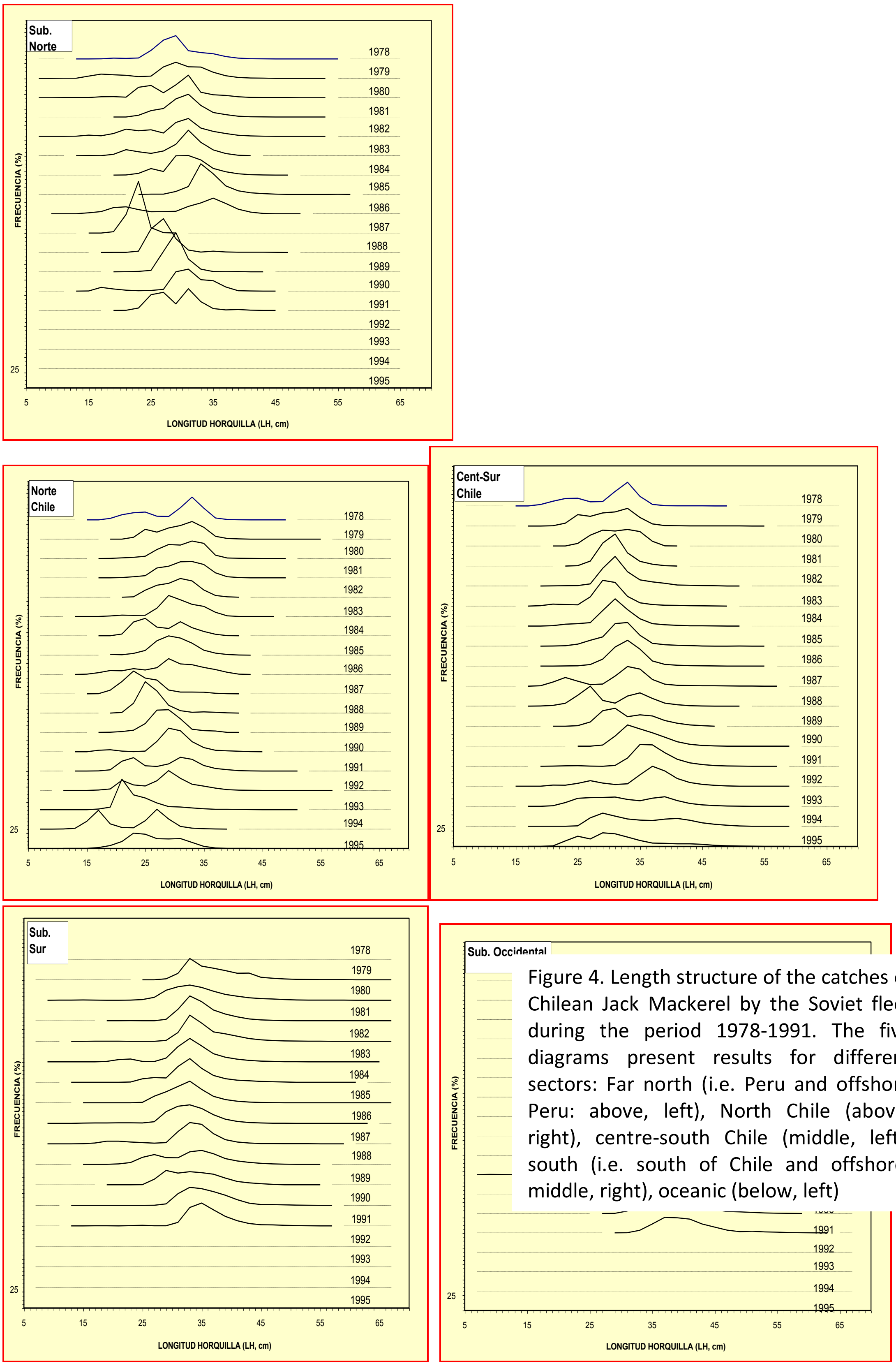

Figure 4. Length structure of the catches of Chilean Jack Mackerel by the Soviet fleet during the period 1978-1991. The five diagrams present results for different sectors: Far north (i.e. Peru and offshore Peru: above, left), North Chile (above, right), centre-south Chile (middle, left), south (i.e. south of Chile and offshore: middle, right), oceanic (below, left)

In this series of figures we can observe, as in the Chilean data, that a strong year class born probably around 1984, appears almost everywhere, and especially in the north and the centre-south. These figures are gatherer in the figure 5 (Grechina, 2009) that displays the catches for 3 areas from east to west (respectively 78ºW-85ºW, 85ºW-90ºW, 90ºW-105ºW, for the latitudes 35ºS-40ºS) where this phenomenon is even clearer.

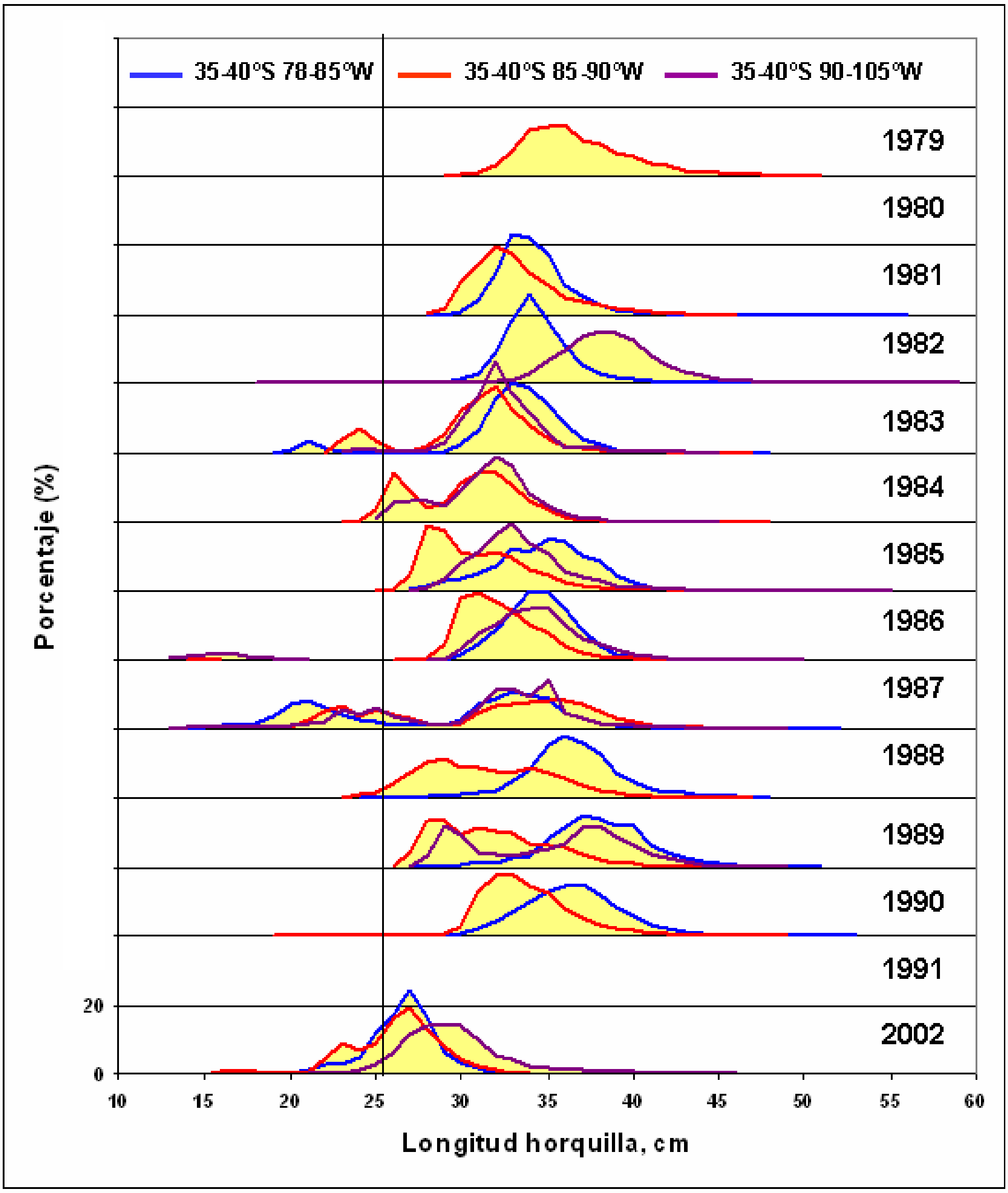

Figure 5. Distribution of CJM by length (fork length) in the Soviet fleet from 1979 to 1991, and in the Russian catches in 2002,for 3 areas of longitudes 78ºW-85ºW, 85ºW-90ºW, 90ºW-105ºW, for the latitudes 35ºS-40ºS (see legend in the figure). From Gretchina, 2009.

In this case too we can observe differences in length structure according to the areas: for instance in 1982, 1988 and 1990 strong differences appear between the eastern and the central regions, although not always with the same pattern.

Peru

The fish lengths in Peru are given in total length. A complete description of the length distribution in the catches since 1072 was presented in the Peruvian report to SPRFMO in Lima, Peru, in October, 2012[2]. This description is given below on the figure 6.

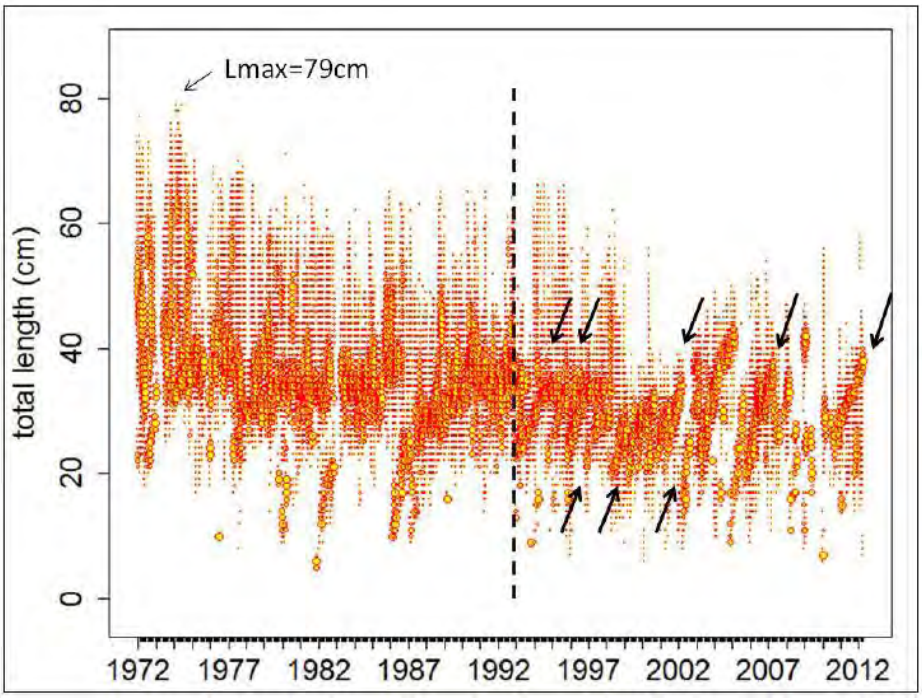

Figure 6. Monthly length distribution of jack mackerel catches in the Peruvian sea, showing the highest size between 1972 and 2012. Arrows show the year classes that could be followed securely during several years; the dotted line separates the data that have not been used (before 1993) in growth studies from those that were used (since 1993).

We can observe that the general pattern of this demographic structure looks similar to the Chilean and the Soviet fleets. It is particularly interesting to see that, as in Peru, the curves show two distinct periods, a first one where no clear modal distribution was visible and a second one with clear modal differentiation.

Inside this common general pattern, some interesting differences between the Chilean and the Peruvian structures appear: a first remarkable one is presented in figure 7, where data from 1996 to 2007 are displayed. The Chilean histograms look much smoother than the Peruvian, and in particular a strong year class appeared in the Peruvian catches in 2005 that was not present in the Chilean catches: it only appeared, in small quantities, in 2007.

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[2] Peru: National report on the situation of the Peruvian stock of jack mackerel (Northern stock) and the Peruvian fishery in national jurisdictional waters, 2012. SWG-11-08a Peru 2nd National Report , Lima, Peru, 15-19 Oct.2012

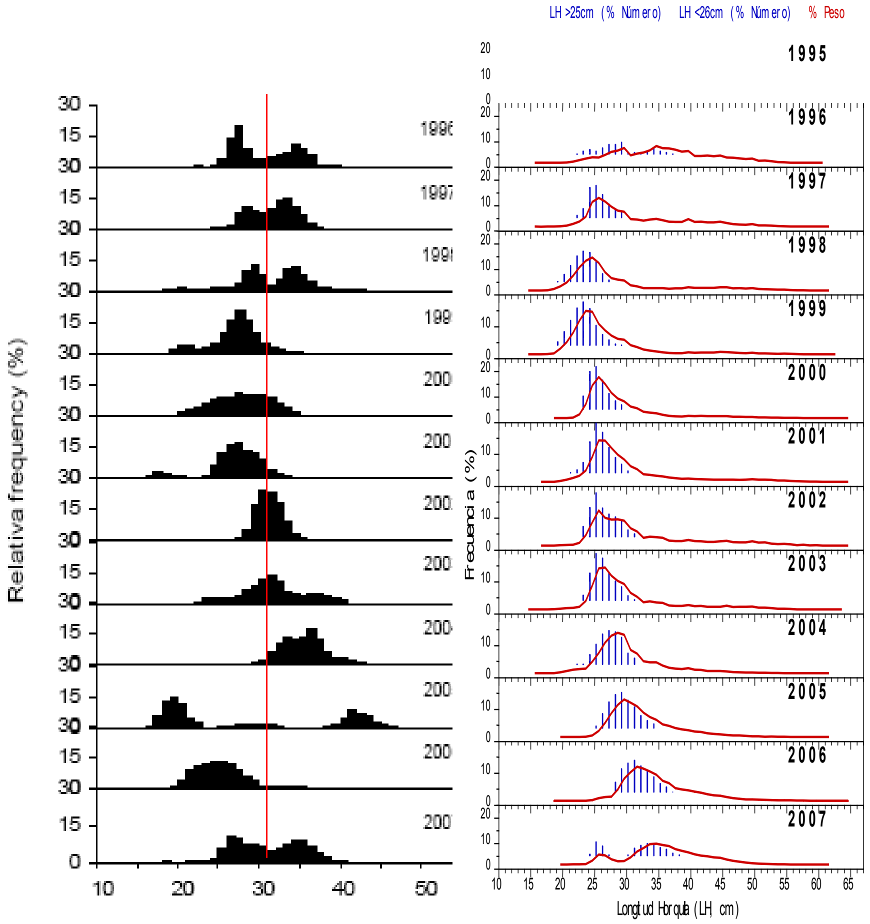

Figure 7. Comparative observation of the demographic structure of catches in Peru (left) and Chile (right) for the period 1996-2007. Note that the Peruvian data are presented in total length and the Chilean in fork length. From Espinoza et al, 2008[3] (Peruvian data) and Gretchina, 2009 (Chilean data).

Another interesting diagram was presented in the literature. Grechina (2009) gathered the results of the catches of CJM outside the Chilean and Peruvian EEZs by the Soviet fleet during a short period (July-October, 1990) of high abundance and catches and displayed them according to the latitude (figure 8). The diagram shows that the fish was distributed in the fishing areas according to its length, the smallest fish being captured in latitudes 13ºS-17ºS, and the largest ones south of 25ºS. The lack of data in the latitude 18ºS-22ºS is likely due to the extension of the Chilean EEZ around the Chilean offshore islands at these latitudes, but can also be interpreted as a low abundance of CJM in this area (see chapter 5, distribution).

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[3] **:** Espinoza, E., Ñiquen M. & Flores R. Chilean Jack Mackerel Workshop. 30 junio-04 julio 2008. Santiago, Chile.

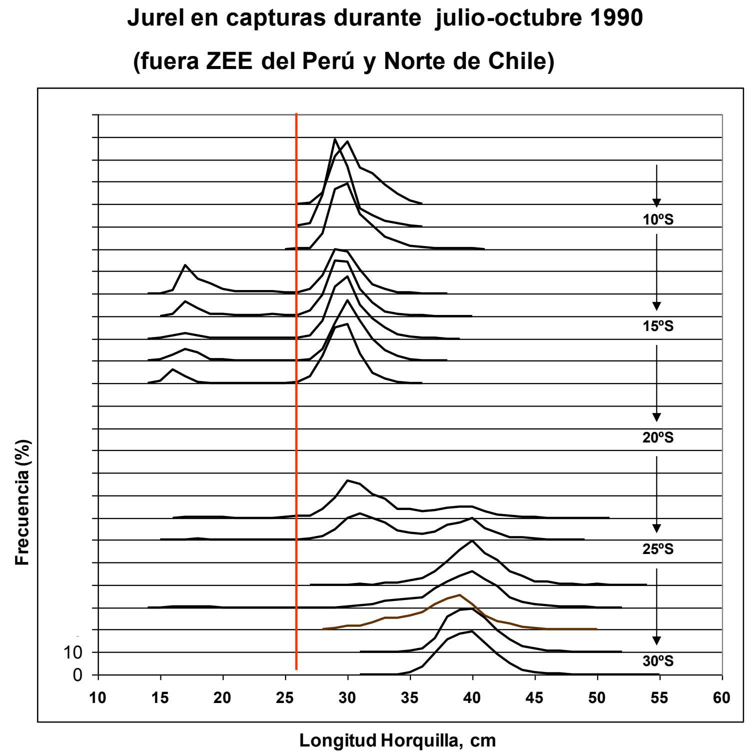

Figure 8. Length structure of catches of the Soviet fleet during the period July-October 1990, according to the latitude. Length measurements in fork length. The red line shows the limit of the minimum length established by USSR for industrial catches (from Grechina, 2009).

European Union.

The fishery is much younger than the former ones, and the length composition is given since 2007 (Corten, 2011: figure 9). The lengths are measured in fork length . The fishing area is also smaller than the others, and the EU fishery was always located on the centre-south region of South-eastern Pacific Ocean, outside the Chilean EEZ.

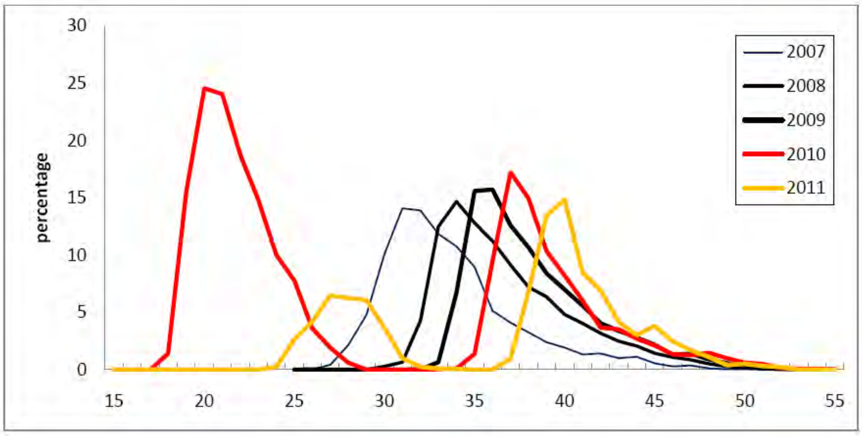

Figure 9. Percentage length composition of jack mackerel in the EU catches in 2007-2011. From Corten, 2011 (SPRFMO, EU National report, Port Vila, 2011)

The data present two interesting features:

- it shows the growth of a single year class from 2007 to 2011, and this clear shift of the mean length of this cohort could help to precise the growth of the fish. In this particular case, the cohort growth was from 31 cm in 2007 to 41 in 2010.
- A new important year class appeared in the recruitment in 2010 and was observed also in 2011 although at a lower level of abundance.

The SPRFMO synthesis

It is important to note that the length structures of the fish depend on the fishing strategies and methods. For instance the national regulations are different as far as mesh size are concerned, which can produce different views of a same panorama.

Once this said, it is interesting comparing the structures for the different fishing grounds. Using the growth curves from the different fisheries the SPRFMO prepared a complete set of histograms of fish by ages for the 4 major fishing areas: Northern Chile (lat 18-23ºS) and centre-south Chile (30-45ºS, 79-90ºW) for the period 1975-2011; far north (mostly Peru and marginally Equator, north of 18.5ºS) for the period 1980-2011; and High Seas (mostly west of 90ºW within latitudes 30ºS to 45ºS). The figures 10 to 12 show the histograms calculated by SPRFMO for the 3 major regions.

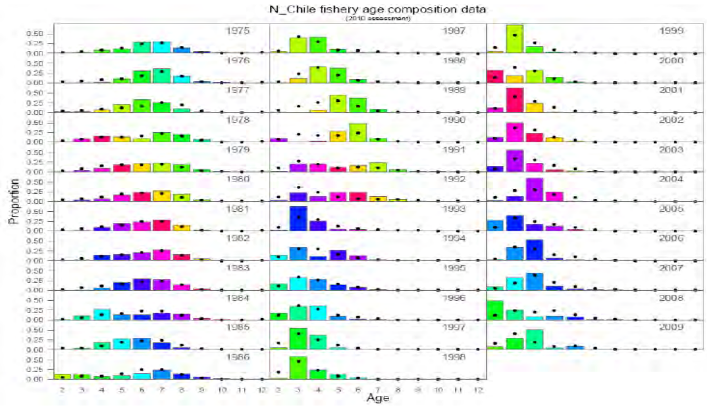

Figure 10. Age composition for the Northern Chilean fishery. Bars represent the observed data and dots represent the model fit; colors code corresponds to cohorts (SPRFMO, 2010)

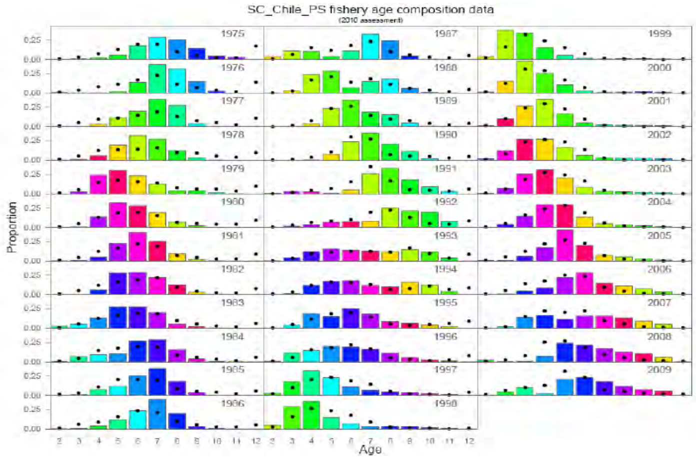

Figure 11. Age composition for the South-central Chilean fishery. Bars represent the observed data and dots represent the model fit; colours code corresponds to cohorts (SPRFMO, 2010)

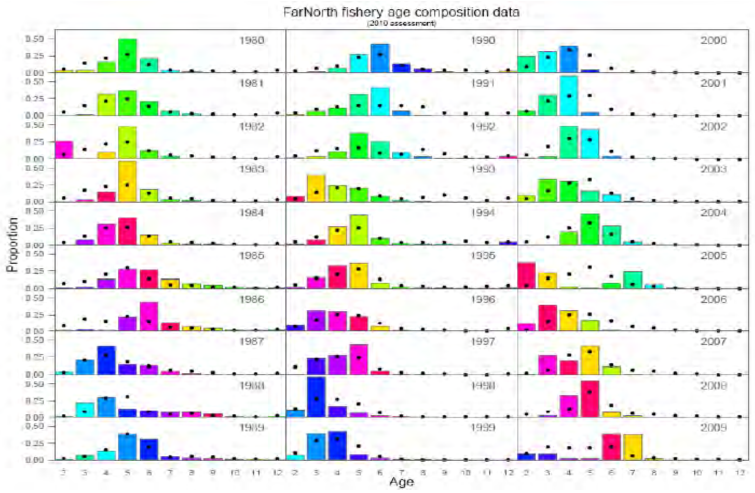

Figure 12. Age composition for the far north fishery. Bars represent the observed data and dots represent the model fit; colours code corresponds to cohorts

In order to allow an easier comparative analysis, we plotted the four series of histograms (Centre-south Chile, Northern Chile, far north - Peruvian fishery, High seas) in a single figure (fig. 13).

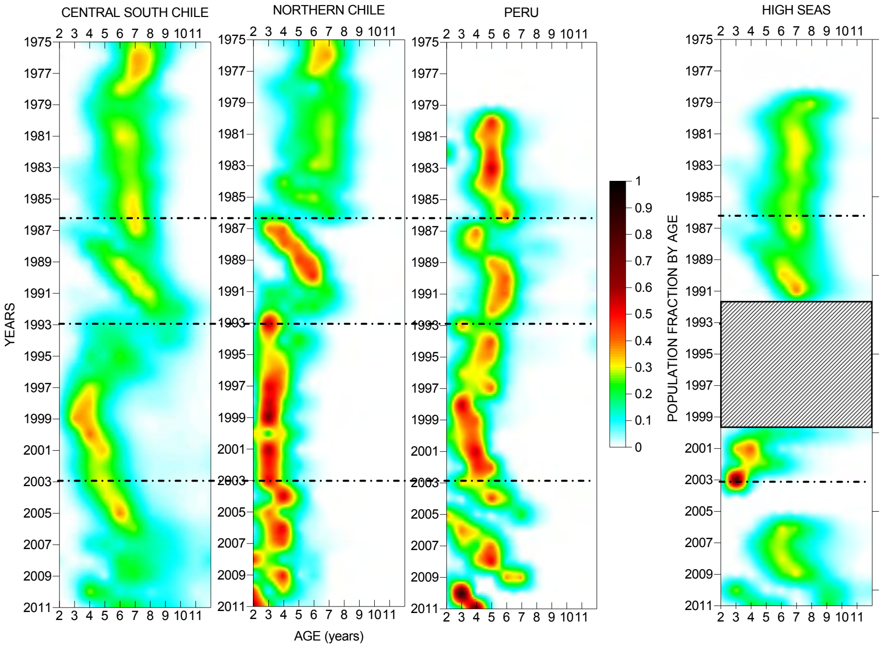

Figure 13. Description of the general demographic dynamics in the four fisheries. The four figures plot the age (axis x) vs. the year (axis y). From left to right, Central South Chile, Northern Chile, Far North (Peru), High Seas. Horizontal dotted lines show the limits of the 4 sub-periods mentioned in the text. The grey rectangle on the HS fishery figure covers the years between the end of the Soviet fishery and the beginning of the Russian fishery (no catch in this sector during this period). Note that high sea catches were obtained with different fishing gears than in Chile and far north (pelagic trawl vs. purse seine),

which particular selectivity curve might generate differences in the demographic structures (from Gerlotto et al., 2012).

From these histograms, we can extract the following observations:

- When comparing the different fishing areas, one can split the period into 4 sub-periods: (i) before 1986, where no clear evolution is visible in the demographic structures in the four fisheries; (ii) 1986-1993, where a clear evolution of classes recruited in 1985 and 1986 is observed, and where these year classes are visible in the four regions and represent the bulk of the catches in the whole sub-period; (iii) 1994-2003, where a clear difference is visible between North Chile (NC) and Centre-South Chile (CSC), the juveniles disappearing from the north at age 4 and appearing at this same age in the south, while no such separation can be seen in the far north (Peruvian) fishery (FN); and (iv) the period after 2003 where cohort evolutions appear in the Peruvian zone but are less visible in the Chilean fisheries. The high sea fishery is difficult to compare with the three other fisheries because it suffered a long interruption and the fishing gears are different (pelagic trawls instead of purse seines).
- The fact that very few juveniles were caught in all of the fishing areas before 1986 may be due to three reasons: (1) there was no juvenile during this period, which means that no consistent recruitment occurred during the decade 1975-1985, which seems quite unlikely; (2) the fishery was beginning and focused mostly on adults, therefore did not exploit the juvenile areas during this period; (3) the juvenile part of the population represented at this time a minor part of the biomass, and these proportions changed when the fishery was fully developed. These three hypotheses have different impacts on the fishery management and models.
- The CS-C fishery is exploiting the widest distribution of adult year classes, with the most regular evolution. Except in two occasions (1989, 1998-1999), juveniles were not significantly present in this area. This reinforces the idea that CS-C represents the feeding zone for the adult population.
- The NC fishery is the area of concentration for juveniles in the Chilean fisheries (NC+CSC), since 1994 (keeping in mind the differences in fisheries regulations).. From this observation, we can assume that the adult zone for the CS-C group moved southward in the early 1990s. Since this year, CSC and FN are completely distinct adult areas, separated by the NC juvenile area. This is in concordance with the trends in mean length that were shown between CSC and NC. Interestingly, two successive high recruitments appeared recently in the NC fishery almost only: one in 2008 and another in 2009.
- The FN, mostly represented by the Peruvian fishery, presents distinct characteristics. The juveniles were observed during all the period but generalmente mixed with adults, and the difference between NC and FN from this point of view is especially remarkable since 2005: fish of age 7 are observed in 2005 in the FN, while CJM of this age have not been observed in the NC since1992. Year 2005 is also interesting because an important new recruited cohort appeared in the FN and represented the most important cohort exploited from 2005 to 2009 while it was not significantly different from former cohorts in the NC. Contrarily, it rapidly disappeared in the NC, probably moving to the CSC where it

did not represent any strong class either. Recruitment in 2005 was much stronger in the FN than in the NC-CSC. Finally a very strong cohort born in 2007-8 appeared in 2009 and was heavily exploited in 2011, giving almost half of the total catch of CJM in this year (Fig. 9). Routine surveys performed by observers in the different fisheries showed a strong spawning that actually occurred in 2007-8. Catches in Peru during January-June 2011 reached 240 000 tons of 28-32 cm long CJM. The same year class (born in 2007) was also recorded in Central Chile and Central Oceanic area, but in smaller quantities and catch statistics provided to SPRFMO by the fishing fleets demonstrated that it remained almost insignificant (www.southpacificrfmo.org). This cohort distribution in FN is different from the one observed in NC where the most recent important cohort was born in 2008 and appeared in the fishery in 2010.

We recall that the ENSO events are almost always followed by a strong recruitment, as stated by various authors (Muck and Sanchez 1987; Dioses 1995; Ganoza 1998). The history of the cohorts born during ENSO events i.e. 2 years before the recruitment, shows that even though in some periods no strong biomass was observed after El Niño, these cohorts were almost always the most important in the population structure of the period and driving the demographic structure. Most of the ENSO cohorts can be observed during more years than the average duration of those born in normal years.

Conclusion on demographic structures

Although it can probably be related to the development of the fisheries and not to ecological changes, it is worth noting that the beginning of the fisheries did not show clear demographic structures (until 1987 for the Soviet and Chilean fisheries, until 1992 for the Peruvian fishery).

This being said, a more general conclusion of these analyses is that the CJM population follows a general pattern that consists in the occurrence of a few strong cohorts, generally associated with an El Niño year. This has been observed a number of times in the series, and especially with the cohorts born in 1973, 1982, 1998.

Another point is that this pattern is common to the different areas of distribution of the CJM: we could observe these strong cohorts in the CSC, NC, FN and even HS. It seems clear that the climate is responsible of this synchrony between the different regions as far as demographic dynamics is concerned.

When conditions are stable significant differences appear between the regions. We can point out the particular case of the NC area, especially since the early 90s, which receives principally juveniles, making this region different from the others. We can also notice that the intensities of the annual recruitments are different between the Peruvian area and the Chilean areas, especially since 2008.

Chapter 5-d

The population structures

Introduction

(This paragraph is based upon a work presenting the hypothesis of metapopulations in the case of the Chilean Jack mackerel, which first version was presented at the Scientific Working group of SPRFMO in 2010 (Document SWG-09-JM-04, Viña del Mar, Oct. 2010), and published in 2012 (Gerlotto et al., 2012). These two documents are the only ones on this topic.)

We have presented in the general introduction of this document the reasons why the definition of the actual structure of the CJM population(s) is indispensable: existence of (i) a huge potential biomass; (ii) a strong variability in the overall biomass depending on a few strong cohorts that occur or not according to the environmental conditions (Konchina and Pavlov, 1999), which increases the risk of overfishing when the stock drops; and (iii) a wide extension in international unregulated waters, making the species available for any fishery. These conditions make a regulation agreement indispensable.

1. Definition of population structures

Description of CJM spatial distribution

The different cases of population structures adopted by a given species are depending on the different characteristics in the biology, the ecology, the dynamics of the populations, etc. These differences have been listed in a synthesis presented in 2008 (ref: Chilean Jack Mackerel Workshop. Report of the South Pacific Regional Fisheries Management Organization Chilean Jack Mackerel Workshop. 30 June-4 July 2008, Santiago, Chile: 71 pages), that we presented in the table 1 of paragraph 5-A.

The three major types of population structure.

Populations can occupy space in different way. Kritzer and Sale (2004) classified the different structures that populations can take in a given space in three groups from completely independent subpopulations to less structured and most homogeneous global population (Fig. 2).

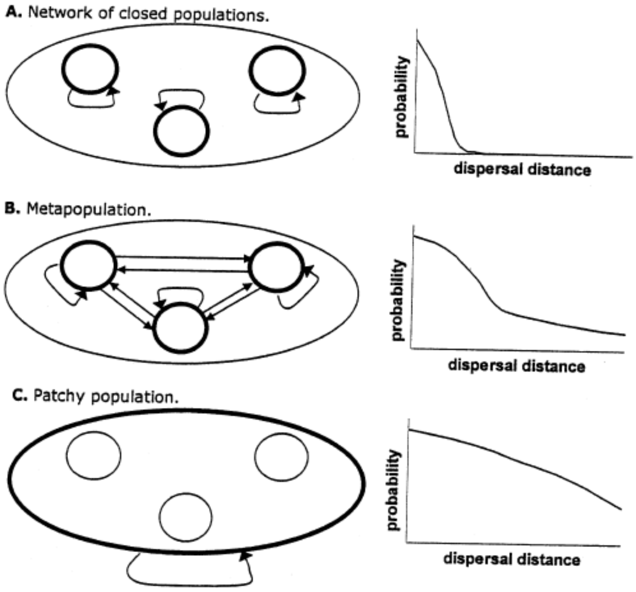

Figure 2. Three types of spatially structured populations with generalised dispersion curves for each local population. A: close local populations with no exchange between them; B: metapopulation; C: Patches of high density inside a single “patchy population”. From Kritzer and Sale (2004).

The three groups defined by Kritzer and Sale (2004) are the followings:

- A “**network of closed populations**”, where each subpopulation in the area has a particular cycle and where no exchange between subpopulations exists. We are here in the case where populations are completely independent and have a separate life. This can lead to speciation.
- A “**metapopulation**”, where the subpopulations have particular cycles but where some exchange between them might occur: *“individuals remain all their life in their natal population, and movements among populations are infrequent, though migration rate is high enough to allow eventual recolonization of habitat patches where a local population has gone extinct*" (Ovaskainen and Hanski, 2004). There are links between the subpopulations especially as far as genetic mixing is concerned.
- A “**patchy population**”, where there is a single cycle for the whole population and where the individuals “*move frequently among habitat patches and may reproduce in several patches during their lifetime*” (Ovaskainen and Hanski, 2004); these patches of abundance being dispersed inside particular sub-areas. This last group requires either a common (albeit wide) spawning area for the whole population or the possibility for every individual to spawn in any spawning grounds, and implies that the “patches” are mostly feeding areas.

The criteria used by these authors were related to the biological cycles that are observed. These cycles can be described by the “migration triangle” (Harden Jones, 1968) where four particular locations can be encountered in a life cycle: area of (i) spawning adults; (ii) larvae; (iii) juveniles; and (iv) feeding adults (Fig. 4).

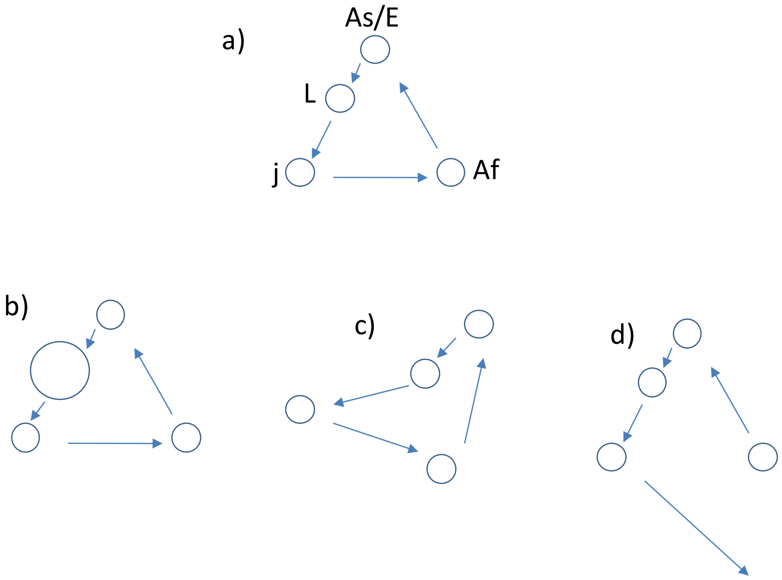

Figure 4. (A) Schematic description of a life cycle (Harden Jones' migration triangle) and possible impacts of a climatic change on: (B) the availability of an habitat; (C) the modification of the geographical location of an habitat or (D) the discontinuity of habitats. Af: feeding adults; As/E: spawning adults and eggs; L: larvae; j: juveniles (from Petitgas et al., 2010)

Applying this scheme to the Chilean part of the CJM population, Arcos et al. (2001) showed that Harden Jones' triangles are describing their hypothesis on the CJM migration route and organization (figure 3). We can use this hypothesis as a tool for analysing the population structure.

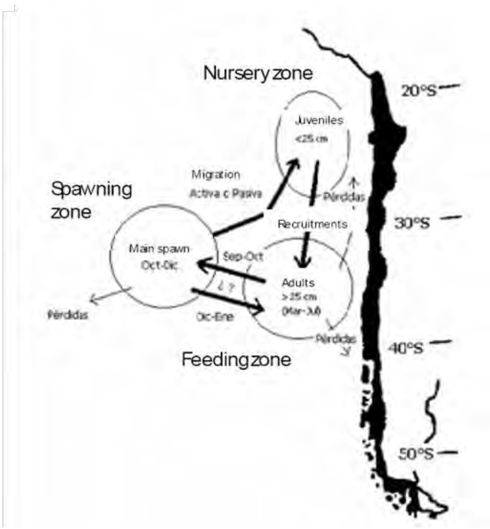

Figure 3. Schematic diagram of CJM migrations in the centre-South area, from catch data and egg-larvae surveys (from Arcos et al, 2001)

After results on genetics (Poulin et al., 2004; Cardenas et al., 2009), parasites, otolithes (paragraph 5-C : Ashford et al., 2011) the general conclusion, as expressed by Ashford et al.(2011), is that "*discrete population hypotheses do not account for the data*".

The results of these population analyses, refute convincingly the possibility of completely independent discrete self-recruiting populations. So the hypothesis of a network of closed population can rather safely be rejected. The question remains as whether the CJM is organised into a unique patchy population or "Superpopulation" or into a metapopulation.

The patchy population hypothesis

The patchy population hypothesis (Ovaskainen and Hanski, 2004) considers a single population that expands and contracts according to its abundance, but with a single biological cycle, as schematized in Figures 2 and 3. When the abundance is large, some parts of the distribution area act as subpopulations, at least for exploiting new feeding areas. The idea underneath this model is that the adults can colonize favourable areas, while the general biological cycle remains unchanged.

This patchy population hypothesis implies generally the existence of a common spawning area for the different subpopulations as far as reproduction is concerned. According to Ashford et al (2011), various spawning areas can exist together as long as there is no particular preferendum from the adults towards one of them. The difference in space occupation, i.e. the existence of "feeding subpopulations", is by definition directly linked to the global abundance. There is no possible genetic or biological divergence between the subpopulations. From this hypothesis we propose a general drawing of the hypothesized CJM patchy population (Fig. 5A).

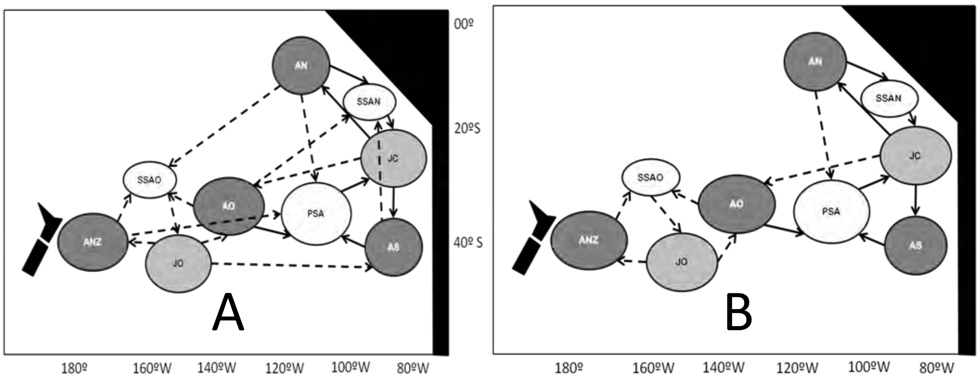

Figure 5. (A) Diagram of the patchy population hypothesis applied to the CJM. Adult individuals present an equal probability to live and spawn in anyone of the feeding and spawning areas. (B) Diagram of the metapopulation hypothesis applied to the CJM. Adults come from a single spawning area where they reproduce. Depending on the area of distribution, the metapopulation can be formed of one (low abundance), two (medium abundance) of up to four (high abundance) subpopulations, each one centred on a particular spawning area. PSA: principal spawning area; SSAN: secondary spawning area north; SSAO: secondary spawning area, oceanic (hypothetical); JC: juveniles, coastline: JO: juveniles, oceanic (hypothetical); AS: Adults, south; AN: Adults, north; AO: adults, oceanic; ANZ: Adults, New Zealand. Solid lines: observed migrations. Dotted lines: hypothesized migrations.

The metapopulation hypothesis

The metapopulation hypothesis (Levin, 1969) considers that subpopulations can have independent (and eventually divergent) lives. We present a diagram of this hypothesis in the case of the CJM (Fig. 5B) where independence between the “subpopulations” is assumed. In this case the fish subpopulations can diverge, at least during a period. This requires a series of conditions that will be studied more in details below. Each subpopulation is mostly linked to a particular spawning area, but a small albeit significant quantity of adults may move from one spawning area to the other.

3. The CJM population structure: the biological evidences

The “migration triangles” (Harden Jones, 1968) give us a methodology for extracting from the complete set of key biological patterns those useful for differentiating populations. They should refer to each one of the “angles” defined by Harden Jones (1968):

- The spawning adults and eggs: whether there is a single or multiple spawning areas is a strong indication of the possibility or not of separate triangles, therefore of separate sub-populations;
- The larvae-juvenile areas, related to environmental conditions;
- The adult feeding and growing areas. The “patches” of high density can be related to larger abundance of prey, or to non-trophic characteristics. Having knowledge of the alimentation regime and plasticity of the CJM behaviour is also important (see Konchina, 1981; Konchina and Pavlov, 1996; Bertrand et al., 2004, 2006).
- The general life cycle, including demographic structures, migrations, genetics, parasitism, and others.

Characteristics of the spawning areas

We assume that the main characteristics that would demonstrate the existence of a metapopulation would be differences in demographic strategies among sub-populations: independent strategies for the different subpopulation would show independence between them. Therefore it is important to have a clear idea of the spawning areas and cycles, and on the demographic structure of the subpopulations. Many works have been done on these points for the CJM. Chapter 2 gives a synthesis of what is known in the reproductive biology and behaviour of CJM. One of the major results is that the spawning areas are extremely wide, not precisely defined by geographic points or hydrological feature, and that several permanent spots in the spawning area exist, the most important ones being first a wide area west of the centre-south region of Chile, second a smaller area in Peruvian waters.

Demographic structure of the CJM stocks in Chile and Peru

As explained before, the best evidence for the existence of metapopulation would be if specific demographic strategies, implying different recruitments, can appear in the different sub-population areas. Here too, a general analysis has been presented in Chapter 5, paragraph E of this work. The figure 6 shows the general information of the demographic structure in age as calculated by SPRFMO (2011) from the catches in three regions: North Chile (NC, lat 18-23ºS) and centre-south Chile (CSC, 30-45ºS, 79-90ºW) for the period 1975-2011; far north (FN, mostly Peru and marginally Equator, north of 18.5ºS) for the period 1980-2011.

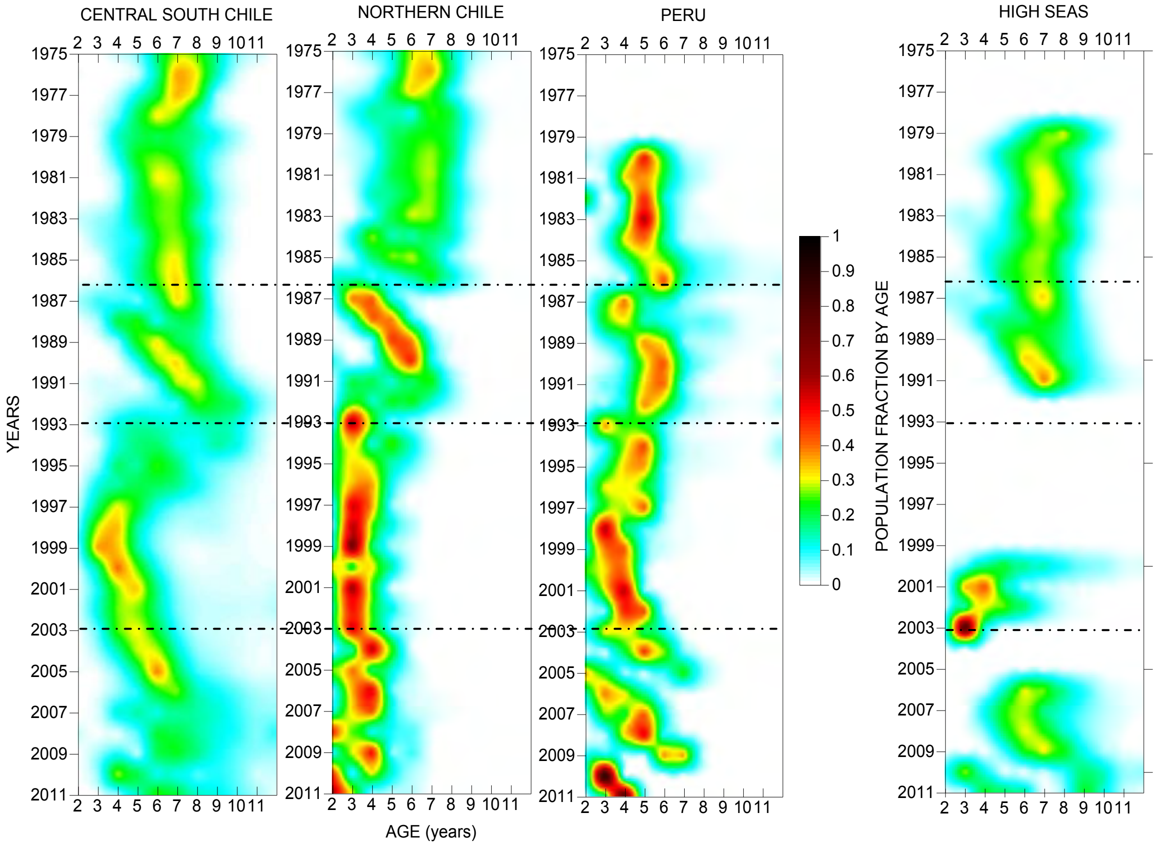

Figure 6. Description of the general demographic dynamics in the four fisheries. The figures represent the age (axis x) v.s the year (y axis). Horizontal dotted lines show the limits of the 4 sub-periods mentioned in the text. Note that high sea catches were obtained with different fishing gears than in Chile and far north (pelagic trawl vs. purse seine), which might generate differences in the demographic structures.

We have observed elsewhere that the ENSO events are almost always followed by a strong recruitment. Most of the ENSO cohorts can be observed during more than the average duration of others. Interestingly this could be linked with an observation done on school type proportions in the Chilean waters during the period 1991-1999, where the dense structures (big schools and dense layers) decreased in proportions during the ENSO (El Niño Southern Oscillation) events (Gerlotto and Barbieri, 2000; see chapt. 2). If we remind that CJM is dispersed during spawning, the coincidence of these high recruitments 2 years after ENSOs and the fact that during ENSOs fish are dispersed is a good confirmation that high recruitments of CJM are partly linked to ENSO events.

4. Discussion

Population concepts

The patchy population concept presents one simple strong requirement, i.e. either there is a single common spawning ground where all the adults spawn, or, if there are different spawning areas, individuals are not linked to a particular one and can spawn in any one of them; which results in an absence of genetic divergence in the whole distribution area. On the contrary, a metapopulation present a series of specificities and characteristics that have been widely discussed in the literature, and we need to enter more in details in order to know whether this concept can fit with the CJM characteristics.

The metapopulation was first defined by Levin (1969) as: "*a population of local populations which were established by colonists, survive for a while, send out migrants, and eventually disappear. The persistence of a species in a region depends on the rate of colonisation successfully balancing the local extinction rate".* The concept has been proved heuristic and was substantially enriched during the last decades. McQuinn (1997) presented a remarkable synthesis of these ideas when applying them to the populations of Atlantic herring, and synthesized Levin's ideas in four characteristics:

> *"(i) There is a large number of sites, each supporting a single local population;*
>
> *(ii) Each local population has a probability of going extinct that may depend on its genetic composition;*
>
> *(iii) The allele frequencies are governed by the classical genetic equations; and*
>
> *(iv) Vacant sites are recolonized by migrants from within the metapopulation"* (McQuinn, 1997).

Also, Grimm et al. (2003) indicated that there is asynchrony in local population dynamics because of partial closure of local populations that counteract homogenization of regional dynamics.

The definitions and description of the metapopulation concept shows that conditions for a metapopulation to exist are more restrictive than those for a patchy population. We thus first listed the conditions for a metapopulation to exist and to what extent the CJM fulfils these requirements or not (Table 1). To achieve this list we used the twelve conditions proposed by Hanski (1999) that we completed by adding four more conditions.

Table 1. Conditions for a metapopulation to exist (extended from Hanski, 1999) applied to the case of the CJM.

	Population characteristics	**The case of the CJM**
1	Population size or density is significantly affected by migrations	Yes, obviously: large movements between subpopulations related to environmental changes
2	Population density is affected by patch areas and isolation	Yes: CJM obviously presents a patchy distribution since its density is not constant all along its range of distribution. Small groups of old adults are always observed by the artisanal fishery along the shore
3	Existence of asynchronous local dynamics	Apparently no, but characteristics possibly within (hidden by) a global synchrony due to strong basin-scale

		environmental signals
4	Population turnover, local extinctions and establishment of new populations	Probably, the case of New Zealand where CJM was unknown before the 1970s is a good example. Also paleoecological results show a series of rise and fall in Peru during the last centuries and a strong increase in the 1970s (Gutiérrez et al., 2009)
5	Presence of empty habitats	Yes if we consider again the case of New Zealand and Tasmania
6	Metapopulations persist despite population turnover	Probably: fisheries have always showed the presence of fish in the central area, Chilean and Peruvian areas. Sporadic presence of small groups of very large sedentary adults along the South America coastline
7	Extinction risk depends on patch area	Yes, probably
8	Colonization rate depends on patch isolation	? This condition probably does not fit with the case of a large pelagic population
9	Patch occupancy depends on patch area and isolation	? This condition probably does not fit with the case of a large pelagic population
10	Spatially realistic metapopulation models can be used to make prediction about metapopulation dynamics in particular fragmented landscape	? No modelling exercise done so far testing the metapopulation hypothesis. Models have been constructed on the basis of the patchy population hypothesis (e.g. SPRFMO 2010)
11	Metapopulation coexistence of competitors	Yes: presence of mackerel in overlapping with the CJM at least in the Peruvian waters
12	Metapopulation coexistence of prey and its predator	? This condition probably does not fit with the case of a large pelagic population
13	Evidence of genetic linkage	Yes (Cardenas et al., 2005, 2009)
14	Genetic or morphometric, meristic or biological/behavioural differences	No: although genetics suggests that there is a single biological group Ashford et al. (2011) show some local differences
15	Existence of source/sink populations	Yes: the central offshore population is clearly the source, Peruvian and western Pacific being "sink" populations
16	Discrete local populations	Clearly no

Selection of the most adapted population structure

From Table 2 it appears that there are few but critical conditions that apparently do not fit with metapopulation definition in the case of CJM. Actually two of them, conditions 3 and 16, are contradictory with the metapopulation definition. Indeed, according to the theory, the different populations cannot be considered as discrete and it is impossible to draw clear borders between the populations with the existing data (condition 16) but the CJM has a strong plasticity (Bertrand et al, 2004, 2006), and can be encountered in the whole "Pacific belt". Also, in contradiction with condition 3, there is no independence between the apparent changes in the different population (synchrony of variations in abundance, migrations, etc.). This is particularly the case in the present time where all the sub-populations are shrinking together, from Peru and Chile to New Zealand. However, most of the other essential requirements of Table 2 are fulfilled by the CJM. This is particularly the case for the genetic linkage (condition 13) since Cardenas et al. (2009) showed that there is a single species and a single genetic population in the South Pacific Ocean, but also that there are differences in the colonization dates, the arrival in New Zealand being more recent than for populations along the coastline.

Nevertheless Gerlotto et al. (2012) observed that a few of the conditions listed in table 2 cannot apply for the particular characteristics of CJM. They conclude that some of the conditions listed do not fit with a large pelagic population, for a series of reasons, and particularly its dimension and spatiotemporal variability: the “incompatibilities” of most of the points are due to specific characteristics of these pelagic populations. It is worth noting that the concept of metapopulation has been first established for sedentary localized terrestrial populations. The major comment of the authors is that “the discussion on the organisation in metapopulation or in other structure must be leaded by empirical observation and practical needs: *The context-specific applicability of metapopulation theory reinforces Hanski’s argument that the metapopulation concept is more of an analytical approach to be used when appropriate rather than a set of strict criteria and definitions (Hanski 1999)”* (cited by Kritzer and Sale, 2004).

The description of CJM as a “patchy population” does not seem fully convincing either because the huge distances between some adult feeding grounds and spawning areas are contradictory with the definition. Indeed, according to the studies on parasite and otolithes chemistry (Ashford et al., 2011), it is unlikely that the CJM could indifferently spawn in any place inside the whole spawning area.

Pelagic populations with large range of distribution present particular characteristics that make uneasy the application of the list of conditions for a patchy vs. a metapopulation established from the literature. It is likely that ideally we should draw a particular series of definitions that fit to pelagic fish with large range of distribution. We consider that the main characteristic that would give sound information is the variation in demographic strategy of the subpopulations and propose the following scheme for the CJM. The “source” population, located off central Chile is the most important in term of abundance and produces “demographic pulsations” linked, among other, to ENSO signals that which induce periodic high recruitments invading the whole potential area of the CJM. Depending on the model selected (patchy vs. metapopulation), this would lead to different modelling of the population (Kritzer and Sales, 2006) and different recommendations for management policy.

A model of metapopulation for the South Pacific Jack Mackerel

We propose a schematic model (Fig. 7) describing the differences that are likely to occur in the CJM distribution and dynamics depending on the type of population. We voluntarily limited the model to the two subpopulations south and north to 20ºS.

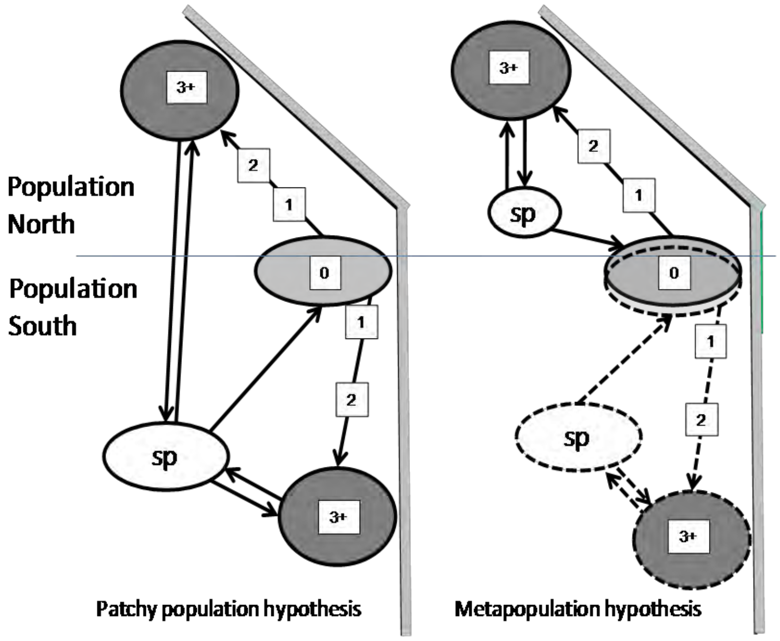

Figure 7. Diagram showing the theoretical differences in the biological cycles of CJM in the case of a patchy population (A) or metapopulation (B) structure of the populations, using the actual migration diagram of the Chilean centre-south stock as a basis. sp = spawning ground; 0 to 3+: year classes. In (B) the two subpopulations are differentiated by solid (north) or dotted lines (south). For simplification, central-oceanic and western subpopulations are not considered in this diagram

In the case of a patchy population (Fig. 7A), the Centre-South population off Chile could be considered as the "source" population, and the Peruvian population as an extension of this source in periods of high abundance. The larvae leave (actively or passively) the spawning area to go to a nursery area (age 0). Then, while growing, fish migrate slowly southward (Chile) or northward (Peru). Here the migration direction is not related to particular parts of the population and individuals should indifferently choose to go north or south, otherwise genetic divergence is likely to occur. At age 3, the young adults begin the annual migratory cycle between the feeding ground and the spawning area. This "patchy population diagram" is similar to the one described by Arcos et al (2001), but extended to the northern population. Ashford et al (2011) showed that this symmetric colonisation has different effects on these two parts of the stock as observed through otolith chemistry, considering the ecosystems north and south of 20ºS are not similar in many aspects, particularly in terms of temperature and depth and intensity of the oxygen minimum zone (see Bertrand et al., under review). We can extrapolate this observation and assume that this difference in feeding areas would have different selective impacts on the biology of the two stocks. If the effects are distinct, then some divergence in the traits of life of the CJM in Chile and Peru should happen sooner or later.

Under a metapopulation hypothesis (Fig. 7B), a specific cycle, different from the south one, appears in the north where the young adults, instead of going to the common spawning ground, create a new one specifically for their population. Indeed a specific spawning ground for each subpopulation is essential in the definition of a metapopulation, as it is the only way for them to be able to diverge genetically from the parent population. This creation is made easy considering that the CJM is rather opportunistic and tends to spawn in any place where the conditions are favourable: we have seen that no real homing exists as far as spawning is concerned and local spawning grounds can appear at the closest place from the feeding areas compatible with the main environmental requirements for spawning to occur. In this case the cycle becomes independent and metapopulation can appear. This metapopulation model is also in agreement with the general hypotheses from Petitgas et al. (2010), who observed the existence of different emerging behaviours in a population that produce migrant and non migrant groups. The fact that the fish share a common juvenile growth area is also observed in the demographic structures of the stocks in Peru and Chile, where the distribution of year classes are symmetric in latitude. Nevertheless exchanges still can occur between individuals from the two sub-populations, as stated by McQuinn (1997) for the herring and Petitgas et al. (2010) for the anchovy in the Bay of Biscay.

Is the superpopulation a patchy population?

It is interesting to study the "superpopulation" hypothesis (figure 10) that was described by Gretchina et al. (2013[1]). Indeed it represents another interpretation of the same observed patterns. We observed the same three major groups gathering an adult area and a spawning area: one along the Peruvian coastline, another one off the centre-south of Chile, and a third one in oceanic waters. Then, the diagram displays a "juvenile sub-population" in south Peru – North Chile. Apart this particular "sub-population", there is a rather good similarity between the diagram of the figure 10 and the one presenting the metapopulation on figure 8.

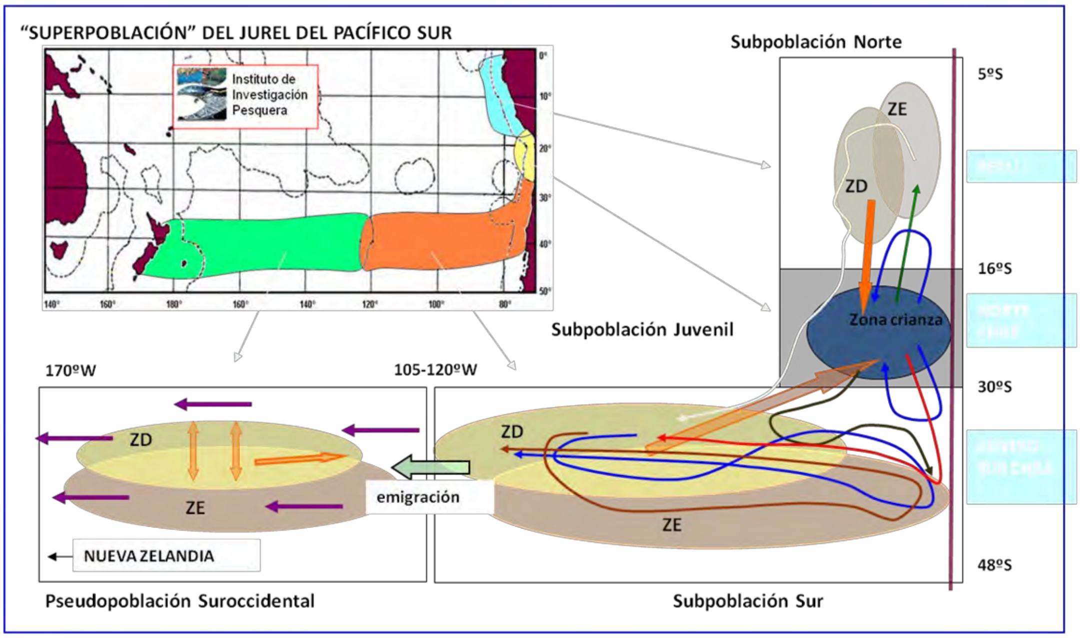

Figure 8. Diagram presenting the "superpopulation hypothesis" for the Chilean jack mackerel

About the "juvenile subpopulation", according to the Harden Jones' migration triangles, it cannot be considered a population, as by definition a population or a sub-population must gather an adult area, a spawning area and a juvenile area. In this particular case, what is called

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[1] Gretchina, A., Sepulveda, A., Nuñez, S., González, C., 2013. J ack mackerel superpopulation and the climate variability in the Pacific Ocean. (REF?)

juvenile sub-population represents a concentration of juveniles from the Chilean and the North populations that may share a common area, as it occurs in many other fish populations (e.g. north sea herring). We consider that the superpopulation hypothesis is not a patchy population for each group has a specific spawning area: it is closely related to a metapopulation scheme.

5. Conclusion

The question asked in this paragraph was: which one of the two models, metapopulation vs. patchy population, is better representing the current situation. The simplest way to test them is evaluating whether the existing spawning grounds and demographic structures observed from surveys and from the fisheries are or are not in contradiction with the patchy population and/or the metapopulation hypotheses. We have seen that there are different cohort histories, some being common to the two areas (NC+CSC vs. FN) while some others remain located in only one area.

Here too, as in the case of the egg distribution and spawning areas, the results are not in contradiction with the metapopulation hypothesis. Nevertheless whatever the result is, the frequent resetting of the ecosystem (by the ENSO and decadal cycles?) does not give enough time for the subpopulations to diverge (Bakun and Broad, 2003). The metapopulation can be effective but leading to no genetic divergence.

From an empirical as well as theoretical point of view we might conclude that the CJM can be still represented by such metapopulation structure. This can change soon if the decreasing of some of the different subpopulations (coastal Chile, offshore, New Zealand) reaches a level of collapse. In this case we will be put into a situation of a single population (the source, remaining the only one), until a new expansion colonises again the whole potential area. But the recent changes observed in 2010-2011 in the northern Peruvian population shows on the contrary that some sub-populations have opposite dynamics. Besides, it seems interesting to compare in details the two schemes of metapopulations and superpopulation: it seems in a first approach that they are practically identical, the only difference being the existence of a “juvenile subpopulation” which meaning is not clear. From these precise comparisons, a final model could be proposed.

The CJM does not present real discrete populations (Cardenas et al., 2009; Ashford et al., 2011). If we apply the definitions from the literature we cannot directly apply neither the metapopulation concept nor the patchy population to it. The need for defining as precisely as possible the organization type of the CJM comes from the managers. In the present context of overfishing and low population state (see www.southpacificrfmo.org), if we consider that the adult “source” of the total population is located in unregulated international waters where everybody can exploit it, then the whole population is in danger. As long as the source was large enough to fill-up the Chilean EEZ, and the other subpopulations (mostly Peruvian and oceanic) were in good shape, the bulk of the catch was taken from them while the “source” was protected by the highest cost of going offshore for fishing. This is no longer the case. As pointed out by several authors (e.g. Hanski, 1999), a practical and heuristic definition is needed before any management decision be taken. In this case, assuming the CJM as forming a metapopulation is a precautionary approach, which considers the central offshore stock as the source and therefore as particularly important. Management of this particular part of the metapopulation becomes a priority, and in case of collapse of the other sub-populations it could be recommended to close of strictly restrict the fishing activity in this particular 'source' area. Another conclusion can be drawn: the concept of metapopulation has been designed on cases from terrestrial and rather small sedentary populations of animals. It is not surprising that the definition and some of the conditions defined do not apply to a world-wide highly versatile and migrating pelagic fish population. Application of the concept to such animals has always been difficult and if in some case it gave remarkable results (e.g. on herring, probably due to the homing behaviour of herring as benthonic spawners, see McQuinn, 1997), in several other no clear conclusion could be obtained. This was the case for the European horse mackerel *Trachurus trachurus* which also presents a wide distribution area (from Norway to Mauritania and Greece) but where the genetic analysis showed, as in the case of the CJM, no difference in the different geographically separated populations (EU Project HOMSIR: www.homsir.com).

In order to go further in the analysis of this metapopulation application to large pelagic stocks, there is need for some theoretical work to evaluate how these populations can be analysed inside the framework of the metapopulation concept, and probably to write adapted definitions for these species.

General conclusion of the synthesis.

This synthesis showed that there is an important material available but mostly in unpublished reports that covers all the aspects of the biology, the ecology and the fishery of the Chilean Jack Mackerel. From this considerable bibliographic base the major characteristics of the traits of life of the CJM have been extracted, and particularly on the elements that can be used for defining the habitat of this species. The documents insisted particularly in three domains where the information received is of interest for the purposes of the Project: Habitat and plasticity of the CJM; Strategies of the populations; population structures. They are detailed below.

Habitat and plasticity of the CJM

(1) Two major points characterize the SE Pacific Ocean: the strength of the climatic signals (e.g. El Niño) and their high variability. Fish populations must develop a high resilience and plasticity to adapt to these characteristics and changes some elements of its behaviour during these periods (schooling).

(2) The biological characteristics show that CJM presents a high plasticity in front of the hydrological conditions. The limits and preferenda of the CJM for the main hydrological characteristics are the following according to the literature:

parameter	Lower limit	Upper limit	Lower preferendum	Upper preferendum
Oxygen	0.1 ml/l	-	0.2 ml/l	-
temperature	9º	26º	15º	20º
Salinity	<minimum observed	>maximum observed	34.9	35.1
Chl a	0.07mg/m3	26 mg/m3	0.1	?
oxycline	-	30 m	-	40 m

(3) Water masses. The CJM can adapt to most of the water masses inside its limitations and preferenda, but is usually encountered inside the subtropical waters.

(4) Interactions with other species (predation, preys, competition) show that the CJM distribution is not overlapping the distribution areas of tunas (potential predators; exception for the albacore in its most southward distribution area) nor the distribution of anchovies (potential preys). Some works seem to show that the CJM was in competition with whales for its alimentation and suffering predation from Cetacean (in the juvenile phase). It presents practically the same ecological characteristics as the mackerel (*Scomber japonicus*) with which it is almost always found in the catches (Peru, EU, others?). The CJM has no serious predator in its distribution area (exception with apbacore, see above; cetaceans?; giant squid (?). Considering that the fish has no major predators in the bulk of its distribution area, the main limiting factor to its distribution and abundance is the prey availability.

Population strategies.

(5) Unity of T. murphyi as a single species in the South Pacific Ocean; although there are patches of high densities in several areas (North Chile, Peru, centre-south Chile, open ocean west of 90ºW, etc.) there is no biological evidence of significant differences between them.

(6) The CJM presents the characteristics to produce strong year classes approximately once each 5-6 years. These successful recruitments seem to be related to the El Niño

events. They are generally observed in the whole distribution area, but in periods of relative stability significant differences appear depending on the regions (North to 22ºS and east to 85ºW; south to 30ºS and east to 85ºW; west 85ºW), the proportion of a given year class inside the whole biomass of the population can be significantly different from a region to another.

(7) There is no general pattern of distribution of the juveniles versus the adults: in some parts of the area there is a clear separation between juveniles and adults, e.g. North Chile (juveniles) and Centre-south Chile (adults); in others (Peru) the groups share the same area; in others (open ocean west of 85ºW) there is a migration westward during the life of the year class.

(8) Spawning occur during the austral summer, mainly in two areas, the largest one being located between 70ºW-90ºW and 30ºS-40ºS, the second one being smaller and more variable, along the Peruvian waters. The spawning area and the recruitment should be monitored yearly.

(9) It seems that the CJM displays a general pattern of varying the surface of the distribution area when changing its abundance, while maintaining unchanged its local density. Some exceptions seem to exist in some cases (inversely, changing the density while the surface remains unchanged). Besides, the CJM populations follow a general pattern that consists in the occurrence of a few strong cohorts, sometimes associated with El Niño occurrence (figure 1).

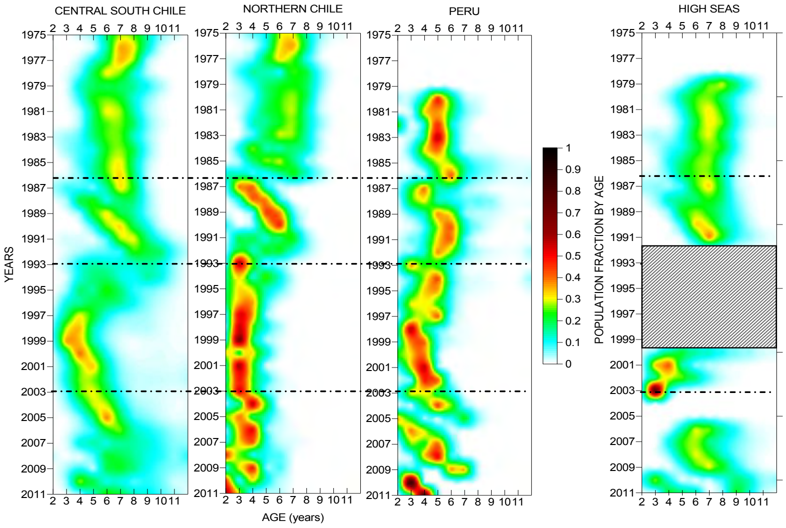

Figure 1 Age structure of CJM caught in the three main fisheries during the period 1975-2011 (from SPRFMO data, in Gerlotto et al., 2012). The grey sector in the high sea fishery corresponds to the period with no fishing activities between the end of the Soviet and the beginning of the Russia fishery.

(10) When environmental changes are strong there is synchrony in the whole CJM belt in terms of expansions and shrinking of the distribution; in periods of stable conditions, significant differences appear between the regions, especially as far as recruitment and distribution are concerned.

<u>Population structure</u>.

(11) Concerning biological markers (genetics, otholiths, parasites), the existing results converge towards the conclusion that there are some differences between the three major areas, North (north Chile and Peru), centre-south Chile and open Pacific Ocean west of Chile, as it appears in many works done with other methods; there is no

genetic differences in fish all over the whole distribution area; there is no discrete borders between the different spawning and population areas although some structures exist, especially between centre-south Chile and the northern (Peruvian) area. The fact that none of these works give significant result does not forbid noticing this convergence of facts, which mean that there is an urgent need to perform international work on this question.

(12) Two synthetic conclusions: <u>Probable existence of at least two separate "groups"</u> (not to say sub-populations) along the coast of south America, approximately north and south of the latitude 22ºS; <u>Huge variability of the overall biomass</u> that is accompanied by large movements of expansion and reduction at the edges of the distribution area.

(13) Among the four hypotheses that have been listed by the SPRFMO, the recent results in studies of biological markers and demographic dynamics allow to reject two of them. The question then remains on whether the global population is organized into a metapopulation or a superpopulation (figure 2).

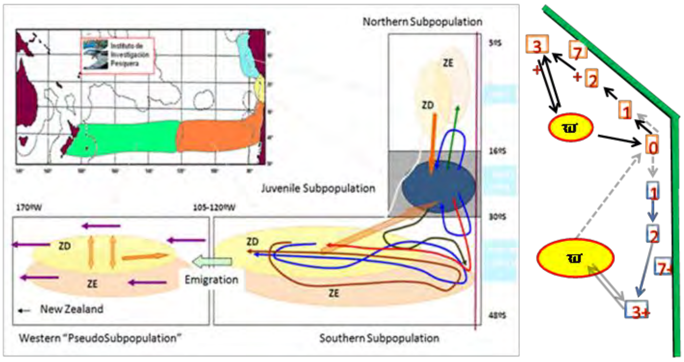

Figure 2. Left: the hypothesis of "superpopulation" (or patchy population); right: schema of the metapopulation hypothesis, limited to the eastern part of the distribution area (ω = spawning area; squares numbered 1 to 7: location of the age classes).

There is a great convergence between the two hypotheses, the final conclusion in terms of management being the only real difference. It seems that the metapopulation hypothesis represents better the different characteristics of the stocks and populations and seems to be the most consistent with the major biological and ecological characteristics of the CJM.

<u>Some intriguing questions remain</u>, e.g. the existence of independent or semi-independent populations, the existence of identified spawning areas and their respective migrations of larvae, the value of the total biomass, etc.

One important recommendations to extract from this work deals with fish population monitoring through the use of acoustic methods aboard scientific and fishing vessels, as already recommended by SPRFMO in 2012. The use of the fleet for monitoring corresponds to a recommendation of the SPRFMO and is particularly efficient. Experiments on the Peruvian fishery were done by the SNP (see above) and demonstrated their richness (figure 3). The feasibility of such monitoring is therefore demonstrated through its application in the case of the Peruvian fleet. The Chilean fishery is also monitored but there is no reference in the literature.

Besides, monitoring is not only a way to get field observation where scientific surveys are impossible: it is the answer to a wider question that could be formulated that way: is the CJM driven only by the fishery, or by both the fishery and the environment. Or in other terms: do the CJM deserve an Ecosystem approach to the fishery? If the answer is negative, then catch and fishing activity data are sufficient to manage the stock; if it is positive, then the use of catch and effort data only will never allow the management of the stock: environmental information is needed. In this case there is no other way that monitoring using the fishing fleet (plus other sources of data: satellites, models, oceanography, ecological studies, scientific surveys, etc.) to understand the dynamics of this population and therefore to model it correctly.

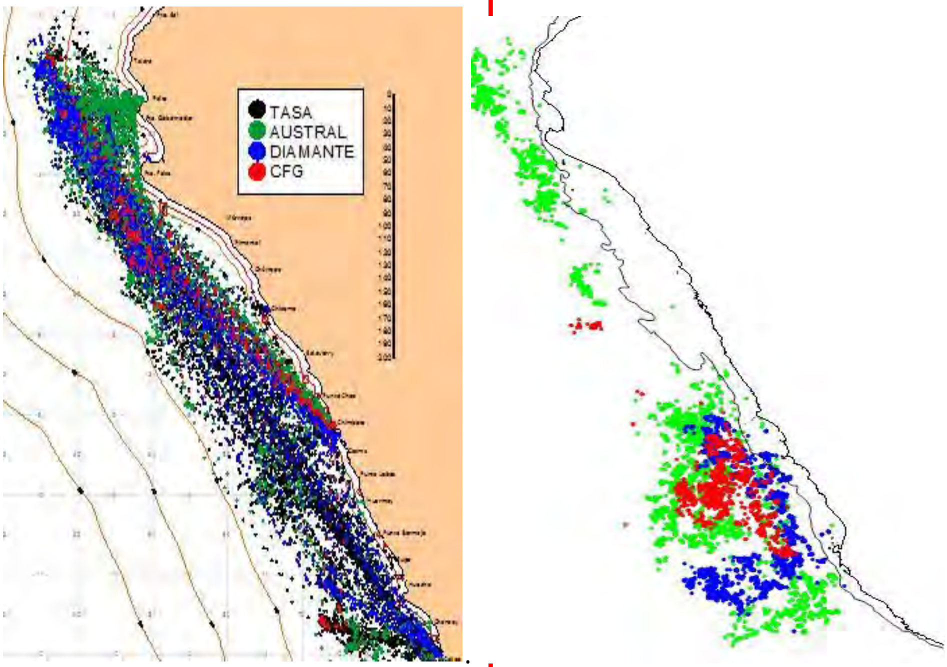

Figure 3. Left: Magnitude of the potential sampling effort: map of the points sampled acoustically by the fishing fleet of the four most important fishing companies in Peru (TASA, Austral, Diamante, CFG), during the period January-March, 2011 (from SNP workshop report, 2011). Right: Purse seine sets on CJM and mackerel in 2011 (green), 2012 (blue) and 2013 (red). The spatial heterogeneity of distribution can be observed, and particularly the fact that CJMs do not enter the shelf inside 180 m isoline (left line) off the coastline (right line). (From SNP workshop report, 2013)

Map of the 150 000 EDSUs sampled by the 4 main fishing companies, January-March, 2011

Bibliographic list on *Trachurus murphyi*

Note. The documents submitted to or produced by the SPRFMO are listed after the bibliographic list.

1. Abramov, A.A.; Kotlyar, A.N. (1980). Some biological features of the Peruvian jack mackerel, *Trachurus symmetricus murphyi*. Journal of Ichthyology 80: 25−31.
2. Abramov, A.A. and A.N. Kotlayar 1980. Some Biological Features of the Peruvian Jack Mackerel, *Trachurus symmetricus murphyi*. J. Ichthyol. 20(1):25-31.
3. Adams, P.B., 1980. Life history patterns in marine fishes and their consequences for fisheries management. Fish. Bull. 78:1-12
4. Agafonov, A. Y. 1994. Bases oceanográficas de la formación de las concentraciones comerciales de jurel en el Pacífico Suroccidental. Páginas: 107-111. En D. ARCOS y A. Grechina (Eds). Biología y Pesca Comercial del jurel en el Pacífico Sur. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 203 pp.
5. Akkiran, N., 1985. A systematic study on Carangidae (Pisces) employing the otolith characters in Eastern Mediterranean, Bilj. Notes Inst. Oceanogr. Ribar., Split, 63: 1-9
6. Aksnes, D. L., and Giske, J. 1990. Habitat profitability in pelagic environments. Marine Ecology Progress Series, 64: 209-215.
7. Alay, F. Gonzalez, F., Gavilán, J., Cabello, J. and Chávez, R., 1994. Sección III. Genética. En: Unidades de stock en el recurso jurel de la I a la IX regiones. Informe final proyecto FIP 019-94: 118 p.
8. Aldana, M., Oyarzún, J., George-Nascimento, M., 1995. Ceratothoa gaudichaudii y C. Trigococephala (Isopoda : Cymothoidae) como indicadores poblacionales del jurel Trachurus symmetricus murphyi (Pices : Carangidae) frente a Chile. Biología Pesquera (Chile) 24, 17-21.
9. Aldana. M., Oyarzun, J. and George-Nascimento, M., 1995. Isopodos parasites como indicadores poblacionales del jurel *Trachurus symmetricus murphyi* (Nichols, 1920) (Pisces: Carangidae) frente a las costas de Chile. Biologia Pesquera (Chile), 24: 23-32
10. Aldana, M., Oyarzún, J., George-Nascimento, M., 1995. Ceratothoa gaudichaudii y C. Trigococephala (Isopoda : Cymothoidae) como indicadores poblacionales del jurel Trachurus symmetricus murphyi (Pices : Carangidae) frente a Chile. Biología Pesquera (Chile) 24, 17-21.
11. Alheit, J. & M. Ñiquen. 2004. Regime shifts in the Humboldt Current ecosystem. Progress In Oceanography 60, 2-4 :201-222.
12. Alegria V.,et al, 1994 Estudio biológico-pesquero sobre el recurso jurel en la zona norte (i y ii regiones) Informe Final Proyecto FIP-IT/ 93-17
13. Andrianov, D.P., 1985. Study on the reproduction of Peruvian scad, Trachurus murphyi (Carangidae), of the Peruvian Shelf. J. Ichthyol. 25(2):32-40.
14. Andrianov, D. P. 1994. Sobre la biología reproductiva del jurel peruano. Páginas: 25-35. En D. ARCOS y A. Grechina (Eds). Biología y Pesca Comercial del jurel en el Pacífico Sur. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 203 pp.
15. Andrianov, D.P., L.A. Lisovenko, A.N. Kotlyar and A.A. Abramov, 1990. Data on reproduction of some near-bottom fishes of the Nazca and Sala y Gomez Submarine Ridges. Trudy Inst. Okeanol. 125:58-96.
16. Annala, J.H. (comp.), 1994. Report from the Fishery Assessment Plenary, May 1994: stock assessments and yield estimates. Unpublished report held in MAF Fisheries Greta Point library, Wellington. 242 p
17. Anonymous (1999). Anuario estadístico de pesca 1998. Servicio Nacional de Pesca, Ministerio de Economía, Fomento y Reconstrucción, Chile, 293 pp. (In Spanish)

18. **Anonymous**, 2001. Fish collection database of the National Museum of Natural History (Smithsonian Institution). Smithsonian Institution-Division of Fishes

19. **Anonymous**, 2002. Fish collection database of the American Museum of Natural History. American Museum of Natural History, Central Park West , NY 10024-5192, USA

20. **Anonymous**, 2003. Fish collection of the Royal Ontario Museum. Royal Ontario Museum.

21. Aracena, O., R. Alarcón, S. Collado, I.Lépez, & D. Arriaga. 1998. Aspectos reproductivos del jurel (Trachurus symmetricus murphyi) de la pesquería de cerco de la Octava Región, Chile, 1994-1995. In: Arcos, D. (ed.). Biología y Ecología del jurel en aguas chilenas. Instituto de Investigación Pesquera, Talcahuano, Chile: 101-114.

22. Arancibia, H.L., and Cubillos, L., 1993. Análisis de la pesquería industrial regional de cerco, dinámica poblacional y situación del recurso jurel, Trachurus murphyi. Doc. Tec. Inst. Invest. Pesq. (IIP), Talcahuano, Vol. 2. Núm. 1. 23 pp + figuras.

23. Arancibia, H., L. Cubillos, L. Vilugrón, D, Arcos. 1994. Dinámica poblacional del jurel, Trachurus murphyi, y análisis de la pesquería industrial de cerco de la zona centro-sur, Chile (1993). Doc. Tec. Inst. Invest. Pesq. (IIP), Vol. 3, Núm. 26 pp.

24. Arancibia, H., Hernandez, A., Vilugrón, L., Cubillos, L., Núñez, S., Alarcón, R., Miranda, L., and Vásquez, G., 1995. Sección I Morfometría y Meristica. In: Unidades de Stock en el recurso jurel de la I a la IX Regiones. Informe final Proyecto FIP 019-94: 118 p.

25. Arancibia, H., Vilugrón, L. y D. Arcos (Eds). 1995. Estudio biológico-pesquero sobre el recurso jurel en la zona centro-sur, V a IX regiones. Informe Final FIP, IT/93-18.

26. Arancibia, H., Cubillos, L., Arcos, D., Grechina, A., Vilugrón, L., 1995. The fishery of horse *Trachurus symmetricus murphyi* in the South Pacific Ocean. With emphasis on the fishery unit off Central Chile. Scientia Marina. 59(2): 113 117.

27. Arancibia H., et al, 1995 Unidades de stock en el recurso jurel de la i a la xi regiones. Informe Final Proyecto FIP-IT/ 94-19

28. Aranis et al, 1999 Inves situación pesqueria pelagica zona centro sur 1998. Informe Final, Proyecto IFOP/1998

29. Aranis et al, 2000 Inv. situación pesqueria pelagica zona centro sur 1999. Informe Final, Proyecto IFOP/1999

30. Aranís et al, 2001 Investigación situación pesquerias pelagicas zona centro sur 2000. Informe Final, Proyecto IFOP/2000

31. Aranís et al, 2002 Inves. situación pesqueria pelagica zona centro sur 2001. Informe Final, Proyecto IFOP/2001

32. Aranís et al, 2003 Inves. situación pesqueria pelagica zona centro sur 2002. Informe Final, Proyecto IFOP/2002

33. Aranís et al, 2004 Investigación situación pesquería pelágica centro-sur 2003. Informe Final, Proyecto IFOP/2003

34. Aranís et al, 2005 Investigación situación pesquería pelágica centro-sur 2004. Informe Final, Proyecto IFOP/2004

35. Aranís et al, 2006 Investigación situación pesquería pelágica centro-sur 2005. Informe Final, Proyecto IFOP/2005

36. Aranís et al, 2006 Investigación situación pesquería pelágica centro-sur 2006. Informe Final, Proyecto IFOP/2006

37. Aranis R., A, L. Caballero, A. Gómez, G. Rosson, M. González, F. Cerna, V. Bocic, A. López, C. Machuca, J. Letelier, C. Vera y Z. Young. 2009. Informe Final, Investigación Situación Pesquería Pelágica Zona Centro-Sur, 2008. Seguimiento del Estado de Situación de las Principales Pesquerías Nacionales. Subsecretaría de Pesca, Inst. Fom. Pesq. Valparaíso, Chile. 186 p + Anexos.

38. Araya, M., Cubillos, L.A., Guzman, M., Peñailillo, S., Sepúlveda, A., 2001. Evidence of a relationship between age and otolith weight in the Chilean jack Mackerel *Trachurus symmetricus murphyi* (Nichols). Fisheries Research 51:17-26

39. Araya, M, M. Medina & H. Arancibia, 2003. Preliminary results of the empirical validation of daily increments in otoliths of Jack mackerel *Trachurus symetricus* (Aires, 1855) marked with oxytetracycline. Depattamento Ciencias del Mar, Universidad Arturo Prat, Iquique –Chile. P 471-475.

40. Anonymous (1997). Review of the state of world fishery resources: marine fisheries. 15 Southeast Pacific, FAO statistical area 87. FAO Fisheries Circular No. 920 FIRM/C920.

41. Arcos, D.F, 1987. Seasonal and short time scale variability in copepod abundante and species composition in an upwelling area off Concepción coast, Chile. Ph.D. Thesis Dissertation, State University of New Cork, Stony Brook, 203 pages.

42. Arcos, D. (ED.) 1998. Biología y Ecología del Jurel en Aguas Chilenas. Ed. Anibal Pinto, Chile, 236 pags

43. Arcos D.,et al, 1994 Estudio biológico-pesquero del recurso jurel en la zona centro-sur (v a ix regiones) Informe Final Proyecto FIP-IT/ 93-18

44. Arcos D.,et al, 1996 Evaluación del stock de jurel a nivel subregional Informe Final Proyecto FIP-IT/95-09

45. Arcos, D., et al, 2005 Condiciones biológicas del jurel en alta mar, año 2004. Informe Final Proyecto FIP-IT/ 2004-33

46. Arcos, D.F., & A.S. Grechina (Eds.), 1994. Biología y pesca comercial del jurel en el Pacífico Sur. Ed. Aníbal Pinto, Concepción, Chile, 203 p.

47. Arcos, D. & A. Gretchina. 1998. In: S.Avaria, J.Carrasco, J.Ruttland & E.Yáñez (eds.). El Niño-La Niña 1997-2000. Sus efectos en Chile. CONA, Chile, Valparaíso, pp.153-177.

48. Arcos, D.F., L.A. Cubillos & S. Núñez. 2001. The jack mackerel fishery and El Niño effects off Chile. En: McKinnell, S.M., R.D. Brodeur, K. Hanawa, A.B. Hollowed, J.J. Polovina & C.I. Zhang (eds.), Pacific climate variability and marine ecosystem impacts from the tropics to the Artic. Progress in Oceanography, 49: 597-617.

49. Arcos, D.A., Cubillos, L.A., Núñez, S. P. 2001. The jack mackerel fishery and El Niño effects off Chile. McKinnell, S.M., R.D. Brodeur, K. Hanawa, A.B. Hollowed, J.J. Polovina, y C.-I. Zhang (eds.), Pacific climate variability and marine ecosystem impacts from the tropics to the Arctic. Progress in Oceanography 49,597-617.

50. Arcos, D., L. Cubillos & S. Núñez. 2004. In: S.Avaria, J.Carrasco, J.Ruttland & E.Yáñez (eds.). El Niño-La Niña 1997-2000. Sus efectos en Chile. CONA, Chile, Valparaíso, pp.153-177.

51. Arcos, D., C. Gatica, P. Ruiz, A. Sepulveda, M.A. Barbieri, R. Alarcon, S. Nuñez, J. Chong, J. Cordova, A. Rebolledo, C. Gonzales, F. Contreras, M. Aguayo, F. Vejar, P. Torres and C. Toro. (2005). Condición biologica de jurel en Alta Mar, año 2004. Informe Final Proyecto FIP 2004-33. Fondo de Investigación Pesquera.

52. Arrieta, S. and M. Giron. 1989. Ecología de las larvas de jurel *Trachurus murphyi* (N) en la costa peruana. I Symposium sobre ecología y conservación en el Perú. Lima, Perú.

53. Astorga M. y R. Galleguillos. 1998. Divergencia genética de jureles del género Trachurus desde el Pacífico noroeste y sureste. Revista de Biología Marina Vol 33 N°1: 155-161.

54. Avdeyev, V.V. (1992). On the possible use of parasitic isopods as bioindicators of the migratory routes of horse mackerels in the Pacific Ocean. Journal of Ichthyology 32: 14–21.

55. Ayón, P., Purca, S. and Guevara-Carrasco, R. (2004) Zooplankton volumes trends off Peru between 1964 and 2001. ICES Journal of Marine Science 61, 478–484.

56. Bahamonde, R. (1978). Distribución y abundancia relitiva de los principales recursos demersales entre Corral (40ºS) y el Cabo de Hornos (57ºS). Instituto de Fomento Pesquero IFOP/JAMARC. Informe Interno.

57. Bahamonde, R., Leiva, B. Leiva, F., y Hernández, C. 2006. Determinación de la distribución espacial de jurel entre la V y X región. Otoño 2006. Informe Final. Subsecretaría de Pesca. Instituto de Fomento Pesquero. 37 p.

58. Bailey, K. (1989). Description and surface distribution of juvenile Peruvian jack mackerel, *Trachurus murphyi*, Nichols from the subtropical convergence zone of the central South Pacific. Fishery Bulletin 87: 273–278.

59. Bailly, N. (2012). *Trachurus murphyi* Nichols, 1920. In: Froese, R. and D. Pauly. Editors. (2012) FishBase. Accessed through: Froese, R. and D. Pauly. Editors. (2012) FishBase at http://www.marinespecies.org/aphia.php?p=taxdetails&id=273303 on 2012-11-22

60. Bakun, A. (2001) 'School-mix feedback': a different way to think about low frequency variability in large mobile fish populations. Progress in Oceanography 49, 485–511.

61. Bakun, A. and Broad, K. (2003) Environmental 'loopholes' and fish population dynamics: comparative pattern recognition with focus on El Nino effects in the Pacific. Fisheries Oceanography 12, 458–473.

62. Barber, R.T. and Chavez, F.P. (1983) Biological consequences of El Niño. Science 222, 1203–1210.

66. Barbieri M.A., et al, 1996 Evaluación hidroacústica del recurso jurel en la zona centro-sur (fase crucero metodologico) Informe Final Proyecto FIP-IT/ 95-07

66. Barbieri M.A., et al, 1998 Análisis de la estructura del stock de jurel fuera de las aguas jurisdiccionales Informe Final Proyecto FIP-IT/ 97-05B

67. Barbieri, M. A., Córdova, J. Lillo, S. Castillo, J. Böhm, G. Blanco, J. L. Yáñez, E. Catasti, V. Robotham, H. Arancibia, H. Guzmán O., y Gerlotto, F. 1996. Evaluación Hidroacústica del recurso jurel en la zona centro-sur (fase crucero metodológico). Informe Final. FIP IT/95-07. Instituto de Fomento Pesquero, Valparaíso, Chile. 52 p. + anexos y Fig.

68. Barbieri MA, Córdova J, Lillo S (1998) Evaluación hidroacústica del recurso jurel en la zona centro-sur (fase crucero metodológico). Informe final Fondo de Investigación Pesquera no. 95–07, Instituto de Fomento Pesquero, Santiago 113 pp.

69. Barbieri, M.A., Córdova, J., Lillo, S., Peña, H., Grechina, A., Núñez, S., Sepúlveda, A., Miranda, L., Rebolledo, H., 1999. Análisis de la estructura del stock de jurel fuera de las aguas jurisdiccionales. Inf. Téc. FIP-IT/97-05B, 121 pp. (www.fip.cl).

70. Barbieri, M. A., Córdova, J. Espejo, M., y Brito, S. 2003. Determinación de la distribución espacial de jurel entre la V y X región. Otoño- invierno 2003. Informe Final. Subsecretaría de Pesca e Instituto de Fomento Pesquero. 18 p.

69. Barbieri, M.-A., J. Cordova, F. Gerlotto, M. Espejo, 2004. Spatial spawning strategy of jack mackerel (*Trachurus symmetricus murphyi*) off the central-south region of Chile. Comm. Grupo de trabajo SPACC, Concepcion, Enero 2004. (version paper): 4 p.

70. Barbieri, M. A., Córdova, J., y Correa, V. 2004. Determinación de la distribución espacial de jurel entre la V y X región. Otoño- invierno 2004. Informe Final. Subsecretaría de Pesca e Instituto de Fomento Pesquero. 18 p.

71. Barbieri, M. A., Correa, V., y J. Córdova. 2005. Determinación de la distribución espacial de jurel entre la V y X región. Otoño 2005. Informe Final. Subsecretaría de Pesca e Instituto de Fomento Pesquero. 37 p.

72. Barbieri, M. A. (2008). Research and management of Chilean jack mackerel (*Trachurus murphyi*) exploited in the South East Pacific Ocean. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

73. Barría, P., Aranis, A., Mora, S., Böhm, G., Catasti, V., Peña, H., González, C., and Vejar, F. 1999. Monitoreo de las capturas de jurel en la zona centro-sur. 1999. Informe final Fondo de Investigación Pesquera n º 98-01. 102 pp.

74. Barría P., et al, 2000 Monitoreo de las capturas de jurel, 1999 Informe Final Proyecto FIP-IT/ 99-02

75. Barría P., et al, 2001 Monitoreo de las capturas de jurel, año 2000 Informe Final Proyecto FIP-IT/2000-02

76. Basten, J.; Contreras, P. (1978). Observaciones preliminares sobre la pesquería del jurel Trachurus murphyi (Nichols) en la zona norte de Chile. Períoda julio 1975–julio 1978. Universidad del Norte Departamento Pesquerías Informe Técnico. 62 p.

77. Bayley, K. 1989. Description and surface distribution of juvenile Peruvian jack mackerel *Trachurus symmetricus murphyi* Nichols from the Subtropical Convergence zone of the central south Pacific. Fish. Bull. U.S., 87(2) : 273-278.

78. Béarez, P. 1996. Lista de los Peces Marinos del Ecuador Continental , Source: Revista de Biologia Tropical, Vol. 44, Page: 731-741

79. Ben Salem, M. & M.H. Ktari. 1991. Classification phénétique par analyse des correspondances des espèces du genre *Trachurus* Rafinesque, 1810 (Poissons, Carangidae). Oceanologica Acta, 14(6): 599-603.

80. Bernal P, F Robles & O Rojas. 1983. Variabilidad física y biológica de la región meridional del sistema de corrientes Chile-Perú. En: Sharp G & J Csirke (eds). Actas de consultas de expertos para examinar los cambios en la abundancia y composición por especies de recursos de peces neriticos. FAC Informes de Pesca (291) 3: 683-711. San José, Costa Rica.

81. Bernal, P. 1986. La oceanografía del sistema de corrientes de Chile-Perú en relación a sus pesquerías, en OLDEPESCA/SELA 1986. Bases biológicas y marco conceptual de los recursos pelágicos en el Pacífico Suroriental. Edición coordinada por O. A. Maticen e I. Tsukayama. Documento de pesca I, 196pp.

82. Bertrand A, Barbieri M.A., Cordova J, Hernandez C, Gomez F, Leiva F (2004) Diel vertical behaviour, predator prey relationships, and occupation of space by jack mackerel (*Trachurus murphyi)* off Chile. ICES J Mar Sci 61: 1105–1112

83. Bertrand A, Barbieri M.A., Gerlotto F, Leiva F, Córdova J (2006) Determinism and plasticity of fish schooling behaviour as exemplified by the South Pacific jack mackerel *Trachurus murphyi.* Mar Ecol Prog Ser 311:145–156

84. Bertrand, A., J. Cordova, M.-A. Barbieri, F. Leiva y F. Gerlotto, 2004. Contrasted day and night ecological preferenda of jack mackerel (*trachurus murphyi*) in the Humboldt Current system: a 'unique' behavioural adaptation to cyclic availability of preys. ICES CM 2004, Vigo, Spain. (version ppt)

85. Bertrand A, Segura M, Gutiérrez M, Vasquez L (2004). From small-scale habitat loopholes to decadal cycles: a habitatbased hypothesis explaining fluctuation in pelagic fish populations off Peru. Fish and Fisheries 5:296–316

86. Blanco, J.L., A.C. Thomas, M.E Carr & P.T. Strub. 2001. Seasonal climatology of hydrographic condition in the upwelling region off norther Chile. J. Geophys. Res., 106: 11451-11467.

87. Bogorov, V.G. (1967). Biomass of zooplankton and productive regions of the Pacific Ocean. Plankton Tikhogo Okeana (Pacific Ocean Plankton), 221–229. Nauka, Moskow.

88. Bohm G.,et al, 1994 Análisis de la captura y del esfuerzo de pesca de las unidades de pesqueria de jurel de la zona centro-sur y norte Informe Final Proyecto FIP-IT/93-22

89. Bohm et al, 1996 Investigación situación pesqueria pelagica zona centro sur 1995. Informe Final, Proyecto IFOP/1995

90. Bohm G.,et al, 1997 Análisis de la captura y del esfuerzo de pesca en la pesquería pelagica de jurel en la zona centro-sur (v a ix regiones) Informe Final Proyecto FIPIT/96-18

91. Boré, D., Henríquez, N., and Espinoza, G. 1988. Chile: sus recursos pesqueros. Instituto de Fomento Pesquero, IFOP, Santiago.

92. Bouchón, M., Cahuín, S., Díaz, E. and Ñiquen, M. (2000) Captura y esfuerzo pesquero de la pesquerı´a de anchoveta peruana (Engraulis rigens). Boletín del Instituto del Mar del Peru´ 19, 109–115. (In Spanish, with English abstract)

93. Bradford, E., and Taylor, P.R. (1995). Trends in pelagic fish abundance from aerial sightings data*. N.Z. Fisheries Assessment Research Document 95/8.* 60 p.

94. Bradford, E. (1997). Estimated recreational catches from Ministry of Fisheries North region marine recreational fishing surveys, 1993-94. New Zealand Fisheries Assessment Research Document 97/7. 16p.

95. Bradford, E. (1998). Harvest estimates from the 1996 national recreational fishing surveys. N.Z. Fisheries Assessment Research Document. 98/16. 27 p.

96. Braun, M. and V. Valenzuela (2008). Seasonal distribution and abundance of jack mackerel (*Trachurus murphyi*) eggs and larvae off northern Chile 1981-2007. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

97. Boyd, R. O., Reilly, J. L. (2002). 1999/2000 National marine recreational fishing survey: harvest estimates. Draft New Zealand Fisheries Assessment Report 2002/xx.

98. Boyd, R. O., Gowing, L., Reilly, J. L. (2004). 2000-2001 National marine recreational fishing survey: diary results and harvest estimates. Draft New Zealand Fisheries Assessment Report 2004/xx.

99. Buitrón, B. and Perea, A. (2000) Aspectos reproductivos de la anchoveta peruana durante el periodo 1992–2000. Boletin del Instuto del Mardel Peru´ 19, 45–54. (In Spanish, with English abstract)

100. Canales, C., R. Serra. 2008. Updated Status of the Chilean Jack Mackerel Stock. Chilean Jack Mackerel Workshop, V Conference SPRFMO, Guayaquil, 2008.

101. Canales-Aguirre, C., Ferrada S. and Galleguillos R., 2009. Isolation and characterization of microsatellite loci for the jack mackerel (*Trachurus murphyi* Nichols, 1920). m Conserv. Genet.DOI 10.1007/s10592-009-9932-y, 2009

102. Canales, C. L Caballero and A Aranís. (2008). Catch per Unit Effort of Chilean jack mackerel (*Trachurus murphyi*) of the purse seine fishery off south-central Chile (32º10′ – 40º10′ S) 1981-2005. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

103. Cárdenas, L., Hernández, C., Poulin, E., Magoulas, A., Kornfield, I., Ojeda, P., 2005. Canales, C. and R Serra. (2008). Chilean jack mackerel stock assessment model. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

104. Carr, M.-E., 2002. Estimation of potential productivity in Eastern Boundary Currents using remote sensing. Deep Sea Research II 49, 59–80.

105. Carr, M.-E. and Kearns, E.J., 2003. Production regimes in four Eastern Boundary Current systems. Deep Sea Research II 50, 3199–3221.

106. Carritt, D.E. and Carpenter, J.H., 1966. Comparison and evaluation of currently employed modifications of the Winkler method for determining dissolved oxygen in seawater; a NASCD report. Journal of Marine Research 24, 286–318.

107. Castillo J., et al, 1994 Evaluación directa del stock de sardina española , anchoveta y jurel (i a iv regiones) Informe Final Proyecto FIP-IT/ 93-21

108. Castillo J., et al, 1995 Evaluación hidroacústica de los stocks de sardina española, anchoveta y jurel de la zona norte (i a iv regiones). Informe Final Proyecto FIP-IT/94-13

109. Castillo J., et al, 1996 Evaluación hidroacústica de los recursos anchoveta, sardina española y jurel en las regiones i a iv Informe Final Proyecto FIP-IT/ 95-03

110. Castillo, J., M. A. Barbieri, and A. Gonzalez. 1996. Relationships between sea surface temperature, salinity, and pelagic fish distribution off northern Chile. ICES J. Mar. Sci. 53:139–146.

111. Castillo, J. y O. Guzman. 1985. Variaciones de la distribución espacial de la sardina española y jurel durante El Niño 1982-1983. Taller Nacional Fenómeno El Niño. Santiago, Chile. Instituto de Fomento Pesquero: 79-93.

112. Castillo, J. P., 2008. Jack mackerel (*Trachurus murphyi*) spatial distribution and seasonal acoustic biomass estimated in the north of Chile. 1981 - 1990. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

113. Castillo, J. and O. Guzman. 1985. Variaciones de la distribución espacial de la sardina española y jurel durante El Niño 1982-1983. Taller Nacional Fenómeno El Niño. Santiago, Chile. *Inst. Fom. Pesq.* : 79-93.

114. Castillo-Jordán, C., Cubillos, L.A., Paramo, J., 2007. The spawning spatial structure of two co-occurring small pelagic fish off central southern Chile in 2005. Aquat. Living Resour. 20, 77–84.

115. Castillo, R., Gutiérrez, M., Ganoza, F. and Aliaga, A. (1998a) Biomasa de especies pelágicas en el mar peruano a comienzos de otoño de 1998. Crucero BIC Humboldt 9803–05 de Tumbes a Tacna. Informe del Instituto del Mar del Perú No. 135, 91–102. (In Spanish, with English abstract)

116. Castillo, R., Gutiérrez, M. and Gonzales, A. (1998b) Biomasa de la principales especies pela´gicas en el mar peruano a fines de otoño 1998. Crucero BIC Jose´ Olaya Balandra 9805−06 de Tacna a Ma´ncora. Informe del Instituto del Mar del Perú No. 137, 1−19. (In Spanish, with English abstract)

117. Castillo, R., Gutiérrez, M., Peraltilla, S. and Herrera, N. (1998c) Biomasa de recursos pesqueros a final del invierno 1998. Crucero BIC Humboldt y BIC José Olaya Balandra 9808−09 de Paita a Tacna. Informe del Instituto del Mar del Perú No. 141, 136−155. (In Spanish, with English abstract)

118. Castillo, R., Gutiérrez, M., Peraltilla, S. and Herrera, N. (1999) Biomasa de los principales recursos pesqueros durante el verano 1999. Crucero BIC José Olaya Balandra 9902−03, de Tumbes a Tacna. Informe del Instituto del Mar del Perú No. 147, 31−45. (In Spanish, with English abstract)

119. Castillo, R., M. Gutiérrez and S. Peraltilla. 1999. Distribución de los recursos pesqueros de mayor abundancia en verano de 1999. Cr. BIC José Olaya Balandra 9902-03 de Tumbes a Tacna. Inf. Inst. Mar Perú. 147:83-97.

120. Castillo R., M. Gutiérrez, S. Peraltilla & A. Aliaga. 1999. Biomasa de los principales recursos pesqueros durante el verano de 1999. Crucero BIC José Olaya Balandra 9902-03. Pta Zorritos (Tumbes) - Morro Sama (Tacna). Inf. Ins. del Mar Perú. 147

121. Castillo R, M. Gutiérrez and A. Aliaga. 1999. Distribución de los recursos pelágicos de mayor interés a finales del otoño de 1999 Crucero Bic Jose Olaya Balandra − Bic Humboldt 9906. Paita − Punta Infiernillos. Inf. Ins. Mar Perú.149.

122. Castillo, R. and M. Gutiérrez, 2000. Biomasas de las especies pesqueras de mayor abundancia en el verano del 2000. Crucero BIC José Olaya Balandra − BIC SNP-2 de Tacna a Tumbes. Inf. Inst. Mar Perú. 159

123. Castillo, R., S. Peraltilla and D. Marin, 2000. Distribución de los recursos pesqueros de mayor abundancia en el verano de 2000. Crucero BIC José Olaya − BIC SNP-2. 0001-02. Tacna − Tumbes. Inf. Inst. Mar Perú. 159

124. Cerda A., et al, 1996 Evaluación bioeconomica de la pesqueria industrial de jurel en la zona centro-sur. fase i Informe Final Proyecto FIP-IT/ 95-12

125. Chaigneau, A. & O. Pizarro. 2005: Mean surface circulation and mesoscale turbulent flow characteristics in the eastern South Pacific from satellite tracked drifters. Journal of Geophysical Research, Vol. 110, No. C5, C05014, 10.1029/2004JC002628.

126. Chaigneau, A. & O. Pizarro. 2005: Surface circulation and fronts of the South Pacific Ocean, east of 120°W. Geophysical Research Letters, 32, L08605 10.1029/ 2004GL022070.

127. Chalen, X. (2000) Estimación de la biomasa de peces pelágicos pequeños entre 1994 y 1999 a través de cruceros de prospección hidroacústica. In: Características oceanográficas y pesqueras en el Ecuador durante 1994−1999. Boletín Especial Instituto nacional de Pesca, Ecuador, pp. 133−157. (In Spanish)

128. Chavez, F. P. A- Bertrand, R. Guevara-Carrasco, P. Soler y J. Csirke. 2008. The Northern Humboldt Current System: Brief history, present status and a view towards the future. Progress in Oceanography, 79, 2-4, p. 95-105.

129. Chavez, F.P., Ryan, J., Lluch-Cota, S.E. and Niquen, M. (2003) From anchovies to sardines and back: multidecadal change in the Pacific Ocean. Science 299, 217−221.

130. Chernyshkov, P., E.Timokhin and A. Glubokov. (2008). Inter-annual and seasonal variability of oceanological conditions in the Southern Pacific Ocean in connection with the pelagic ecosystem structure. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June − 4 July 2008.

131. Chipollini, A., A. Echevarria, A. Salas and G. Cárdenas. 1999. Aspectos biológico-pesqueros de los recursos pelágicos durante el verano 1999. Crucero BIC José Olaya Balandra 9902-03 de Tumbes a Tacna. Inf. Inst. Mar Perú. 147:21-30.

132. Chirichingo, N. 1974. Clave para identificar los peces marinos del Perú. Instituto del Mar del Perú, Informes, 44: 1-387.

133. Chirichingo, N. 1982. Catálogo de especies marinas de interés económico actual o potencial para América Latina. INFOPESCA FAO: Parte II.

134. Chirichingo, N., W. Fischer y C. Nauen. 1982 Catálogo de especies marinas de interés económico actual o potencial para América Latina. Parte II- Pacífico centro y suroriental. Roma: FAO/PNUD. INFOPESCA. 1-588.

135. Clarke, A.J. and Lebedev, A. (1999) Remotely driven decadal and longer changes in the coastal Pacific waters of the Americas. Journal of Physical Oceanography 29, 828−835.

136. Cliaga R, M. Gutiérrez, S. Peraltilla and A. Aliaga. 1999. Biomasa de los principales recursos pesqueros durante el verano de 1999. Crucero BIC José Olaya Balandra 9902-03. Pta Zorritos (Tumbes) - Morro Sama (Tacna). Inf. Ins. del Mar Perú. 147

137. Coker, R.E. 1908. Primer diagnóstico de la pesquería peruana (Informes publicados entre 1907-1910). Compilado por Hernán Peralta Bouroncle. Tecnológica de Alimentos. 2008. Lima-Perú. 555 pp.

138. Coppola, S.R., W. Fischer, L. Garibaldi, N. Scialabba and K.E. Carpenter0 SPECIESDAB: Global species database for fishery purposes. User's manual. FAO Computerized Information Series (Fisheries). No. 9. Rome, FAO. 103 p.

139. Córdova J, et al, 1997 Evaluación hidroacústica del recurso jurel en las regiones v a ix Informe Final Proyecto FIP-IT/ 96-13

140. Córdova, J. et al. (1998). Evaluación hidroacústica del recurso jurel en la ZEE de Chile. IFOP/FIP 98-11. Informe Final. 200 págs. +figs.

141. Córdova J, et al, 1999 Evaluación hidroacústica del recurso jurel en la zee de Chile Informe Final Proyecto FIP-IT/ 98-11 Final, Proyecto IFOP/1998

142. Cordova J, et al, 2000 Evaluación acustica del recurso jurel en la zee de chile. Informe Final Proyecto FIP-IT/ 99-03

143. Cordova J, et al, 2001 Evaluación hidroacústica de jurel en la zee de chile, año 2000. Informe Final Proyecto FIP-IT/ 2000-03

144. Cordova J, et al, 2002 Evaluación hidroacústica de jurel en la zee, marzo 2001. Informe Final Proyecto FIP-IT/ 2001-02

145. Cordova J, et al, 2003 Evaluación hidroacústica de jurel en la zee, año 2002. Informe Final Proyecto FIP-IT/ 2002-02

146. Cordova J, et al, 2004 Evaluación hidroacústica del recurso jurel entre la v y x regiones, año 2003. Informe Final Proyecto FIP-IT/ 2003-02

147. Cordova J, et al, 2005 Evaluación hidroacústica del recurso jurel entre la v y x regiones, invierno año 2004. Informe Final Proyecto FIP-IT/ 2004-06

148. Cordova et al, 2006 Evaluación hidroacústica jurel v a x regiones 2005. Informe Final, Proyecto IFOP/2005

149. Cordova et al, 2006 Evaluación hidroacústica jurel v a x regiones 2006. Informe Final, Proyecto IFOP/2006

150. Cordova, et al, 2006 Evaluación hidroacústica del recurso jurel entre la v y x región, verano, año 2006. Informe Final Proyecto FIP-IT/2006-02

145. Córdova, J., Barbieri, M. A. Miranda, H. Espejo, M., y Rojas, M. 1998. Evaluación hidroacústica de jurel en la centro sur, V a IX Regiones (año 1997). Informe Final, Fondo de Investigación Pesquera FIP-IT/96-13, IFOP, Valparaíso, Chile, 234 p.

146. Córdova, J., Barbieri, M. A. Miranda, H. Espejo, M., y Rojas, M. 1999. Evaluación hidroacústica de jurel en la ZEE de Chile (año 1998) Informe Final, Fondo de Investigación Pesquera FIP-IT/98-11, IFOP, Valparaíso, Chile, 310 p.

147. Córdova, J., Barbieri, M. A. Miranda, H. Espejo, M., y Rojas, M. 2000. Evaluación acústica del recurso jurel en la ZEE de Chile (año 1999) Informe Final, Fondo de Investigación Pesquera FIP-IT/99-03, IFOP, Valparaíso, Chile, 294 p.

148. Córdova, J., Barbieri, M. A., and Lillo, S. 1998. Evaluación hidroacústica de jurel. In Evaluación hidroacústica de jurel en la ZEE de Chile. Instituto de Fomento Pesquero, Santiago, Chile. 161 pp.

149. Córdova, J., Barbieri, M. A., and Lillo, S. 1999. Evaluación hidroacústica de jurel. In Evaluación hidroacústica de jurel en la ZEE de Chile. Instituto de Fomento Pesquero, Santiago, Chile. 200 pp.

150. Córdova, J., Barbieri, M. A., and Lillo, S. 2000. Evaluación acústica del jurel. In Evaluación hidroacústica de jurel en la ZEE de Chile. Instituto de Fomento Pesquero, Santiago, Chile. 200 pp.

151. Córdova, J., Barbieri, M. A., y Espejo, M. 2001. Evaluación hidroacústica de jurel en la ZEE de Chile, año 2000. Informe Final, Fondo de Investigación Pesquera FIP-IT/2000-03, IFOP, Valparaíso, Chile, 325 p.

152. Córdova, J., Barbieri, M. A. y Espejo, M. 2002. Evaluación hidroacústica de jurel en la ZEE 2001. Informe Final, Fondo de Investigación Pesquera FIP-IT/2001-02, IFOP, Valparaíso, Chile, 297 p.

153. Córdova, J., Barbieri, M. A., y Espejo, M. 2003. Evaluación hidroacústica de jurel en la ZEE, año 2002. Informe Final, Fondo de Investigación Pesquera FIP-IT/2002-02, IFOP, Valparaíso, Chile, 275 p.

154. Córdova, J., Barbieri, M. A., and Espejo, M. 2004. Evaluación hidroacústica del recurso jurel entre la V y X Regiones, año 2003. Informe Final, Fondo de Investigación Pesquera FIP-IT/2003-02, IFOP, Valparaíso, Chile, 272 p.

155. Córdova, J., Barbieri, M. A., y Espejo, M. 2005. Evaluación hidroacústica del recurso jurel entre la V y X Regiones, invierno año 2004. Informe Final, Fondo de Investigación Pesquera FIP-IT/2004-06, IFOP, Valparaíso, Chile, 318 p.

156. Córdova, J., Barbieri, M. A., y Lang, C. 2006. Investigación Evaluación directa de jurel V y X Regiones, 2005. Informe Final, Subsecretaría de Pesca BID Nº 30033968-0, IFOP, Valparaíso, Chile, 362 p.

157. Córdova, J., C Hernández y V Correa 2007. Investigación Evaluación hidroacústica jurel V- X, 2006. Informe Final, Subsecretaría de Pesca BID N° 30043859-0, IFOP, Valparaíso, Chile, 326 p.

158. Córdova, J., F. Leiva y C Hernández. 2008. Evaluación hidroacústica del recurso jurel entre la V y X Regiones, año 2007. Informe Final, Fondo de Investigación Pesquera FIP-IT/2007-07, IFOP, Valparaíso, Chile, 350 p.

159. Córdova, J., C. Lang y C Hernández. 2009. Evaluación hidroacústica de jurel entre la V y X Regiones, año 2008. Informe Final, Fondo de Investigación Pesquera FIP-IT/2008-05, IFOP, Valparaíso, Chile, 323 p.

153. Cordova, J. R Bahamonde and V Catasti. (2008). Jack mackerel (*Trachurus murphyi*, Nichols, 1920) acoustic survey in the central coast of Chile. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

154. Cordova, J., M. Espejo, S. Nuñez, y J. Ortiz. (2005). Evaluación hidroacústica del recurso jurel entre la V y X Regiones. Invierno año 2004. Informe Final. Proyecto FIP2004-06.

155. Corten, A., 2007. Scientific research for distant water operations of the EU pelagic fleet. Presented In: The jack mackerel fishery in the South Pacific Meeting. March 22, 2007, Talcahuano, Chile.

156. Corten, A. 2008. The fishery for jack mackerel in the Eastern Central Pacific by trawlers from the European Union in 2007. Paper 18. In: Chilean Jack Mackerel WorkShop. Organized by SPRFMO and the Chilean UnderSecretary of Fishing. 30 June – 4 July 2008. FAO Regional Office for Latin America. Santiago-Chile.

157. Csirke, J. 1988. Small shoaling pelagic fish stocks. *In* Fish Population Dynamics (2nd ed.), pp. 271–302. Ed. by J. A. Gulland. J. Wiley & Sons, Chichester. 422 pp.

158. Csirke, J. (1989) Changes in the catchability coefficient in the Peruvian anchoveta (Engraulis ringens) fishery. In: The Peruvian Upwelling Ecosystem: Dynamics and Interactions (eds D. Pauly, P. Muck, J. Mendo and I. Tsukayama), Vol. 18. ICLARM Studies and Reviews, Manila, pp. 207–219.

159. Csirke, J. 1995. Fluctuations in abundance of small and mid-sized pelagics. Scientia Marina. 59(3-4): 481-490.

160. Csirke, J., Guevara-Carrasco, R., Cárdenas, G., Ñ iquen, M. and Chipollini, A. (1996) Situación de los recursos anchoveta (Engraulis ringens) y sardina (Sardinops sagax) a principios de 1994 y perspectivas para la pesca en el Perú , con particular referencia a las regiones norte y centro de la costa peruana. Boletín del Instituto del Mar del Perú 15, 1−23. (In Spanish, with English abstract)

161. Cubillos L., et al, 2001 Condicion biologica de jurel en alta mar, año 2000. Informe Final Proyecto FIP-IT/ 2000-10

162. Cubillos L., et al, 2002 Condicion biologica de jurel en alta mar, año 2001. Informe Final Proyecto FIP-IT/ 2001-12

163. Cubillos L., et al, 2003 Condicion biologica de jurel en alta mar, año 2002. Informe Final Proyecto FIP-IT/ 2002-12

164. Cubillos, L., R. Alarcón, L. Vilugran, A. Sepúlveda, M. George-Nascimento, M. Araya, M. Medina, J. Zambrano, M. Guzman, L. Martinez, J. Peñailillo, R. Gili, Z. Young, V. Alegria, V. Bocic, L. Muñoz y L. Cid. (1998). Validación de los métodos aplicados en la determinación de edad y crecimiento y determinación de la mortalidad del jurel en la zona centro.sur. Informe Final Proyecto FIP 95-10, 170 p.

165. Cubillos, L.A., J*.* Páramo, P*.* Ruíz, S*.* Núñez and A*.* Sepúlveda*.* 2008*.* The spatial structure in the oceanic spawning of jack mackerel (*Trachurus murphyi*) off central Chile (1998-2001)*. Fisheries Research*, 90: 261-270.

166. Daneri, G., Dellarossa, V., Quiñones, R., Jacob, B., Montero, P. and Ulloa, O. (2000) Primary production and community respiration in the Humboldt Current System off Chile and associated oceanic areas. Marine Ecology Progress Series 197, 41−49.

167. Dejnik T.V, M. M. Nevinskiy, G. Z. Galaktionov, A. A. Nesterov & G. P. Rudometkina. 1994. Estimación de la fraccipon desovante del stock de jurel segun estudios de ictiloplancton. In: D. Arcos y A. Greshina (Eds). Biología y pesca commercial del jurel en el Pacífico Sur, pag. 161-166.

168. Dejnik, T. V. y M. M. Nevintskyi. 1994. Distribución y abundancia de huevos y larvas Páginas: 37-42. En D. ARCOS y A. Grechina (Eds). Biología y Pesca Comercial del jurel en el Pacífico Sur. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 203 pp.

169. Deriso, R.B., Quinn II, T.J., Neal, P.R., 1985. Catch-age analysis with auxiliary information. Can. J. Fish. Aquat. Sci. 42:815-824.

170. DeVries T. J., L. Ortlieb, A. Diaz, L. Wells & C. Hillaire-Marcel. 1997. Determining the Early History of El Niño. Science 276, 965. DOI: 10. 1126/sciencie. 276.5314.965.

171. Dioses, T.; Alarcon, V.H.; Nakama, M.H.; Echevarria, A. (1989). Desarrollo ovocitario, fecundidad parcial y distribucion vertical de los cardumenes en desove del jurel *Trachurus murphyi* (N). (Oocyte development, partial fecundity and vertical distribution of the spawning schools of jack mackerel, *Trachurus murphyi* N.). Revista de la Comision Permanente del Pacifico Sur. 287−294.

172. Dioses, T. 1995. Análisis de la distribución y abundancia de los recursos jurel y caballa frente a la costa peruana. *Inf. Prog. Inst. Mar Perú*. 03:55 pp. (in Spanish with english abstract)

173. Duran, B.L.E.; Oliva, M.M. (1983). List of Peruvian marine fish parasite copepods. Estudios Oceanologicos. Facultad de Recursos del Mar, Universidad de Antofagasta 3: 69−73.

174. Dyer, B.S. and M.W. Westneat, 2010. Taxonomy and biogeography of the coastal fishes of Juan Fernáandez archipelago and desventuradas islands, Chile. Revista de Biología Marina y Oceanografía 45(S1):589-617.

175. Elizarov A.A, Grechina A.S., Kotenev B.N., Kznetsov A.N. 1992. Peruvian jack mackerel *Trachurus symetricus murphyi* in open water of the southern part of the Pacific Ocean. Questions of Ichthyology. Vol 32. Issue 6. Pp 57-73 (In Russian).

176. Elizarov, A.A., Grechina, A.S., Kotenev, B.N., Kuzetsov, A.N., 1993. Peruvian jack mackerel, *Trachurus symmetricus murphyi*, in the open waters of the South Pacific. J. Ichthyol. 33, 86−104.

177. **Eschmeyer, W.N.**, 1990. Catalog of the genera of recent fishes. California Academy of Sciences, San Francisco, USA. 697 p

178. Escribano, R., G. Daneri, L. Farías, V. A. Gallardo, H.E. González, D. Gutierrez, C. Lange, C. E. Morales, O. Pizarro, O. Ulloa & M. Braun. 2004. Biological and chemical consequences of the 1997–1998 El Niño in the Chilean coastal upwelling system: a synthesis. Deep-Sea Research II 51 (2004) 2389–2411.

179. Escribano, R., P. Hidalgo, H. González, R. Giesecke, R. Riquelme-Bugueño & K. Manríquez. 2007. Seasonal and inter-annual variation of mesozooplankton in the coastal upwelling zone off central-southern Chile. Progress in Oceanography, 75: 470-485.

180. Escribano, R. and Hidalgo, P. (2000) Influence of El Niño and La Niña on the population dynamics of *Calanus chilensis* in the Humboldt Current ecosystem of northern Chile. ICES Journal of Marine Science 57, 1867–1874.

181. Espino, M. 2003. Estrategia de Gestión Oriental para el Pacífico Oriental con especial mención a la pesquería peruana. Tesis para optar el grado de Magíster en Geografía con mención en Ordenamiento y Gestión Ambiental. Unidad de Post Grado, Facultad de Ingeniería Geológica, Minera, Metalúrgica y Geográfica, Universidad Nacional Mayor de San Marcos. 102 p.

182. Espino, M. and C. Wosnitza-Mendo. 1989. Biomass of hake (*Merluccius gayi*) off Peru, 1953–1987. Pages 297–305 *in* D. Pauly, P. Muck, J. Mendo, and I. Tsukayama, eds. The Peruvian upwelling ecosystem: dynamics and interactions. ICLARM Conf. Proc. 18. ICLARM, Manila. A.A.

183. Espinoza, E., Ñiquen, M and Flores, R. (2008). Changes in the latitudinal and longitudinal distribution of the aggregations of jack mackerel (*Trachurus murphyi*) in the Perúvian sea during 1996 – 2007. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

184. Esterov, V., Chur, N. 2008. El-Nino and distribution of Jack mackerel (Trachurus murphyi) inthe open part (outside 200-mile zone) of the South-Eastern Ocean. Santiago, June 30 – July 3th 2008 HCS005

185. Evseenko, S.A. 1987. Reproduction of Peruvian Jack Mackerel, *Trachurus symmetricus murphyi,* in the Southern Pacific. *J. Ichth*., 27(3): 151-160.

186. Evseenko, S.A. 1987. On the reproduction of the Peruvian jack mackerel, *Trachurus symmetricus murphyi* (Nichols), in the southern part of the Pacific Ocean. Voprosy Ikhtiologii 27(2), 264-273.

187. Evseenko, S.M., S.M. Karavaev Y T.V. Sazonova. 1982. Composición, calidad y distribución delictioplancton en el Pacífico Suroriental en el período otoño-primavera de 1980. En:Investigaciones pesqueras en el Pacífico Suroriental. VNIRO, Moscú: 63-90. (en ruso)

188. FAO. 1983a. Proceedings of the Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources. FAO Fish. Rep. 291, Rome. 553 p.

189. FAO yearbook 1990. Fishery statistics. Catches and landings. FAO Fish. Ser. (38). FAO Stat. Ser. 70:(105):647 p. (Ref. 4931)

190. FAO. 1997. Review of the state of world fishery resources: marine fisheries. Fisheries Circular 920. Food and Agriculture Organization of the United Nations, Rome. 173 p.

191. Fernández, D., Escribano, R. and Hidalgo, P. (2002) Distribución de eufaúsidos en el sistema de surgencia frente a la península de Mejillones (23 _S) asociada a condiciones previas y durante El Niño 1997–98. Investigaciones Marinas 30, 25–43. (In Spanish, with English abstract)

192. Ferrière, R. and B. Cazelles. 1999. Universal power laws governing intermittent rarity in communities of interacting species. Ecology 80: 1505–1521.

193. Fiedler, P.C. (2002) Environmental change in the eastern tropical Pacific Ocean: review of ENSO and decadal variability. Marine Ecology Progress Series 244, 265–283.

194. Fischer, W., Krup, F., Schneider, W., Sommer, C., Carpenter, K. E. and Niem, V. H. 1995. Guia FAO para la Identificacion de Especies de para los fines de la Pesca. Pacifico Centro-Oriental. Volumen II. Vertebrados - Parte 1. , Vol. 2, Page: 647-1200

195. Flores, H.G. and P.Z. Rojas, 1987. Stomach content of *Dissostichus eleginoides* Smitt 1898, caught off Valparaiso (Perciformes - Notothemiidae). Invest. Mar. 15:33-40

196. Fréon, P. and O. Misund. 1999. Dynamics of pelagic fish distribution and behaviour : effects on Fisheries and Stock Assessment. Fishing News Books. 348 pp.

197. Fréon, P., Mullon, C. and Voisin, B. (2003). Investigating remote synchronous patterns in fisheries. Fisheries Oceanography 12, 443–457.

198. Fréon, P. and Bouchón Corrales M.. 2004. Impact of El Niño events on the pelagic fisheries in Peruvian waters. Deep Sea Res. II. 51: 563–574.

199. Frimodt, C**.**, 1995. Multilingual illustrated guide to the world's commercial coldwater fish. Fishing News Books, Osney Mead, Oxford, England. 215 p

200. Froese, R. and D. Pauly. 2000. FishBase 2000: concepts, design and data sources. ICLARM, Los Baños. 344 p.

201. **Fuentes, H., E. Antonietti and P. Muck**, 1989. Alimentacion de la merluza (*Merluccius gayi peruanus*) de la zona de Paita. Memorias del Simposio Internacional de los Recursos Vivos y las Pesquerías en el Pacífico Sudeste Viña del Mar, 9-13 Mayo 1988., Comisión Permanente del Pacífico Sur (CPPS), Rev. Pacífico Sur (Número Especial).

202. Galatkionov, G.Z. and N.N. Reshetnikova, 1983. Composición del ictioplancton y particularidades de la distribución de huevos y larvas de peces masivos pelágicos del Pacífico Suroriental. En: Problemas de ovogénesis temprana de peces. Resumenes de trabajos de la III° Reunión de Toda Unión, 25-26 de mayo 1983, Kaliningrad: 87-89. (en ruso)

203. Galatkionov, G. Z. 1994. Formación de cardúmenes y migraciones verticales diarias del jurel peruano. Páginas: 179-184. En D. ARCOS y A. Grechina (Eds). Biología y Pesca Comercial del jurel en el Pacífico Sur. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 203 pp.

204. Galleguillos, R., Montoya, M., Quiñones, R., 1998. Tipificación genética de poblaciones de *Trachurus symmetricus* (jurel) mediante PCR. En: Proyecto FIP 1996-15 Migración de jurel desde y hacia la ZEE de Chile Central. 256 pp.

205. Galleguillos, R., Torres, A., 1988. Identificación de unidades poblacionales pelágicas. Tercera etapa. Informe final. Subsecretaría de Pesca. 67 p

206. Ganoza, F. (1998) Abundancia y comportamiento del jurel (*Trachurus picturatus murphyi*) a través de prospecciones acústicas de 1983 a 1994. Informe del Instituto del Mar del Perú No. 136, 23–47. (In Spanish, with English abstract)

207. Ganoza, F., Castillo, P.R. and Marín, D. (2000). Variaciones estacionales en la distribución y biomasa de anchoveta entre 1983 y 2000. Boletín del Instituto del Mar del Perú 19, 157–177. (In Spanish, with English abstract)

208. Ganoza, F. 1998. Abundancia y comportamiento del jurel (*Trachurus picturatus murphyi*) a través de prospecciones acústicas de 1983 a 1994. Inf. Inst. Mar Perú. 136: 23-47.

209. Garcia, C. (2008). Maximum sustainable yield (MSY) and optimum effort of fishing of jack mackerel (*Trachurus murphy*) and pacific mackerel (*Scomber japonicus*) in Perú (1997-2006). Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

210. García-Godos Naveda, I**.**, 2001. Patrones morfológicos del otolito sagitta de algunos peces óseos del mar Peruano. Bol. Inst. Mar Perú 20(1-2):1-83.

211. George, M.R. (1995). Aspects of the reproductive cycle of southern Pacific jack mackerel, *Trachurus murphyi* Nichols, 1920, off northern coast of Chile. Ices C.M 1995/H30: 12.

212. George-Nascimento, M., 2000. Geographical variations in the jack mackerel *Trachurus symmetricus murphyi* populations in the southeastern Pacific Ocean as evidenced from the associated parasite communities. The Journal of Parasitology. 86 (5), 929-32.

213. George-Nascimento, M., Arancibia, H., 1992. Stock ecológicos del jurel (*Trachurus symmetricus murphyi* Nichols) en tres zonas de pesca frente a Chile, detectados mediante comparación de su fauna parasitaria y morfometría. Revista Chilena de Historia Natural 65, 453-470.

214. George-Nascimento, M., Arancibia, H., Labrín, A., 1994. Informe Final. Sección 2: Parasitofauna. En Proyecto FIP 1994-19 Unidades de stock en el recurso jurel de la I a la XI Regiones.

215. Gerlotto, F. and M.-A. Barbieri, 1999. Pression de pêche et dynamique du comportement spatial des bancs de chinchard *Trachurus symmetricus murphyi*. ECOS (action C97B06), Rapport d'activité année 1999: 5 pages

216. Gerlotto F., M. Gutierrez & A. Bertrand, 2010. The distribution of jack mackerel Trachurus murphyi in the South Pacific Ocean: a metapopulation hypothesis. FAST-ICES-WG annual meeting. SWNFS, NOAA, San Diego, April 2010.

217. Gerlotto, F. & M.-A. Barbieri, 2000. Pression de pêche et dynamique du comportement spatial des bancs de chinchard *Trachurus symmetricus murphyi*. ECOS (action C97B06), Exposé scientifique : 14 pages

218. Gerlotto, F. & M.-A. Barbieri, 2000. Presión pesquera y dinámica del comportamiento espacial de los cardúmenes de jurel (*Trachurus symmetricus murphyi*). ECOS (action C97B06), Informe científico : 14 p.

219. Gerlotto, F., Gutiérrez, M., and Bertrand, A., 2012. Insight on population structure of the Chilean jack mackerel (*Trachurus murphyi*). Aquatic Living Resources, *in press*

220. Gili, R., V. Alegría, V. Bocic, L. Cid y H. Miranda. (1996). Estudio biológico pesquero del recurso jurel en la zona centro sur, V a X Regiones. Determinación de la estructura de edad y parámetros de crecimiento del jurel. FIP 018 - 93.

221. Gili, R., L. Cid, V. Bocic, V. Alegría, H. Miranda & H. Torres. 1995. Determinación de la estructura de edad del recurso jurel. En: Estudio biológico pesquero sobre el recurso jurel en la zona centro-sur, V a IX Regiones. Informes Técnicos FIP/IT-93-18: 121 pp.

222. Goncharov, S.M., E.S. Borisenko and A.I. Pyanov. 1989. Jack mackerel school defence reaction to a surveing vesssel. *Proc. I.O.A.*, 11(3): 74-78.

223. Gorbunova, N.N., Evseenko, S.A., Garetovsky, S.V., 1985. Distribution of ichthyoplankton in the frontal zones of the Peruvian waters. J. Ichthyol. 25, 67−79.

224. Gorbunova N.N., Evseenko S.A and Garetovskyi. S.V. 1985. Sobre la distribución del ictioplancton en las zonas frontales de las aguas peruanas. Voprosy ictiologii, Vol.25, Publ. 5:770-782. (in russian)

225. Gorbunova, N.N., S.A. Evseenko and Garetovskyi. S. V. 1985. Distribution of Ichthyoplankton in the Frontal Zones of the Peruvian Waters. J. Ichth. 25(6): 67-79. (in russian)

226. Grechina, A. 1992. Historia de investigación y aspectos básicos de la ecología del jurel (*Trachurus symmetricus murphyi*) en alta mar del Pacifico Sur. En: H. Arancibia y L. Cubillos (eds). Documento Técnico. Instituto de Investigación Pesquera, Talcahuano, 1(2):1-47.

227. Grechina, A. S. 1994. Influencia de "El Niño" de los años 1982-1983 en la distribución de las concentraciones comerciales del jurel. Páginas: 123-127. En D. ARCOS y A. Grechina (Eds). Biología y Pesca Comercial del jurel en el Pacífico Sur. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 203 pp.

228. Grechina, A. S. 1998. Historia de investigaciones y aspectos básicos de la ecología del jurel *Trachurus symmetricus murphyi* (Nichols) en alta mar del Pacífico Sur. En D. ARCOS (Ed). Biología y Ecología del jurel en Aguas Chilenas. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 216 pp. : 11-34.

229. Grechina, A. S. and Arcos D. F. 1994. Distribución y migración del jurel, *Trachurus symmetricus murphyi* (nichols), en el Pacífico Suroriental. Doc. Téc. Inst. Invest. Pesq. (IIP), Talcahuano. Chile. Vol. 3. Núm. 4: 1-40.

230. Grechina, A.; C. Gonzalez, S. Nùñez & A. Sepùlveda. 2008. Patrones migratorios del Jurel en el Pacìfico Sur: Pesquerias y Oceanografìa. In litteris. INPESCA 24 pags.

231. Grechina, A.S., Núñez, S., Arcos, D., 1998. Biología reproductiva del jurel (*Trachurus symmetricus murphyi*) en el Pac´ıfico sur. In: Arcos, D. (Ed.), Biología y ecología del jurel en aguas chilenas. Instituto de Investigación Pesquera, Talcahuano, pp. 77−79.

232. Grechina, A, S. Nuñez y A. Sepulveda, 2006. Estado del conocimiento sobre la distribución del jurel fuera de la ZEE frente a Chile y Perú. Instituto de Investigación Pesquera. Presentado en: Taller Científico sobre el jurel en el pacífico Sur, Comisión Permanente del Pacífico Sur (CPPS), Santiago, Chile, agosto del 2006

233. Grechina, A. S., S. P. Nuñez y D. F. Arcos. 1998. El desove del recurso jurel, *Trachurus symmetricus murphyi* (Nichols), en el Océano Pacífico Sur. Páginas: 117-140. En D. ARCOS (Ed). Biología y Ecología del jurel en Aguas Chilenas. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 216 pp.

234. Grove, J.S. and Lavenberg, R. J. 1997. The fishes of the Galápagos islands. , Vol. 0, Page: 863pp

235. Guillen, O. y R. Calienes. 1981.Productividad y afloramiento frente a las aguas costeras peruanas. *Bol. Inst. Mar Perú*. Volumen Extraordinario: Investigaciones Cooperativa de la anchoveta y su ecosistema (ICANE) entre Perú y Canadá. 130-143 p.

236. Gunther, E. R. 1936. A report on the oceanographical investigations in the Peru coastal current. Discovery Reports, 13: 107–276.

237. Gutierrez, D., Siffedine, A., Fields, D.B., Ortlieb, L., Vargas, G., Chávez, F.P., Velazco, F., Ferreira, V., Tapia, P., Salvatteci, R., Boucher, H., Morales, M.C., Valdes, J., Reyss, J.-L.m Campusano, A., Boussafir, M., Mandeng-Yogo, M., Garcia, M., Baumgartner, T., 2009. Rapid reorganization in ocean biogeochemistry off Peru towards the end of the Little Ice Age. Biogeosciences, 6:85-848

238. Gutiérrez, M. (2001) Efectos del evento El Niño 1997–98 sobre la distribución y abundancia de anchoveta (*Engraulis ringens*). In: El Niño en América Latina: impactos biológicos y sociales (eds J. Tarazona, W.E. Arnts and E. Castillo de Maruenda). Consejo Nacional de Ciencia y Tecnología, Lima, Perú, pp. 55–72. (In Spanish, with English abstract)

239. Gutiérrez. M. 2002. A technical and scientific approach about needs of new sustainable fisheries. Proceedings of Seoul Ocean Seminar. 1st APEC Ocean-related Ministerial Meeting. Korea Maritime Institute. Pp 75-90.

240. Gutiérrez, M., A. Bertrand, M. Ballón, P. Espinoza, A. Alegre and F. Gerlotto, 2008. Distribution changes and interactions of Jack Mackerel off Peru as observed using acoustics (1983-2008) Documento Técnico CDP-12V4-Junio2008

241. Gutiérrez, M., Castillo, R., Peraltilla, S. (1999a) Biomasa de recursos pesqueros a finales de la primavera 1998. Crucero BIC José Olaya Balandra9811–12. Informe del Instituto del Mar del Perú No. 146, 11–18. (In Spanish, with English abstract)

242. Gutiérrez, M., Herrera, N. and Marin, D. (1999b) Distribución y abundancia de anchoveta y otras especies pelágicas entre los eventos El Niño 1982–83 y 1997–98. Boletín del Instituto del Mar del Perú 18, 77–88. (In Spanish, with English abstract)

243. Gutiérrez M. and D. Maclennan, 1998. Resultados preliminares de las mediciones de Fuerza de Blanco *in situ* de las principales especies pelágicas. Inf. Inst. Mar Perú 135: 16-19.

244. Gutiérrez, M., Vásquez, L., Castillo, R., Dioses, T., Mori, J. and Perea, M. (1998) Distribución, concentración y biomasa de los principales recursos pelágicos a final del invierno e inicios de primavera 1997. Crucero BIC Humboldt 9709–10 de Matarani a Paita. Informe del Instituto del Mar del Perú No. 130, 13–44. (In Spanish, with English abstract)

245. Guzman, O.; Castillo, J.; Lillo, S.; Pineda, P.; Rodriguez; Giakoni, I. (1983). Estudio de recursos pelágicos. Programa monitoreo de los recursos pelágicos. I. Prospección zona Arica–Coquimbo. (18º30′–30º00′S). CORFO. Gerencia de Desarrollo. IFOP (AP 83–32). 48 p.

246. Hancock J, Hart JB, Antezana T (1995) Searching behaviour and catch of horse mackerel (*Trachurus murphyi*) by industrial purse-seiners off south-central Chile. ICES J Mar Sci 52:991–1004

247. Hebbeln D., M. Marchant & G. Wefer. 2002. Paleoproductivity in the southern Peru-Chile Current through the last 33 000 yr Marine Geology 186 (2002) 487-504.

248. Hernández, A., Sepúlveda, A., 1998. Análisis del esfuerzo y rendimientos de pesca de la pesquería del jurel en la zona centro sur de Chile entre 1987 y 1995. En: Biología y ecología del jurel en aguas chilenas. Instituto de Investigación Pesquera, Talcahuano. Chile. 216 pp.

249. Hernández, A., Sepúlveda, A. 1999. Morfometría del jurel en aguas Chilenas, con énfasis en la determinación del efecto alométrico en la comparación de ejemplares de distintos rangos de tamaño. *In:* Libro Resumen XX Congreso de Ciencias del Mar, Universidad de Antofagasta, Antofagasta.

250. Hernández, A., Sepúlveda, A., Miranda, L., 1998. Morfometría y merística del jurel (Trachurus symmetricus murphyi) a lo largo de Chile. En Arcos, D (ed). Biología y ecología del jurel en aguas chilenas. Instituto de Investigación Pesquera, Talcahuano, 47-63 pp.

251. Hidalgo, P. and Escribano, R. (2001) Succession of pelagic copepod species in coastal waters off northern Chile: the influence of the 1997–98El Nin˜o. Hydrobiologia 453, 153–160.

252. Hilborn, R. 1985. Fleet dynamics and individual variation : why some people catch more fish than others. *Can. J. Fish. Aqua. Sci*., 42 : 2-13.

253. Hilborn, R. 1990. Determination of fish movement patterns from tag recoveries using maximum likelihood estimators. Canadian Journal of Fisheries and Aquatic Sciences 47:635-643.

254. Hilborn R, Maunder M, Parma A, Ernst B, Payne J, Starr P (2003) Coleraine: A Generalized Age-Structured Stock Assessment Model: User's Manual Version 2.0. Technical Report. School of Aquatic and Fishery Science, Fisheries Research Institute, Washington University [Rep. Fish. Res. Inst. Wash. Univ.], likelihood estimators. Canadian Journal of Fisheries and Aquatic Sciences 47:635-643.

255. Hildebrand, S.F. 1946. A descriptive catalog of the shore fishes of Peru. , Source: Bull. U.S. Nat. Mus., Vol. 189, Page: 1-530

256. Hoese, D.F., D.J. Bray, J.R. Paxton and G.R. Allen, 2006. Fishes. In Beasley, O.L. and A. Wells (eds.) Zoological Catalogue of Australia. Volume 35. ABRS & CSIRO Publishing: Australia Part 1, pp. xxiv 1-670; Part 2, pp. xxi 671-1472; Part 3, pp. xxi 1473-2178.

257. Horn, P.L. (1991a). Assessment of jack mackerel stocks off the central west coast, New Zealand, for the 1990–91 fishing year. *N.Z. Fisheries Assessment Research Document 91/6:* 14 p.

258. Horn, P.L. (1991b). Trawl survey of jack mackerels (*Trachurus* spp.) off the central west coast, New Zealand, February-March 1990. *N.Z. Fisheries Technical Report No. 28:* 39 p.

259. Horn, P.L. (1993). Growth, age structure, and productivity of jack mackerels (*Trachurus* spp.) in New Zealand waters. *N.Z. Journal of Marine and Freshwater Research 27*: 145–155.

260. Hunter JR (1968) Effects of light on schooling and feeding of jack mackerel, *Trachurus symmetricus*. J Fish Res Board Can 25:393–407

261. Hureau, J.-C., 1991. La base de données GICIM : Gestion informatisée des collections ichthyologiques du Muséum. p. 225-227. In Atlas Préliminaire des Poissons d'Eau Douce de France. Conseil Supérieur de la Pêche, Ministère de l'Environnement, CEMAGREF et Muséum national d'Histoire naturelle, Paris.

262. Hutchings, J. A. 2000. Collapse and recovery of marine fishes. Nature 406: 882–885.

263. **Ibáñez, C.M., C. González and L. Cubillos**, 2004. Dieta del pez espada *Xiphias gladius* Linnaeus, 1758, en aguas oceánicas de Chile central en invierno de 2003. Invest. Mar. 32(2):113-120

264. Icochea L., A. Chipollini & M. Ñiquen, 1988. Análisis de pesquería de arrastre pelágica en la costa peruana durante 1983-1987 y su relación con el medio ambiente. Rev. Com. Perm. Pacif. Sur. 455-465. Memorias del Simposio Internacional de los Recursos Vivos y las Pesquerías en el Pacífico Sudeste. Viña del Mar, 9-13 mayo 1988.

265. IMARPE. 2010. Aspectos biologico-pesqueros de los recursos jurel (*Trachurus murphyi*) y caballa (*Scomber japonicus peruanus*) durante el 2010. Inf. Interno Inst. Mar Perú, mayo 2011.

266. IMARPE, 2011. Crucero de Evaluación Jurel, Caballa y Pota BIC OLAYA 1110-12. Doc. Interno.

267. Iriarte, J.L. and González H.E. (2004) Phytoplankton size structure during and after the 1997/98 El Niño in a coastal upwelling area of the northern Humboldt Current System. Marine Ecology Progress Series 269, 83–90.

268. Iriarte, J.L., Pizarro, G., Troncoso, V.A. and Sobrazo, M. (2000) Primary production and biomass of size-fractionated phytoplankton off Antofagasta, Chile (23–24 _S) during pre-El Niño and El Niño 1997. Journal of Marine Systems 26, 37–51.

269. IUCN, 2006. 2006 IUCN red list of threatened species. www.iucnredlist.org.

270. Jahncke, J., Ayala, L. and Mendoza, C. (1998) Abundancia relativa y distribución de aves marinas frente a la costa peruana y su relación con la abundancia de anchoveta. Crucero

BIC Humboldt 9808−09, de Piura a Lima. Informe del Instituto del Mar del Perú No. 141, 85−95. (In Spanish, with English abstract)

271. Jimenez-Prado, P. and Béarez, P. 2004. Peces marinos del Ecuador continental / Marine fishes of continental Ecuador , Vol. tomo 1 y 2, Page: 0

272. Jiménez Prado, P. and P. Béarez, 2000 Peces Marinos del Ecuador continental. Tomo 2: Guía de Especies / Marine fishes of continental Ecuador. Volume 2: Species Guide. IMBIOE/NAZCA/IFEA.

273. Jahncke, J., Checkley, D. and Hunt G.L., Jr (2004) Trends in carbon flux to seabirds in the Peruvian upwelling. Fisheries Oceanography 13, 208−223.

274. Jones, J.B. (1988). Jack mackerels. *N.Z. Fisheries Assessment Research Document 88/19.* 19 p.

275. Jones, J.B. (1990). Jack mackerels (*Trachurus* spp.) in New Zealand waters. *N.Z. Fisheries Technical Report No. 23:* 28 p.

276. Jordan, A., Pullen, G., Marshall, J.-A., Williams, H., 1995. Temporal and spatial patterns of spawning in jack mackerel, *Trachurus declivis* (Pisces: Carangidae), during 1988−91 in Eastern Tasmanian waters. Mar. Freshwater Res. 46, 831−842.

277. Jordán, J. 1983, Variabilidad de los recursos pelágicos en el Pacífico Sudeste. En Sharp, G.D. y J.Csirke (eds) Actas de la Consulta de Expertos para examinar los cambios en la abundancia y composición por especies de recursos de peces neríticos. San José, Costa Rica, 18-29 abril 1983. Una reunión preparatoria para la Conferencia Mundial de la FAO sobre ordenación y desarrollo pesqueros. FAO Fish.Rep./FAO,Inf,Pesca, (291) vol.2:553p.

278. Kaiser, C.E., 1973. Age and growth of horse mackerel, *Trachurus murphyi* off Chile. Trans. Am. Fish. Soc. (3):591-595.

279. Kalchugin, P.V. (1992). The population structure of the Peruvian jack mackerel. Soviet Journal of Marine Biology 17: 95−100.

280. Kashirin, K. V., V. V. Nekrasov, A. A. Nesterov, N. A. Nazarov y D. D. Tomorsov. 1994. Migraciones. Páginas: 175-177. En D. ARCOS y A. Grechina (Eds). Biología y Pesca Comercial del jurel en el Pacífico Sur. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 203 pp.

281. Kashkin, N.I., 1989. Mesopelagic ichthyofauna of the southwestern Pacific. J. Ichthyol. 29(3):116-127.

282. Kawahara, S., Uozumi, Y., Yamada, H., 1988. First record of a carangid fish *Trachurus murphyi* from New Zealand. Jpn. J. Ichthyol. 35, 212−214.

283. Kawasaki, T., 1983 . Why do some pelagic fishes have wide fluctuations in their numbers? Biological basis of fluctuationsfrom the viewpoint of evolutionary ecology. FAO Fish. Rep.293:1065−1080.

284. Kearns, E.J. and Carr, M.-E. (2003). Seasonal climatologies of nutrients and hydrographic properties on quasineutral surfaces for four coastal upwelling systems. Deep Sea Research II 50, 3171-3179

285. **Kijima, A., N. Taniguchi and A. Ochiai**, 1988. Genetic divergence and relationship among fifteen species of genera *Trachurus*, *Decapterus*, *Selar*, and *Selaroides*. Jap. J. Ichthyol. 35(2):167-175

286. Kochkin, P.N. (1994). Age determination and estimate of growth rate for the Peruvian jack mackerel, *Trachurus symmetricus murphyi*. Journal of Ichthyology 34: 39−50.

287. Konchina, Y.V. (1979). The feeding of the Peruvian jack mackerel, *Trachurus symmetricus murphyi*. Journal of Ichthyology 19: 52−61.

288. Konchina, Y. 1980. The peruvian jack mackerel *Trachurus symmetricus murphyi,* a facultative predator in the coastal upwelling ecosystem. J. Ichthyol. 20 (5): 46-59.

289. Konchina, Y. V. 1981. The Peruvian jack mackerel, *Trachurus symmetricus murphyi*, a facultative predator in the coastal upwelling ecosystem. Journal of Ichthyology, 21: 46-59.

290. Konchina, G.V. (1983). The Peruvian jack mackerel, Trachurus symmetricus murphyi, a facultative predator in the coastal upwelling ecosystem. Journal of Ichthyology 20(5):46-59.

291. Konchina, Y.V. (1991). Trophic status of the Peruvian anchovy and sardine. Journal of Ichthyology 31, 59–72.

292. **Konchina, Y.V.**, 1992. Trophic status of Peruvian pseudoneritic fish in oceanic epipelagic water. J. Ichthyol. 32(8):20-39

293. Konchina, Y.V., Nesin, A.V., Onishchik, N.A., Pavlov, Y.P., 1996. On the migration and feeding of the jack mackerel *Trachurus symmetricus murphyi* in the Eastern Pacific. J. Ichthyol. 36, 753–766.

294. Kotenev B.N. y Kuzetsov A.N.. 1993. Peruvian jack mackerel, *Trachurus symmetricus murphyi*, in the open waters of the South Pacific. Journal of Ichtyology, 33(3), 86-104.

295. Koval, L.I. (1996). Polymorphic locus frequency in Peruvian horse mackerel and females intrapopulation heterogeneity in growth rate. ICES Council Meeting Papers., ICES, Copenhagen (Denmark) CM 1996/H:35, 9 pp.

296. Kusnetsov, A. N. 1994. Pesca comercial del jurel peruano y su efectividad económica. Páginas: 195-202. En D. ARCOS y A. Grechina (Eds). Biología y Pesca Comercial del jurel en el Pacífico Sur. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 203 pp.

297. Leth, O. 2000. Ocean Circulation In The Eastern South Pacific: An ObservationalAnd Numerical Modelling Study, Tesis para optar al grado de Ph. D. en Oceanografía University of Copenhagen.

298. Lillo S., J. Córdova, A. Paillaman. 1995. Target Strength measurements of hake and jack mackerel. ICES Journal of Marine Science, 53: 267-271.)

299. Lin, C.-L. and J.-s. Ho 2002 Two species of siphonostomatoid copepods parasitic on pelagic fishes in Taiwan. J. Fish. Soc. Taiwan 29(4):313-332. (Ref. 48562)

300. Mace, P., L. Botsford, J. Collie, W. Gabriel, P. Goodyear, JJ. Powers, V. Restrepo, A. Rosenberg, M. Sissenwine, G. Thompson, J. Witzig. 1996. Scientific review of definitions of overfishing in U.S. Fishery Management Plans. Supplemental Report. NOAA Technical Memorandum NMFS-F/SPO-21. 20 pp.

301. Markwitz. A., Grambole, D., Herrmann, F., Trompetter, W.J., Dioses, T., Gauldie, R.W., 2000. Reliable micro-measurements of strontium is the key to cracking the life-history code of fish otolith. Nuclear instruments and Methods in Physics Research B 168 (2000):109-116

302. Martínez et al, 1996 Investigación situación pesqueria pelagica zona norte 1995. Informe Final, Proyecto IFOP/1995

303. Martínez et al, 2000 Inv. situación pesqueria pelagica norte 1999 Informe Final, Proyecto IFOP/1999

304. Martínez et al, 2001 Investigación situación pesqueria pelagica norte 2000. Informe Final, Proyecto IFOP/2000

305. Martínez et al, 2002 Inves. stuacion pesqueria pelagica zona norte 2001. Informe Final, Proyecto IFOP/2001

306. Martínez et al, 2003 Inves. stuacion pesqueria pelagica zona norte 2002. Informe Final, Proyecto IFOP/2002

307. Martínez et al, 2004 Investigación situación pesquería pelágica zona norte 2003. Informe Final, Proyecto IFOP/2003

308. Martínez et al, 2005 Investigación situación pesquería pelágica zona norte 2004. Informe Final, Proyecto IFOP/2004

309. Martínez et al, 2006 Investigación situación pesquería pelágica zona norte 2005. Informe Final, Proyecto IFOP/2005

310. Martínez et al, 2006 Investigación situación pesquería pelágica zona norte 2006. Informe Final, Proyecto IFOP/2006

311. Martínez C, G. Böhm, E. Díaz, L. Ossa, H. Reyes, J. Letelier; R. Aravena, H. Padilla, F. Cerna, V. Bocic, C. Machuca, L. Muñoz, M. Troncoso. 2009. Informe Final Investigación Situación Pesquería Pelágica Zona Norte, 2008. Seguimiento del Estado de Situación de las

Principales Pesquerías Nacionales. Subsecretaría de Pesca, Inst. Fom. Pesq., Valparaíso, Chile. 259 p+Anexos.

312. Massé, J. and Gerlotto, F. (2003) Introducing nature in fisheries research: the use of underwater acoustics for an ecosystem approach of fish population. Aquatic Living Resources 16, 107−112.

313. Miranda, L., A. Hernández, A. Sepúlveda & M. Landaeta (1998). Alimentación del jurel y análisis de la selectividad en la zona centro-sur de Chile. En: D. Arcos (ed.) Biología y ecología del jurel en aguas chilenas. Instituto de Investigación Pesquera, Talcahuano- Chile: 173-187.

314. Muck, P. 1989. Major trends in the pelagic ecosystem off Peru and their implications for management. Pages 386−403 *in* D. Pauly, P. Muck, J. Mendo, and T. Tsukayama, eds. The Peruvian upwelling ecosystem: dynamics and interactions. Proc. Workshop on Models for Yield Prediction in the Peruvian Ecosystem, Callao. ICLARM Conf. Proc. 18. ICLARM, Manila.

315. Muck, P. and G. Sanchez. 1987. The importance of mackerel and horse mackerel predation for the Peruvian anchoveta stock (a population and feeding model). Pages 276−293 *in* D. Pauly and I. Tsukayama, eds. The Peruvian anchoveta and its upwelling ecosystem: three decades of change. ICLARM Stud. Rev. 15. ICLARM, Manila.

316. Muck, P., Castillo, O.S.D., Carrasco, S., 1987. Abundance of sardine, mackerel and horse mackerel eggs and larvae and their relationship to temperature, turbulence and anchoveta biomass off Peru. In: Pauly, D., Tsukayama, I. (Eds.), The Peruvian anchoveta and its upwelling ecosystem: three decades of change. ICLARM Studies and Reviews, 15, pp. 268−293.

317. Muck, P., De Moreno, A.Z. and Aranda, C. (1989) The seasonal dynamics of sea surface temperature and its impact on anchoveta distribution off Peru. In: The Peruvian Upwelling Ecosystem: Dynamics and Interactions (eds D. Pauly, P. Muck, J. Mendo and I. Tsukayama), Vol. 18. ICLARM Studies and Reviews, Manila, pp. 33−44.

318. Nakamura, I., T. Inada, M. Takeda and H. Hatanaka 1986 Important fishes trawled off Patagonia. Japan Marine Fishery Resource Research Center, Tokyo. 369 p. (Ref. 27363)

319. Nazarov, N.A., Nesterov, A.A., 1990. Jack mackerel *Trachurus murphyi* in the southwestern part of the Pacific Ocean. Sumaries of papers of the All-Union Conference. Reserve food biological resources of the open ocean and USSR seas. Kaliningrad. March 10-22, 1990, 131-133. (In Russian).

320. Neira, S.; Arancibia, H.; Cubillos, L. (2004) Comparative analysis of trophic structure off central Chile in 1992 and 1998. Ecological Modelling. 172: 233-148.

321. Nekarov, V. V., V. N. Chur, K. V. Kashirin, N. A. Nazarov y D. D. Tormosov. 1994. Distribución del jurel peruano. Páginas: 169-173. En D. ARCOS y A. Grechina (Eds). Biología y Pesca Comercial del jurel en el Pacífico Sur. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 203 pp.

322. Nekrasov V.V., 1994. Mackerel of the World Ocean (genus Trachurus) VNIRO, Moscow, pp. 1-228.

323. Nesterov. A.A., V.N. Chur, F.V. Kolomeyko, 2007 . Russian fishery and researches in the Southern Pacific Ocean in 1978-1991 and 2002-2003. Presented In: The jack mackerel fishery in the South Pacific Meeting. March 22, 2007, Talcahuano, Chile. Atlantic Research Institute of Marine Fisheries and Oceanography (AtlantNIRO), Kaliningrad, Russia

324. Nesterov, A.A.; Chur, V.N., 2006. El-Nino and distribution of Jack mackerel *(Trachurus murphyi)* in the open part (outside 200-mile zone) of the South-Eastern Pacific Ocean. *Comm. Symposium El Niño, Lima, Dec. 2006.*

325. Nichols, J.T. 1920. A key to the species of Trachurus. , Source: Bull. Amer. Mus. Nat. Hist., Vol. 42, Page: 477-481

326. Nosov, E.V & P.V. Kalchugin. 1990. New data on distribution of Peruvian horse mackerel *Trachurus symmetricus murphyi* (Nichols, 1920) in waters of the New Zealand plateau. Express information of VNIIERKH. Series Utilization of fisheries resources of the World Ocean, 2:8-14.

327. Núñez, S., J. Letelier, D. Donoso, A. Sepúlveda & D. Arcos. 2004. Relating spatial distribution of Chilean Jack mackerel eggs and environmental factors in the oceanic waters off Chile. Pan

Ocean Remote Sensing Conference – 2004. Remote Sensing of Oceans, Coasts and the Atmosphere: Developments and Applications. J. Stuardo, A. Valdenegro, R. Abarca & S. Torres (eds.). Vol. II. Gayana 68(2): 444-449.

328. Núñez, S., S. Hormazábal, F. Gómez, J. Letelier & A. Sepúlveda. 2006. Some evidences of physical-biological coupling between Jack mackerel larvae and mesoscale structures off central Chile. The Humboldt Current system International Conference. Lima, Perú, Nov. 27 – Dec 1, 2006.

329. Núñez, S, S Vásquez, P Ruiz and A Sepúlveda. (2008). Distribution of early developmental stages of jack mackerel in the Southeastern Pacific Ocean. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

330. Ñiquen, M,. and Carranza. (2008). Program Bio-oceanographic research of resources jack mackerel and Pacific mackerel in Perú. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

331. Ñiquen, M.A. and C.L. Peña. (2008). Distribution of jack mackerel (*Trachurus murphyi*) related to oceanographical features between north Perú to north Chile. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

332. Ñiquen, M. y R. Vilchez. 1988. Fluctuaciones poblacionales del recurso Jurel (*Trachurus murphyi* N.) en la costa peruana del 1980 a 1987. Simposio Internacional de los Recursos Vivos y las Pesquerías en el Pacífico Sudeste. Viña del Mar–Chile. Pág. 253-260.

333. Ñiquen, M., Bouchón, M., Cahuín, S. and Diaz, E. (2000) Pesquería de anchoveta del mar Peruano1950–1999. Boletín del Instituto del Mar del Perú 19, 117–123. (In Spanish, with English abstract)

334. Ojeda P., Poulin E., 2002. Identificación de Unidades de stock del jurel (*Trachurus murphyi* Nichols) en el Pacifico surorintal mediante Análisis de mercadores Moleculares. Informe final PUC.

335. Ojeda,P, V. Bocic and L. Muñoz. (2008). Methodology employed for age determination in Chilean jack mackerel (*Trachurus murphyi*). Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

336. OLDEPESCA-SELA. 1986. Bases Biológicas y Marco Conceptual para el Manejo de los Recursos Pelágicos en el Pacífico Suroriental. Publicación sobre los resultados del Proyecto Regional de Evaluación de los Recursos Sardina, Jurel y Caballa en el Pacífico Suroriental, ejecutado por Ecuador, Perú y Chile. Edición coordinada por O.A. Mathisen e I. Tsukuyama. OLDEPESCA, *Documento de Pesca* 1, 196 pp.

337. Oliva J.,et al, 1995 Estudio biológico pesquero del recurso jurel en la zona norte (regiones i y ii) fase ii Informe Final Proyecto FIP-IT/ 94-17

338. Oliva, J. 2003. Estudio de las estrategias del stock centro-norte del jurel (*Trachurus picturatus murphyi)* del Perú frente a las variaciones del ambiente y de la presión de la pesca: variación de las estructuras espaciales de los bancos y agregaciones en relación con las variaciones de abundancia y del esfuerzo de pesca. Informe final. Centro de Investigación de Ciencias Biológicas. Universidad Nacional Pedro Ruiz Gallo, Lambayeque, Perú.

339. Oliva, J., F. Gerlotto y J. Cordova, 2004. Análisis of the spatial strategies of the southeast Pacific Jack Mackerel *Trachurus symmetricus murphyi* in relation to variations in its abundance. IRD, UR ACTIVE 067, Internal report:19p.

340. Oliva, J; G. Claramunt; G. Herrera; C. Padilla y P. Pizarro (1995). Reproducción In: Alegría, V. (Ed.), Estudio Biológico Pesquero sobre el recurso jurel en la zona norte (Regiones I y II). IFOP.

341. Oliva, M. 1999. Metazoan parasites of the jack mackarel *Trachurus murphyi* (Teleostei, Carangidae) in a latitudinal gradient from South America (Chile and Peru). Parasites, 6: 223-230.

342. Oliva, M.E. 1999. Metazoan parasites of the jack mackerel *Trachurus murphyi* (teleostei, Carangidae) in a latitudinal gradient from South America (Chile and Peru). Parasite 6: 223-230.

343. Oyarzún, C. y S. Gacitúa. (2002). Aspectos reproductivos, fecundidad parcial y frecuencia de desove del jurel, año 2001. In: Cubillos, L. (Ed.) Condición biológica del jurel en alta mar, año 2001. Preinforme Final Corregido, FIP 2001-12. 168 p. + Anexo.

344. Oyarzún, C., J. Chong & M. Malagueño. 1998. Fenología reproductiva en el jurel, Trachurus symmetricus (Ayres, 1855) (Perciformes, Carangidae) en el área de Talcahuano-Chile: 1982-1984. En: Arcos, D. (ed.), Biología y ecología del jurel en aguas chilenas, Instituto de Investigación Pesquera, Talcahuano, Chile, 67-75.

345. Palma, P., W. J. Pizarro and C. Flores. 1994. Variación estacional de la abundancia de larvas de trachurus symmetricus murphyi (PISCES: PERCIFORMES) en la zona norte de Chile.

346. Parrish, J. K. and A. D. MacCall. 1978. Climatic variation and exploitation in the Pacific mackerel fishery. Calif. Fish Game Fish. Bull. 167. 110 p.

347. Parrish, R.H., 1989. The south Pacific oceanic horse mackerel (*Trachurus picturatus murphyi*) fishery. In: Pauly, D., Muck, P., Mendo, J., Tsukayama, I. (Eds.), The Peruvian Upwelling Ecosystem: Dynamics and Interactions. ICLARM Conference Proceedings, vol. 18, pp. 321–331.

348. Paulin, C., A. Stewart, C. Roberts and P. McMillan, 1989. New Zealand fish: a complete guide. National Museum of New Zealand Miscellaneous Series No. 19. 279 p.

349. Pauly, D. and I. Tsukayama, eds. 1987. The Peruvian anchoveta and its upwelling ecosystem: three decades of change. ICLARM Stud. Rev. 15. ICLARM, Manila.

350. Penney, A. and P Taylor. (2008). An overview of the New Zealand jack mackerel fishery: Catch composition, catch trends, seasonality and length-frequency composition. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

351. Peña H., et al, 1998 Dinamica espacial y temporal de las zonas de pesca del jurel en chile centro-sur y su relacion con procesos ambientales Informe Final Proyecto FIPIT/97-06

352. Peña, H., C. González & F. Véjar. 2001. Spatial dynamics of jack Mackerel (Trachurus symmetricus murphy) fishing grounds and environmental conditions using GIS. Proceedings of the First International Symposium on Geographic Information Systems (GIS) in fishery science. Seattle Wsahington, USA, 2-4 March 1999. T. Nishida, P. J. Kailola & C.E. Hollingwoth (eds).

353. Peña, N. 1975. Notas preliminares sobre la madurez sexual del jurel (*Trachurus symmetricus murphyi*) del área pesquera del Callao. Tesis Bach. Ciencias Biol. Univ. Nac. San Antonio Abad del Cuzco. 50 pp.

354. Peña, N. & L. Mariátegui. 1987. Variación estacional de la actividad reproductiva del jurel Trachurus murphyi. En: H. Salzwedel y A. Landa (eds.). En Recursos y Dinámica del Ecosistema de Afloramiento Peruano. Bol. Inst. Mar Perú. Callao. Vol. Extraord. 285 – 289.

355. Peña, N. y L. Mariategui. 1987. Variación estacional de la actividad reproductiva del jurel (*Trachurus murphyi*). En: H. Salzwedel y A. Landa (eds.) Recursos y Dinámica del Ecosistema de Afloramiento Peruano. *Bol. Inst. Mar Perú* (volumen extraordinario):285-289.

356. Pequeño R., G. 1989. Peces de Chile. Lista sistemática revisada y comentada. , Source: Revista de Biología Marina, Valparaiso, Vol. 24, Page: 1-132

357. Peterson, W. T., Arcos, D. F., McManus, G. B., Dam, H., Bellantoni, D., Johnson, T., and Tiselius, P. 1988. The nearshore zone during coastal upwelling: daily variability and coupling between primary and secondary production off central Chile. Progress in Oceanography, 20: 1–40.

358. Pineda, J. and López, M. (2002) Effects of El Niño on nearshore stratification and larval settlement. In: Extended Abstracts of the El Niño Symposium and Workshop, 7–10 August 2002, Viña del Mar, Chile (eds S. Salinas, H.-J. Urban, and W.-E. Arentz). Investigaciones Marinas 30, 126–127.

359. Pitcher, T.J. (1995) The impact of pelagic fish behaviour on fisheries. Scientia Marina 59, 295–306.

360. Pitcher, T.J. (1997) Fish shoaling behaviour as a key factor in the resilience of fisheries: shoaling behaviour alone can generate range collapse in fisheries. In: Developing and Sustaining World Fisheries Resources: the State of Science and Management (eds D.A. Hancock, D.C.

Smith, A. Grant and J.P. Beumer) Proceedings of the 2nd World Fisheries Congress, CSIRO, Collingwood, Australia, pp. 143– 148.

361. Pitcher, T.J., Watson, R., Forrest, R., Pór Valtysson, H. And Guénette, S. (2002) Estimating illegal and unreported catches from marine ecosystems: a basis for change. Fish and Fisheries 3, 317–339.

362. Pizarro, O., S. Hormazabal, A. González & E. Yánez. 1994. Coastal wind, sea level and temperature variability in the north of Chile. Investigaciones Marinas, 22:85-101

363. Poulin, E., Cárdenas, L., Hernández, C.E., Kornfield, I., Ojeda, F.P., 2004. Resolution of the taxonomic status of Chilean and Californian jack mackerel using mitochondrial DNA sequence. J. Fish. Biol. 65,1160-1164.

364. Quiñones R., et al 1995 Evaluación hidroacústica del stock de jurel en la zona centro-sur, v a ix regiones Informe Final Proyecto FIP-IT/ 94-12

365. Quiñones, R., Serra, R., Núñez, S., Arancibia, H., Córdova, J., Bustos, F., 1997.Relación espacial entre el jurel y sus presas en la zona centro-sur de Chile. In: Tarifeño, E. (Ed.), Gestión de sistemas oceanográficos del Pacífico oriental. UNESCO COI/INF – 1046, pp. 187–202.

366. Raganik, B., Dlugosz, R., Milosz, J. and Borowski, W.L., 1995. Reconnaissance and exploitation of the Chilean jack mackerel by the Polish fleet in 1978-1984. Scientia marina, 59(3-4):527-532.

367. **Randolph, S. and M. Snyder**, 1993. The seafood list: FDA's guide to acceptable market names for seafood sold in interstate commerce. U.S. Government Printing Office, Washington, USA. pag. var

368. Reed D. L, Carpenter K. E, deGravelle M. J., 2002. Molecular systematics of the Jacks (Perciformes: Carangidae) based on mitochondrial cytochrome *b* sequences using parsimony, likelihood, and Bayesian approches. Mol. Phyl. Evol., v. 23, p. 513-524.

369. Reid D (Ed), 2000. Report on echo trace classification. ICES Coop. Res. Rep. 238

370. Riede, K. 2004 Global register of migratory species - from global to regional scales. Final Report of the R&D-Projekt 808 05 081. Federal Agency for Nature Conservation, Bonn, Germany. 329 p. (Ref. 51243)

371. Roberts, C.D., 1991. Fishes of the Chatham Islands, New Zealand: a trawl survey and summary of the ichthyofauna. N.Z. J. Mar. Freshwat. Res. 25(1):1-19

372. Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea and W.B. Scott 1991. World fishes important to North Americans. Exclusive of species from the continental waters of the United States and Canada. Am. Fish. Soc. Spec. Publ. (21):243 p.

373. Romero, R. C.; Kuroki, H. B., (1985). *Lernanthropus antofaganstensis* sp. nov. (Copepoda: Lernanthropidae) parasitic on *Anisotremus scapularis* in Chilean waters, and new records of *Lernanthropus trachure* (Brian 1903). Journal of Natural History 19: 407–414.

374. Sameoto DD (1986). Influence of the biological and physical environment on the vertical distribution of mesozooplankton and micronekton in the eastern tropical Pacific. Mar Biol 93:263–279

375. Robertson, D.A. (1978). The New Zealand jack mackerel fishery. *In* Habib, G. and Roberts, P.E. (Eds.). Proceedings of the pelagic fisheries conference, July 1977. FRD Occasional Publication No. 15. pp. 43–47.

376. Ruiz, P., A Sepúlveda, L Cubillos, C Oyarzún and J Chong. (2008). Reproductive parameters and spawning biomass of jack mackerel (*Trachurus murphyi*), in 1999-2006, determined by the daily egg production method. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

377. Rutllant, J. & V. Montecino, 2002. Multiscale upwelling forcing cycles and biological response off north-central Chile. Revista Chilena de Historia Natural. 75:217-231.

378. **Sanches, J.G.**, 1989. Nomenclatura Portuguesa de organismos aquáticos (proposta para normalizaçao estatística). Publicaçoes avulsas do I.N.I.P. No. 14. 322 p

379. Sanchez, G. and P. Muck. 1984. La situación alimentaria del jurel *Trachurus murphyi* NICHOLS en un año normal (1979) y en El Niño 1982/83. *Bol. Inst. Mar Perú*. Vol. 11(4):146-177.

380. Santander, H. and C. S. De Castillo. 1971. Desarrollo y distribución de huevos y larvas de "jurel" *Trachurus symmetricus murphyi* (nichols), en la costa peruana. Instituto del Mar del Perú. Informe N° 36, 23pp.

381. Santander, H. and C.S. De Castillo. 1977. Ichthyoplankton from the peruvian coast. Proc. Symp. Warm Water Zooplancton:105-125.

382. Santander, H. and R. Flores. 1983. Los desoves y distribución larval de cuatro especies pelágicas y sus relaciones con las variaciones del ambiente marino frente al Perú. (Spawning and larval distribution of four pelagic species and their relations to marine environmental variations off Peru) In: *Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources, San Jose (Costa Rica), 18 Apr 1983.* Sharp, G.D. and J. Csirke (Eds), *Proceedings: FAO Fisheries Report, FAO, Rome, Italy*, 291(2-3): 835 - 870 (in Spanish).

383. Schoener, T.W., Spiller, D.A. and Losos, J.B. (2001) Predators increase the risk of catastrophic extinction of prey populations. Nature 412, 183−186.

384. Schwartzlose, R.A., Alheit, J., Bakun, A. et al. (1999) Worldwide large-scale fluctuations of sardine and anchovy populations. South African Journal of Marine Science 21, 289−347.

385. Sepúlveda, J.I.V. and G.R. Pequeño, 1985. Fauna íctica del archipiélago de Juan Fernández. p. 81-91. In P. Arana (ed.) Escuela de Ciencias del Mar. Universidad Católica del Valparaiso, Valparaiso.

386. Sepulveda A., et al, 1997 Migración de jurel desde y hacia la zee de chile central Informe Final Proyecto FIP-IT/ 96-15

387. Sepulveda A., et al, 2000 Condiciones biologicas del jurel en alta mar. Informe Final Proyecto FIP-IT/ 99-14

388. Sepulveda A., et al, 2006 Condición biológica de jurel en alta mar, año 2005. Informe Final Proyecto FIP-IT/ 2005-11

389. Sepulveda A., et al, 2006 Condición biológica de jurel en alta mar, año 2006. Informe Avance Proyecto FIP-IT/2006-05

390. Sepúlveda, A., R. Alarcón & C. González. 2006. Evaluación de la biomasa de jurel con embarcaciones de la flota pesquera 2005. Doc. Téc. Inst. Invest. Pesq. (IIP), Talcahuano, 14(4):1-52.

391. Sepúlveda, A., L. Cubillos & D. Arcos. 2003. Pesquerías pelágicas chilenas: una síntesis sobre la incertidumbre biológica. pages 91-107. In: Laz actividad pesquera y de acuicultura en Chile. E. Yáñez (Ed.). Pontificia Universidad Católica de Valparaíso.

392. Sepúlveda, A., Miranda, L., Rebolledo, H., 1999. Análisis de la estructura del stock de jurel fuera de las aguas jurisdiccionales. Inf. Tec. FIP-IT/97-05B, 121 pp. (www.fip.cl).

393. Sepúlveda, A., R. Alarcón, S. Núñez, M. Aguayo, P. Escobar, R. Vargas, M. Correa & C. González. 2009. Evaluación directa del jurel con naves de la flota. Pre-Informe Final Proyecto FIP 2007-24. 211 pp.

394. Sepúlveda, A., Núñez, S., Cubillos, L., Hernández, A., Canales, M.T., Bucarey, D., Rojas, A., Vejar, F., Gonzalez, C., Barbieri, M.A., Córdoba, J., Espejo, M., Lillo, S. 2000. Condiciones biológicas del jurel en alta mar. Informe Final FIP 99-14.

395. Serra, J.R. (1983). Changes in the abundance of pelagic resources along the Chilean coast. In: G.D. Sharp and J. Csirke (Eds.) Proceedings of the Expert Consultation to examine changes in abundance and species composition of neritic fish resources. San José, Costa Rica, 18 - 29 April 1983. FAO Fish. Rep. 291 (2): 255 - 284.

396. Serra, J.R y C. Canales, 2007. Evaluación y Captura Total Permisible de Jurel (*Trachurus symmetricus murphyi*) Sub Regional, 2008. Pre-Informe Final, Instituto de Fomento Pesquero, Valparaíso, Chile, 85 pp.

397. Serra, R. 1991. Important life history of the chilean jack mackerel, *Trachurus symmetricus murphyi*. Invest. Pesq. (Chile), 36: 67-83.

398. Serra, R. (1991). Long - term variability of the Chilean sardine. In: Proceedings of the International Symposium on the Long - Term Variability of Pelagic Fish Populations and

their Environment. T. Kawasaki, S. Tanaka, Y. Toba and A. Taniguchi (eds.) New York: Pergamon Press. pp 165 - 172.

399. Serra et al, 1994 Investigación evaluacion del stock del jurel 1994. Informe Final, Proyecto IFOP/1993

400. Serra R.,et al, 1994 Evaluación directa del stock de jurel en la zona centro-sur Informe Final Proyecto FIP-IT/ 93-02

401. Serra et al, 1995 Investigación evaluacion del stock de jurel 1995. Informe Final, Proyecto IFOP/1994

402. Serra et al, 1998 Inves. evaluacion del stock de jurel 1998 Informe Final, Proyecto IFOP/1997

403. Serra R.,et al, 1997 Bases biológicas para prevenir la sobreexplotación en el recurso jurel Informe Final Proyecto FIP-IT/ 96-16

404. Serra et al, 1998 Investigación situación pesqueria pelagica zona centro sur 1997. Informe Final, Proyecto IFOP/1997

405. Serra et al, 1999 Inves. evaluacion del stock de jurel 1999 Informe Final, Proyecto IFOP/1998

406. Serra et al, 2001 Investigación ctp jurel 2001 Informe Final, Proyecto IFOP/2000

407. Serra et al, 2002 Inves. ctp de jurel 2002 Informe Final, Proyecto IFOP/ 2001

408. Serra et al, 2003 Inves. ctp de jurel 2003 Informe Final, Proyecto IFOP/2002

409. Serra et al, 2004 Investigación ctp jurel 2004 Informe Final, Proyecto IFOP/2003

410. Serra et al, 2005 Investigación ctp jurel 2005 Informe Final, Proyecto IFOP/2004

411. Serra et al, 2006 Evaluación de stock y ctp jurel 2006 Informe Final, Proyecto IFOP/2005

412. Serra et al, 2006 Evaluación de stock y ctp jurel 2007 Pre-Informe Final, Proyecto IFOP/2006

413. Serra, R. and R. Gili. 1995. Identificación de anillos anuales en otolitos de jurel. Informe de Taller, IFOP. Junio, 1995.

414. Serra, R and A Glubokov. (2008). Population structure of Chilean jack mackerel, *Trachurus murphyi*, in the South Pacific Ocean: Full proposal for an international joint research programme. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

415. Serra, R., C. Canales and L. Caballero. (2005).Investigación Evaluación de stock y CTP de jurel, 2005. Informe Final. IFOP/SUBPESCA. 43 p. +anexos.

416. Serra, R., Rojas, O., Aguayo, M., Inostroza, M., Cañón, J., 1979. Jurel In: Estado actual de las principales pesquerías nacionales. Bases para un desarrollo pesquero. Peces I. CORFO-IFOP, 36 pp.

417. Shaboneyev, I.Y. (1980). Systematics, morpho-ecological characteristics and origin of Carangids of the genus *Trachurus*. J. Ichthyology 20: 15-24.

418. Shiga, B. & V. Ishiyama, 1992. 1992.Ogenesis en Trachurus picturatus murphyi en la zona del Callao, Perú. Boletín de Lima N°83.Setiembre-1992.

419. Simeone A. & X. Navarro. 2002. Explotación humana de aves marinas durante el Holoceno medio en la costa del sur de Chile. Human exploitation of seabirds in coastal southern Chile during the mid-Holocene.. Revista Chilena de Historia Natural *75*: 423-431.

420. Smith, R. L. 1992. Coastal upwelling in the modern ocean. *In* Upwelling Systems: Evolution Since the Early Miocene, pp. 9–28. Ed. by C. P. Summerhayes, W. L. Prell and K. C. Emeis. Geological Society Special Publication, No. 64. The Geological Society, London. 519 pp.

421. Smith-Vaniz, W.F. 1995 Carangidae. Jureles, pámpanos, cojinúas, zapateros, cocineros, casabes, macarelas, chicharros, jorobados, medregales, pez pilota. p. 940-986. In W. Fischer, F. Krupp, W. Schneider, C. Sommer, K.E. Carpenter and V. Niem (eds.) Guia FAO para Identification de Especies para los fines de la Pesca. Pacifico Centro-Oriental. 3 Vols. FAO, Rome. (Ref. 9283)

422. Sokolov, V. A. and A. N. Kuznetsov. 1994. Historia de la investigación pesquera industrial en el Océano Pacífico Suroriental. Páginas: 13-17. En D. Arcos and A. Grechina (Eds). Biología y

Pesca Comercial del jurel en el Pacífico Sur. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 203 pp.

423. Soldat V.T., Kolomeiko F.V., Glubokov A.I., Nesterov A.A., Chernyshkov P.P. and Timokhin E.N. (2008). Jack Mackerel (Trachurus murphyi) distribution peculiarities in the high seas of the South Pacific in relation to the population structure. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

424. Soria, M., 1999. Compte-rendu de l'étude des distributions spatiales des agrégations observées au cours de la campagne de prospection « jurel93 ». Annexe rapp. ECOS 1999 : 25 p.

425. Stepien, C.A. & R.H. Rosenblatt. 1996. Genetic divergence in antitropical pelagic marine fishes (*Trachurus, Merluccius* and *Scomber*) between North ans South America. Copeia, 1996(3) 586- 598.

426. Stevenson, M.L. 2004 Trawl survey of the west coast of the South Island and Tasman and Golden Bays, March-april 2003 (KAH0304). New Zealand Fisheries Assessment Report 2004/4. 69 p. (Ref. 58489)

427. Storozhuk, A. Y., M. S. Dobrusin and E. I. Eliseeva. 1994. Dinámica estacional de los cambios de materia (composición corporal) del jurel en la subdivisión sur del Pacífico Suroriental. Páginas: 61-67. En D. Arcos y A. Grechina (Eds). Biología y Pesca Comercial del jurel en el Pacífico Sur. Instituto de Investigación Pesquera Talcahuano. Chile. Editora Aníbal Pinto S. A. 203 pp.

428. Storozhuk, A.Y., K.A. Truveller, A.L. Baturin, I.B. Guleva y G.N. Nefedov. (1987). Estructura poblacional del jurel peruano. En: D. Arcos y A. Grechina (eds.). 1994. Biología y Pesca Comercial del Jurel en el Pacífico Sur. Pp: 131-140.

429. Taylor, P.R. (2002). Stock structure and population biology of the Peruvian jack mackerel, *Trachurus symmetricus murphyi*. New Zealand Fisheries Assessment Report 2002/21. 78 p.

430. Taylor P.R. (2004) Species composition and seasonal variability in commercial catches of jack mackerel (*Trachurus declivis*, *T. symmetricus murphyi*, and *T. novaezelandiae*) in JMA 1, JMA 3, and JMA 7 during 2000–01. *New Zealand Fisheries Assessment Report 2004/28.* 22 p.

431. Teirney, L.D.; Kilner, A.R.; Millar, R.E.; Bradford, E.; Bell, J.D. (1997). Estimation of recreational catch from 1991/92 to 1993/94. *N.Z. Fisheries Assessment Research Document 97/15.* 43 p.

432. Thomas, A.C., Huang, F., Strub, P.T. and James, C. (1994) Comparison of the seasonal and interannual variability of phytoplankton pigment concentration in the Peru and California Current systems. Journal Geophysical Research 99, 7355–7370.

433. Tsukayama, I. 1983. Recursos pelágicos y sus pesquerías en el Perú. *Rev. Com. Perm. Pacífico Sur* 13:25-63.

434. Ulloa, O., Escribano, R., Hormazabal, S., Quiñones, R. A., González, R. R. and Ramos, M. (2001) Evolution and biological effects of the 1997–98 El Nin˜o in the upwelling ecosystem off northern Chile. Geophysical Research Letters 28, 1591–1594.

435. Valdivia, J.E. (1978) The Anchoveta and El Niño. Rapports et Procès-verbaux des Réunions du Conseil international pour l'Exploration de la Mer 173, 196–202.

436. Vasilyev, D., A Glubokov and D Kim. (2008). Preliminary estimation of current state of Chilean Jack Mackerel (*Trachurus murhyi*) stock in the high seas of the South East Pacific. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

437. Vásquez, S., Correa-Ramírez, M., Parada, C., Sepúlveda A., 2013. The influence of oceanographic processwes on jack mackerel (*Trachurus murphyi*) larval distribution and population structure in the southeastern Pacific Ocean. ICES Journal of Marine Science, May, 2013 (in press)

438. Vignaux, M. 1996. Analysis of spatial structure in fish distribution using commercial catch and effort data from the New Zealand hoki fishery. *Can. J. Fish. Aquat. Sci.*, 53 : 963-973.

439. Vinogradov, M.E., Shushkina, E.A., Evseyenko, S.A., 1991. Plankton biomass and potential stocks of the Peruvian jack mackerel in the southeastern Pacific subantartic zone. J. Ichthyol. 31, 146–151.

440. Whittle. Fishing News Books, Oxford, 352 pp. Boré, D., Henríquez, N., and Espinoza, G. 1988. Chile: sus recursos pesqueros. Instituto de Fomento Pesquero, IFOP, Santiago.

441. Wilen, J. E. 1979. Fisherman behavior and the design of efficient fisheries regulation programs. Journal of the Fisheries Research Board of Canada, 36: 855–858.

442. Williams, H. and G. Pullen. 1993. Schooling behaviour of jack mackerel *Trachurus declivis* (Jenyns), observed in the Tasmanian purse seine fishery. *Aust. J. Mar. Freshwater Res*., 44: 577-587.

443. Wolter, K. and Timlin, M.S. (1998). Measuring the strength of the ENSO events: How does 1997/98 rank? Weather 53, 315–324.

444. **Wu, H.L., K.-T. Shao and C.F. Lai (eds.)**, 1999. Latin-Chinese dictionary of fishes names. The Sueichan Press, Taiwan. 1028 p

445. Yáñez, E. R., V. V. Catasti, M. A. Barbieri, and G. S. Böhm. 1996. Relaciones entre la distribución de recursos pelagicos pequenos y la temperatura superficial del mar registrada con satélites NOAA en la zona central de Chile. Invest. Mar. 24: 107–122.

446. Yáñez, E., Barbieri, M.A., Silva, C., Nieto, K. and Espíndola, F. (2001) Climate variability and pelagic fisheries in northern Chile. Progress in Oceanography 49, 581–596.

447. Yáñez, E., M.A. Barbieri, C. Silva, J. Castillo, K. Nieto, G. Böhm, F. Gómez & J. Córdova. 2002. Climate variability and pelagic fisheries in the South-Eastern Pacific. Globec International Newsletter, Vol. 8, Nº2:18-19.

448. Yáñez, E.R., C. Silva, K. Nieto, M. A. Barbieri, G. Martinez, and B. Ramirez. 2002. Prediction of probable fishing grounds in northern Chile from pelagic distributions and environmental conditions. Pages 324–326 *in* C. D. van der Lingen, C. Roy, P. Fréon, L. Castro, M. Gutierrez,

449. Zhang, M. Y Xu. and C Wang (2008). Genetic variation on mt-DNA Cyt-b sequence of three populations of Chilean jack mackerel, Trachurus murphyi from the Southern Pacific. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008.

450. Zhang, M., X Zou and Y Zhou. (2008). Report of data collection on jack mackerel in South-East Pacific. Paper presented to the SPRFMO Chilean Jack Mackerel Workshop, Santiago, 30 June – 4 July 2008Zuta, S., Tsukayama, I., Villanueva, R., 1983. El ambiente marino y las fluctuaciones de las principales poblaciones pelagicas de la costa peruana. FAO Fish. Rep. 2 (291), 179–294.

451. Zuta, S., I Tsukayama & R. Villanueva, 1983. El ambiente marino y las fluctuaciones de las principales poblaciones pelágicas de la costa peruana. En Sharp, G.D. & J. Csirke (eds) Actas de la Consulta de Expertos para examinar los cambios en la abundancia y composición por especies de recursos de peces neríticos. San José, Costa Rica, 18-29 abril 1983. Una reunión preparatoria para la Conferencia Mundial de la FAO sobre ordenación y desarrollo pesqueros. FAO Fish. Rep./FAO Inf, Pesca (291) vol.2:553p.

452. Zuta, O. and Guillén, O. (1970) Oceanografía de las aguas costeras del Perú. Boletín del Instituto del Mar del Perú 2, 157–324. (In Spanish, with English abstract)

Working documents on *Trachurus murphyi*, SPRFMO

Meeting #1 (Wellington, 2006)

1. Kotenev, B.N., Kukhorenkho, K.G., Glubokov, A.I. Main results of mthe Russian multidisciplinary ecosystem research, and exploratory fish-finding of concentrations of hydrobionts and their fisheries development in the South Pacific.

Meeting #2 (Hobart, 2006)

2. Anonymous, 2006. Report on the Chilean Jack Mackerel.SPRFMO working Document, 2006:57 p.

3. Anonymous, 2006. Science Working Group Intersessional task. International Consultations on the Establishment of the SPRFMO Science Working group. Hobart, 2006 (pdf version of a ppt presentation): 18 p.

Meeting #3 (Reñaca, 2007)

4. Anonymous, 2007. Template for the compilation of information describing fisheries and related species in the Southern Pacific Ocean. Doc. SPRFMO-III-SWG-05, 2007: 9 p.

5. Anonymous, 2007. Template for the compilation of information describing associated and dependant species in the sourhern Pacific Ocean. Doc. SPRFMO-III-SWG-06, 2007: 6 p.

6. Anonymous, 2007. Template for the compilation of information describing specific habitats in the southern Pacific Ocean. Doc. SPRFMO-III-SWG-07, 2007: 7 p.

7. Anonymous, 2007. Information describing the Chilean Jack Mackerel (*Trachurus murphyi*) fisheries related to the South Pacific Regional Fisheries Management Organisation. Revised, 23 April 2007. Doc. SPRFMO-III-SWG-16, 2007: 26 p.

8. Anonymous, 2007. Report from Chile on jack mackerel research and stock assessment. Doc. SPRFMO-III-SWG-18, 2007:59 p.

9. Anonymous, 2007. Stock assessment and current status of the Chilean stock on jack mackerel. Doc. SPRFMO-III-SWG-18a-part 2, 2007. Pdf version of a ppt presentation: 9 p.

10. Anonymous, 2007. Data inventory for jack mackerel stock assessment. Draft proposal prepared by Chile for discussion in the Science Working Group (SWG) during the 3rd International Meeting of the SP-RFMO. Doc. SPRFMO-III-SWG-20, 2007: 3 p.

11. Anonymous, 2007. Population structure of the jack mackerel *Trachurus murphyi*, in the South Pacific Ocean: proposal for discussion for a regional joint research. Draft proposal prepared by Chile for discussion in the Science Working Group (SWG) during the 3rd International Meeting of the SP-RFMO. Doc. SPRFMO-III-SWG-21, 2007: 24 p.

12. Anonymous, 2007. Population structure of the jack mackerel *Trachurus murphyi*, in the South Pacific Ocean: proposal for discussion for a regional joint research. Draft proposal prepared by Chile for discussion in the Science Working Group (SWG) during the 3rd International Meeting of the SP-RFMO. Doc. SPRFMO-III-SWG-21a, 2007. Pdf version of a ppt presentation: 7 p.

13. Canales, C., 2007. Research for management of Chilean Jack Mackerel (*Trachurus murphyi*) exploited in the South East Pacific Ocean. Doc. SPRFMO-III-SWG-18a-part 1, 2007. Pdf version of a ppt presentation: 23 p.

14. Glubokov, A.I., Nesterov, A.A., Kotenev, B.N., Corten, A., Trotsenko, B.G., Romanov, E.V., 2007. Objectives of science in functioning of regional Fisheries Management Organizations in relation to the establishment of a new organization in the South Pacific. Doc. SPRFMO-III-SWG-19, 2007: pdf version of a ppt presentation: 22 p.

Meeting #4 (Noumea, 2007)

(no paper concerning *T. murphyi*)

Meeting #5 (Guayaquil, 2008)

15. Anonymous, 2008. Proposed interim terms of reference for the Jack Mackerel Sub-Group & Deepwater Sub-Group. Doc. SPRFMO-V-SWG-07, 2008: 5 p.

16. Anonymous, 2008. Population structure of the Chilean jack mackerel, *Trachurus murphyi*, in the South Pacific ocean. Doc. SPRFMO-V-SWG-13, 2008: 4 p.

17. Anonymous, 2008. Progress on the Chilean jack mackerel Workshop (CHJMWS). Doc. SPRFMO-V-SWG-14, 2008, pdf version of a ppt presentation: 8 p.

18. Anonymous, 2008. National Fishery Institute, Ecuador: Jack-Mackerel (*Trachurus murphyi*); fishery and biological aspects in Ecuadorian waters. Doc. SPRFMO-V-SWG-15, 2008: 5 p.

19. Canales, C., and Serra, R., 2008. Technical summary: Updated status of the Chilean jack Mackerel stock. Doc. SPRFMO-V-SWG-11, 2008: 10 p.

20. Shubina, E.A., Ponomareva, E.V., Glubokov, A.I., 2008. Recent genetic studies of Pacific jack mackerel *Trachurus* murphyi in Russia. Doc. SPRFMO-V-SWG-12, 2008: 10 p.

Meeting #6 (Canberra, 2008)

21. Anonymous, 2008. Report of the South Pacific Regional Fisheries management Organization Chilean Jack Mackerel Workshop, 30 June-$ July 2008, Santiagl, Chile. Doc. SPRFMO-VI-SWG-02, 2008: 70 p.

22. Anonymous, 2008. Information describing Chilean jack mackerel (*Trachurus murphyi*) fisheries relating to the South Pacific Regional Fishery Management Organisation: working draft. Doc. SPRFMO-VI-SWG-03, 2008: 30 p.Chilean jack mackerel management system: synthesis and recommendation. Doc. SPRFMO-VI-SWG-04, 2008: 23 p.

23. Anonymous, 2008. Terms of reference, workshop on the stock assessment framework for the jack mackerel. Doc. SPRFMO-VI-SWG-05, 2008: 2 p.

24. Anonymous, 2008. Jack mackerel high sea catches 2007, Australian government, Bureau of Rural Science. Doc. SPRFMO-VI-SWG-info-01, 2008: 1 p.

Meeting #7 (Lima, 2009)

25. Anonymous, 2009. Report of the Chilean jack mackerel assessment methods workshop, 4-8 May 2009, Lima, Peru. Doc. SP-07-SWG-JM-01, 2009: 23 p.

26. Anonymous, 2009. Information describing Chilean jack mackerel (*Trachurus murphyi*) fisheries relating to the south Pacific Regional Fishery Management Organisation. Doc. SP-07-SWG-JM-02, 2009: 30 p.

27. Anonymous, 2009. Acoustic data proposal for consideration of the Science Working Group (SWG) of SPRFMO. Doc. SP-07-SWG-JM-INF-06, 2009: 3 p.

28. Canales-Aguirre, C., Ferrada S. and Galleguillos R., 2009. Isolation and characterization of microsatellite loci for the jack mackerel (*Trachurus murphyi* Nichols, 1920). Doc. SP-07-SWG-JM-10, 2009: 3 p. (reprint from Conserv. Genet.DOI 10.1007/s10592-009-9932-y, 2009)

Meeting #8 (Auckland, 2009)

29. Anonymous, 2009. Annual national report to the SPRFMO Science Working Group. Doc. SP-08-SWG-06, 2009: 27 p.

30. Anonymous, 2009. Peru annual report to the SPRFMO Scientific Working Group. Doc. SP-08-SWG-05, 2009: 12 p.

31. Anonymous, 2009. National report of China to the SPRFMO Science Working Group. Doc. SP-08-SWG-13, 2009: 8 p.

32. Anonymous, 2009. Annual report of Vanuatu to the SPRFMO Science Working Group, Doc. SP-08-SWG-15, 2009: 5 p.

33. Anonymous, 2009. Diagnosis of the Chilean jack mackerel. SP-08-SWG-JM-09, 2009: 13 p.

34. Anonymous, 2009. Revised Chilean jack mackerel (*Trachurus murphyi*) fisheries relating to the South pacific regional Fishery Management Organization. Working draft. SP-08-SWG-JM-12, 2009: 35 p.

35. Anonymous, 2009. Methodological proposal for direct stock assessment of marine resources in the SPRFMO area. Ecosysten indexes obtained from fishing monitoring. SP-08-SWG-JM-13, 2009: 11 p.

36. Anonymous, 2009. Differences between mackerel (*Trachurus* species) data submitted to SPRFMO versus the FAO. SP-08-SWG-INF-02, 2009: 7 p.

37. Anonymous, 2009. Proposed Process for the 2009 Review of jack mackerel fishery indicators by the SPRFMO science working group – jack mackerel sub-group. SP-08-SWG-INF-07, 2009: 3 p.

38. Aranis, A., Bernal, C., Gómez, A., Martínez, F., 2009. Main biological indicators of jack mackerel (*Trachurus murphyi*). SP-08-SWG-JM-04, 2009: 7 p.

39. Caballero, L., and Böhm, G., 2009. Fishing indicators of jack mackerel in Chile, 1995-2008. SP-08-SWG-JM-05, 2009: 6 p

40. Canales, C., and Serra, R., 2009. Interpretation of biological-fishing indicators of jack mackerel exploited off central-southern Chile. SP-08-SWG-JM-10, 2009: 10 p.

41. Córdova, J., Bahamonde, R., Castati, V. and Bosic, V., 2009. Acoustic biomass of jack mackerel (*Trachurus murphyi, Nichols, 1920*) structured by size and age in the central coast off Chile. SP-08-SWG-JM-03, 2009: 13 p.

42. Corten, A., 2009. National report of the European Community to the SPRFMO Science Working Group on the fisheries in the Pacific in 2008. Doc. SP-08-SWG-05, 2009: 5 p.

43. Corten, A., 2009. The fishery for jack mackerel in the Eastern Central Pacific Ocean. SP-08-SWG-JM-01, 2009: 10 p.

44. Karp, W., Kloser, R., Gerlotto, F., Peña, H., Gutiérrez, M., 2009. Guidelines for acoustic data collection aboard fishing vessels operating in the SPRFMO area. SP-08-SWG-JM-11, 2009: 18 p.

45. Kim Doo Nam and Chang Dae Soo, 2009. National report of Korea to the SPRFMO Sciencde Working Group. Doc. SP-08-SWG-10, 2009: 4 p.

46. Lanza, V., 2009. Belize's annual report to the Interim Secretariat of SPRFMO, 29 October 2009. Doc. SP-08-SWG-07, 2009: 5 p.

47. Núñez Elías, S.., Correa Ramirez, M., and Vasquez Pastene, S., 2009. Variability of the Chilean jack mackerel fishing habitat in the southern Pacific Ocean. SP-08-SWG-JM-06, 2009: 30 p.

48. Penney, A., 2009. Composite distribution of jack mackerel catches and surveyed acoustic biomass off the Chilean coast from 24ºS to 52ªS. SP-08-SWG-JM-07, 2009: 5 p.

49. Ruiz, P., Sepúlveda, A., Cubillos, L., Oyarzún, C., Chong, J., 2009. Reproductive parameters and spawning biomass of Chilean jack mackerel (*Trachurus murphyi*) in 1999-2008, determined by the daily egg production method. SP-08-SWG-JM-02, 2009: 11 p.

50. Serra, R., and Canales, C., 2009. Updated status of the Chilean jack mackerel stock. SP-08-SWG-JM-08, 2009: 20 p.

Meeting #9 (Viña del Mar, 2010)

51. Anonymous, 2010. Annual national report to the SPRFMO Science Working Group. Jack mackerel fishery in Chile. SWG-09-09, 2010: 11 p.

52. Anonymous, 2010. National report of the Russian Federation to the SPRFMO Science Working Group on the fisheries in the Pacific in 2008-2009. SWG-09-10, 2010: 16 p.

53. Anonymous, 2010. National report of China to the 2010 SPRFMO Science Working Group. SWG-09-11, 2010: 7 p.

54. Anonymous, 2010. Peru annual national report to the SPRFMO Scientific Working Group, 2010. SWG-09-12, 2010: 9 p.

55. Anonymous, 2010. Government of the Republic of Vanuatu: Annual report to the SPRFMO Science Workong group. SWG-09-13, 2010: 4 p.

56. Anonymous, 2010. Report from the assessment simulation task team on Chilean jack mackerel stoc assessments. SWG-09-JM-01, 2010: 22 p.

57. Anonymous, 2010. Report from the assessment simulation task team on Chilean jack mackerel stock assessment. SWG-09-JM-02A, 2010: 17p.

58. Anonymous, 2010. Report from the assessment simulation task team workshop on using the joint jack mackerel assessment model (JJM). SWG-09-JM-02B, 2010: 26 p.

59. Anonymous, 2010. Report on the Chilean jack mackerel activities during the FAST working group. ICES WGFAST, San Diego, 25-30 April, 2010. SWG-09-JM-03, 2010: 2 p.

60. Anonymous, 2010. Report of the acoustic group. SWG-09-JM-05, 2010: 8 p.

61. Anonymous, 2010. Russian Federation CPUE 1987-97. SWG-09-INF-04, 2010: 1 p

62. Anonymous, 2010. Instrumental evaluation of Pacific jack mackerel biomass made by AtlantNIRO in the South Pacific (1083-2003). SWG-09-INF-05, 2010: 1 p.

63. Anonymous, 2010. Russian Federation jack mackerel South Pacific catches by region. SWG-09-INF-06, 2010: 1 p.

64. Anonymous, 2010. Russian Federation jack mackerel catch by age and number, 1979-1991. SWG-09-INF-08, 2010: 1 p.

65. Corten, A., and Janusz, J., 2010. National report of the European Union to the 2010 SPRFMO Science Working Group (revised version including new 2010 data). SWG-09-04, 2010: 35 p.

66. Gerlotto, F., Bertrand, A., Gutierréz, M., and Sepúlveda, A., 2010. Population structure of the Chilean mackerel (*Trachurus murphyi*) in the South Pacific Ocean. SWG-09-JM-04, 2010: 38 p.

67. Kim Doo Nam and Lee Dong Woo, 2010. National report of Korea. SWG-09-06, 2010: 4 p.

68. Raganik, B., Dlugosz, R., Milosz, J. and Borowski, W.L., 1995. Reconnaissance and exploitation of the Chilean jack mackerel by the Polish fleet in 1978-1984. Scientia marina, 59(3-4):527-532. Presented at SPRFMO as SWG-09-INF-03, 2010: 6 p.

69. Zaporowski, R., 2010. Preliminary report from cruise on board of F/V Alina to open waters of south-eastern Pacific on 09-09 to 07-09 2009. SWG-09-JM-06, 2010: 30 p.

70. Zelenina, D.A., and Rastorguev, S.M., 2010. Russian population genetics study of jack mackerel in the South Pacific. SWG-09-INF-07, 2010: 7 p.

Meeting #10 (Port Vila, 2011)

71. Anonymous, 2011. Jack mackerel fishery in Chile: Annual national report Science Working Group 2011. SWG-10-07, 2011:16 p.

72. Anonymous, 2011. National report of China to the 2011 SPRFMO Science Working Group. SWG-10-09, 2011: 9 p.

73. Kim D. N., Kim Z. G, and Lee D.W., 2011. National report of Korea to the SPRFNO Science Working group. SWG-10-10, 2011: 5 p.

74. Anonymous, 2011. Peru Annual national report to the SPRFMO Scientific Working Group: 2010-2011. SWG-10-11, 2011:13 p.

75. Anonymous, 2011. National report of the Russian Federation to the SPRFMO Science Working Group on the fisheries in the Pacific in 2008-2011. SWG-10-12, 2011:13 p.

76. Anonymous, 2011. Report on the Russian Scientific Observation in the cruise onboard Russian BATM#K-2176 "Leader" in the south-east Pacific (SEPO), March-May, 2011. SWG-10-12a, 2011:27 p.

77. Anonymous, 2011. Government of the Republic of Vanuatu. Annual report to the SPRFMO Science Working Group. SWG-10-13, 2011:3 p.

78. Anonymous, 2011. Report of the Chilean jack mackerel otolith interpretation and ageing workshop, 4-13 July, 2011. SWG-10-JM-01, 2011: 38 p.

79. Anonymous, 2011. Bio-acoustics South Pacific Regional Fisheries management Organization (BA-SPRFMO). Minutes of meeting held in Reykjavik, Iceland, 12 May, 2011. SWG-10-JM-03, 2011: 2 p.

80. Buryakova, M.E., and Glubokov, A.I., 2011. Russian population genetics study of jack mackerel in the South Pacific. SWG-10-JM-05, 2011: 6 p.

81. Corten, A., and Janusz, J., 2011. National report of the European Union to the 2011 SPRFMO Science Working Group. SWG-10-04, 2011:18 p.

82. Gerlotto, F., Gutiérrez, M., Josse, E. and Aliaga, A., 2011. Acoustic data obtained from fishing vessels: what can be obtained that research vessel cannot offer? (Results from a SNP/IRD workshop on the Peruvian fishery, March, 2011). SWG-10-JM-02, 2011: 18 p.

83. Hintzen, N., 2011. Estimating FMSY assuming a variety of stock-recruitment relationships. SWG-10-JM-08, 2011: 3 p.

84. Gang Li, Ziaorong Zou, and Yinqi Zhou, 2011. Standardization of catch per unit effort for Chilean jack mackerel (*Trachurus murphyi*) from Chinese trawl fleet on the High seas in the southeast Pacific Ocean (2001-2010). SWG-10-JM-06, 2011: 14 p.

85. Penney, A., and Ianelli, J., 2011. Effect of reducing fishing mortality on immature jack mackerel. SWG-10-JM-07, 2011: 8 p.

86. Penney, A.J., Loveridge, C.J., J.A. a,d George, K., 2011. Estimation of new Zealand monthly purse-seine and midwater trawl catches of *Trachurus novaezelandiae, T. declinis* and *T. murphyi* by fisheries management area from October 1985 to December 2010. SWG-10-INF-02, 2011: 59 p.

87. SNP, 2011. Report of 2011 SNP Workshop on acoustic and geostatistical assessment of abundance, distribution changes and size structure of jack mackerel (*Trachurus murphyi*) during first half of 2011 within the Peruvian EEZ. SWG-10-JM-04, 2011: 20 p.

Meeting #11 (Lima, 2012)

88. Anonymous, 2012. National report of China. SWG-11-04, 2012: 9 p.

89. Anonymous, 2012. Annual national report SPRFMO- Science Working Group: Jack mackerel fishery in Chile. SWG-11-07, 2012: 19 p.

90. Anonymous, 2012. Report on the fishing activities of the Peruvian fleet in the area of the South Pacific Regional Fisheries Managemeont Organization (SPRFMO). SWG-11-08 (rev. 1), 2012: 13 p.

91. Anonymous, 2012. National report on the situation of the Peruvian stock of jack mackerel (northern stock) and the Peruvian fishery in national jurisdictional waters. SWG-11-08a, 2012: 65 p.

92. Anonymous, 2012. South Pacific regional Fisheries Management Organisation (SPRFMO): Draft research program. SWG-11-09, 2012: 8 p.

93. Anonymous, 2012. Jack mackerel (*Trachurus murphyi*) in Ecuadorian waters. SWG-11-11, 2012: 11 p.

94. Anonymous, 2012. Comments and suggestions regarding the parameters and the age-structured model currently used for the assessment of jack mackerel in the SPRFMO. SWG-11-JM-02, 2012: 8 p.

95. Anonymous, 2012. Characteristics of the Peruvian stock (northern stock) of jack mackerel (*Trachurus murphyi*) in the southeast Pacific and notes on the scientific basis for its differentiation. SWG-11-JM-03, 2012: 27 p.

96. Anonymous, 2012. Working Plan Chilean jack mackerel age estimation. SWG-11-JM-05, 2012: 3 p.

97. Anonymous, 2012. F limit reference points about preventing recruitment overfishing and its uncertainty. SWG-11-JM-10, 2012: 6 p.

98. Anonymous, 2012. Minutes of bio-acoustical technical group meeting. SWG-11-INF-04, 2012: 3 p.

99. Anonymous, 2012. South Pacific Regional Fisheries Management Organization (SPRFMO) draft research program. SWG-11-WD-02, 2012: 12p.

100. Afanaziev, P.K., Rabchun, M.A., and Glubokov, A.I., 2012. Russian population genetics stidues of jack mackerel in the South Pacific. SWG-11-JM-11, 2012: 6 p.

101. Canales, C., 2012. Jack mackerel biological reference points (BRP). SWG-11-JM-01, 2012: 16 p.

102. Canales, C., and Hintzen, N., 2012. Reference point estimation. SWG-11-JM-09, 2012: 30 p.

103. Choi, S.G., Yeon, I., and Lee, D.W., 2012. National report of Korea to the 2012 SPRFMO Science Working group. SWG-11-05, 2012: 8 p.

104. Gerlotto, F., Gutierréz, M., and Bertrand, A., 2012. Insight on population structure of the Chilean jack mackerel (*Trachurus murphyi*). Aquatic living Resources, DOI: 10.1051/alr/2012036, in press. Presented at SPRFOM under ref. SWG-11-JM-04, 2012: 25 p.

105. Leal, E., Diaz, E., and Saavedra J.C., 2012. Reproductive timing and maturity at length and age of jack mackerel *Trachurus murphyi*, in the Chilean coast. SWG-11-JM-07, 2012: 12 p.

106. Li G., Zou X., Zhou Y., and Lei L., 2012. Update standardization of CPUE for Chilean jack mackerel (*Trachurus murphyi*) from Chinese trawl fleet. SWG-11-JM-08, 2012: 8 p.

107. Saavedra, J.C., Caballero L., and Canales C., 2012. Analysis of the CPUE in the jack mackerel fishery in centre-south Chile. SWG-11-JM-06, 2012: 10 p.

FAO workshop

- Meeting documents FAO: *South Pacific Regional Management Organisation*, Chilean Jack Workshop, 30 June to 4 July 2008.
- Canales C (2008) "Catch per Unit Effort of Chilean Jack Mackerel *(Trachurus murphyi)* of the purse seine fishery off south-central Chile (32o10’ – 40o10’ S) 1981–2005 FAO: *South Pacific Regional Management Organisation*, Chilean Jack Workshop, CHJMWS:10.
- Núñez S, S Vásquez, P Ruiz and A Sepúlveda (2008) "Distribution of early developmental stages of jack mackerel in the Southeastern Pacific Ocean" FAO: *South Pacific Regional Management Organisation*, Chilean Jack Workshop, CHJMWS:2.
- Peña, Hector (2008) "In situ target-strength measurements of Chilean jack mackerel *(Trachurus symmetricus murphyi)* collected with a scientific echosounder installed on a fishing vessel" *ICES J. Mar. Sci.* **65** (4): 594–604. {doi|10.1093/icesjms/fsn043}
- Penney A and P Taylor (2008) "An Overview of the New Zealand Jack Mackerel Fishery: Catch Composition, Catch Trends, Seasonality and Length-Frequency Composition" FAO: *South Pacific Regional Management Organisation*, Chilean Jack Workshop, CHJMWS:19.
- Vasilyev D and A Glubokov (2008) "Preliminary estimation of current state of Chilean Jack Mackerel *(Trachurus murhyi)* stock in the high seas of the South East Pacific" FAO: *South Pacific Regional Management Organisation*, Chilean Jack Workshop, CHJMWS:22.

Referneces from the text that are not directly related to Trachurus murphyi

Metapopulations

Anonymous, 2008. Chilean Jack Mackerel Workshop. Report of the South Pacific Regional Fisheries Management Organization Chilean Jack Mackerel Workshop. 30 June-4 July 2008, Santiago, Chile.

Arcos, D., Cubillos, L., Nuñez, S., 2001. The jack mackerel fishery and El Niño 1997-1998 effects off Chile. Progress in Oceanography, 49, 597-617

Ashford J., Serra, R., Saavedra, J. C., Letelier, J., 2011. Otolith chemistry indicates large-scale connectivity in Chilean jack mackerel (Trachurus murphyi), a highly mobile species in the Southern Pacific Ocean. Fisheries Research 107 (2011), 291–299

Bakun A., Broad, K., 2003. Environmental 'loopholes' and fish population dynamics: comparative pattern recognition with focus on El Nino effects in the Pacific. Fish. Oceanogr. 12 (4-5), 458–473

Barber, R.T., Chavez, F.P., 1983. Biological consequences of El Niño. Science 222, 1203-1210.

Barbieri, M.A., Cordova, J., Lillo, S., Peña, H., Grechina, A., Nuñez, S., Sepulvbeda, A., Miranda, L., Rebolledo, H., 1999. Análisis de la estructura del stock de jurel fuera de las aguas juridiccionales. Inf. Téc. FIP-IT/97-05b, 121 p. (www.fip.cl)

Barbieri, M.A., Cordoba, J., Espejo, M., 2001. Ecoprospecciones de jurel (Trachurus murphyi) en la zona central de Chile (Operaciones Rastrillo). En Informe del Segundo Taller Regional sobre Metodologías de Evaluación Hidroacústica de Recursos Pesqueros. Comisión Permanente del Pacífico Sur (CPPS), 51-53.

Barbieri, M.-A., Cordova, J., Gerlotto, F., Espejo, M., 2004. Spatial spawning strategy of jack mackerel (*Trachurus symmetricus murphyi*) off the central-south region fo Chile. Comm. GLOBEC/SPACC Workshop on characterizing and comparing the spawning habitats of small pelagic fishe, Concepcion, Chile, 12-13 January, 2004, 4 pp

Bertrand, A., Barbieri, M.A., Cordova, J., Hernandez, C., Gomez, F., Leiva, F., 2004. Diel vertical behaviour, predator prey relationships, and occupation of space by jack mackerel (*Trachurus murphyi)* off Chile. ICES Journal of Marine Science, 61, 1105–1112

Bertrand, A., Barbieri, M.A., Gerlotto, F., Leivam F,, Córdova, J., 2006. Determinism and plasticity of fish schooling behaviour as exemplified by the South Pacific jack mackerel *Trachurus murphyi.* Marine Ecology Progress Series, 311, 145–156.

Bertrand, A., Chaigneau, A., Peraltilla, S., Ledesma, J., Graco, M., Monetti, F., Chavez, F.P., under Review. Oxygen, a fundamental property regulating pelagic ecosystem structure in the coastal southeastern tropical Pacific. PLoS ONE.

Cárdenas, L., Hernández, C., Poulin, E., Magoulas, A., KornWeld, I., Ojeda, F., 2005. Origin, diversification, and historical biogeography of the genus Trachurus (Perciformes: Carangidae). Molecular Phylogenetics and Evolution. doi:10.1016/j.ympev.2005.01.011

Cárdenas, L., Silva, A.X., Magoulas, A., Cabezas, J., Poulin, E., Ojeda, F. P., 2009. Genetic population structure in the Chilean jack mackerel, *Trachurus murphyi* (Nichols) across the South-eastern Pacific Ocean. Fisheries Research, 100, 109-115

Chavez, F.P., Ryan, J., Lluch-Cota, S.E. and Niquen, M., 2003. From anchovies to sardines and back: multidecadal change in the Pacifc Ocean. Science 299, 217-221.

Chavez, F., Bertrand, A., Guevara, R., Soler, P., Csirke, J., 2008. The northern Humboldt Current System: Brief history, present status and a view towards the future. Progress in Oceanography 79 (2008), 95–105

Cubillos, L.A, Paramo, J., Ruiz, P., Núñez, S., Sepúlveda, A. 2008. The spatial structure of the oceanic spawning of jack mackerel (*Trachurus murphyi*) off central Chile (1998 – 2001). Fisheries Research 90: 261-270Dioses, T., 1995. Análisis de la distribución y abundancia de los recursos jurel y caballa frente a la costa Peruana. Informe Progresivo del Instituto del Mar del Perú No. 3, 55 pp. (In Spanish, with English abstract)

Dioses, T., 1995. Análisis de la distribución y abundancia de los recursos jurel y caballa frente a la costa Peruana. Informe Progresivo del Instituto del Mar del Perú No. 3, 55 pp. (In Spanish, with English abstract)

Evseenko, S.A., 1987. Reproduction of Peruvian jack mackerel, *Trachurus symmetricus murphyi*, in the southern Pacific. J. Ichthyol. 27, 151–160.

Ganoza, F., 1998. Abundancia y comportamiento del jurel (*Trachurus picturatus murphyi*) a través de prospecciones acústicas de 1983 a 1994. Informe del Instituto del Mar del Perú No. 136, 23–47. (In Spanish, with English abstract)

Gerlotto, F., Barbieri, M.-A., 2000. Pression de pêche et dynamique du comportement spatial du chinchard (*Trachurus symmetricus murphyi*). Exposé Scientifique du projet ECOS nº C97B06, 2000 : 25 pp (in French)

Gorbunova, N.N., Evseenko, S.A., Garetovskiy, S. V., 1985. Distribution of Ichthyoplankton in the Frontal Zones of the Peruvian Waters. Journal of Ichthyology, 25(6), 67-79.

Grechina, A., 1998. Historia de investigaciones y aspectos básicos d e la ecología del jurel *Trachurus symmetricus murphyi* (Nichols) en alta mar del Pacífico Sur. In: Arcos D (ed) Biología y ecología del jurel en aguas Chilenas. Instituto de Investigación Pesquera, Concepción, Chile, 11–34

Grechina, A.S., Nuñez, S.P., Arcos, D.F., 1994. Desove del recurso jurel (*Trachurus symmetricus murphyi*) en el océano Pacífico Sur. Documento Técnico de Investigaciones Pesqueras (IIP), Talcahuano, vol. 3, 1-44

Grimm, V., Reise, K., Strasser, M., 2003. Marine metapopulations : a useful concept ? Helgoland marine Research, 56(4), 222-228

Gutiérrez, D., Sifeddine, A., Field, D.B., Ortlieb, L., Vargas, G., Chávez, F., Velazco, F., Ferreira, V., Tapia, P., Salvatteci, R., Boucher, H.,Morales, M.C., Valdés, J., Reyss, J.-L., Campusano, A., Boussafir, M., Mandeng-Yogo, M., García M., Baumgartner T., In press. Rapid reorganization in ocean biogeochemistry off Peru towards the end of the Little Ice Age. Biogeosciences.

Hanski, I.A., 1999. Metapopulation ecology. Oxford University Press

Harden-Jones, F., 1968. Fish migration. Edward Arnold Ltd, London.

Konchina Y.V., Y.P. Pavlov. 1999. On the Strength of Generations of the Pacific Jack Mackerel Trachurus symmetricus murphyi. Journal of Ichthyology, 39, 748-754.

Konchina YV (1981) The Peruvian jack mackerel, Trachurus symmetricus murphyi, a facultative predator in the coastal upwelling ecosystem. Journal of Ichthyology 21, 46–59

Kritzer, J.P., Sales, P.F , 2006. The metapopulation ecology of marine coral fishes. In . Marine metapopulations (eds Kritzer, J.P., Sales, P.F.), 2006. Academic Press, Amsterdam.

Kritzer, J.P., Sales, P.F, 2004. Metapopulation ecology in the sea: from Levin's model to marine ecology and fisheries science. Fish and Fisheries (2004), 5:131-140

Levin, R., 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. Bulletin of Entomological Society of America 15:237-240

McQuinn, I., 1997. Metapopulations and the Atlantic Herring. Reviews in Fish biology and fisheries, 7:297-329

Muck, P., Sanchez, G., 1987. The importance of mackerel and horse mackerel predation for the Peruvian anchoveta stock (a population and feeding model). In: The Peruvian Anchoveta and its Upwelling Ecosystem: Three Decades of Change (eds D. Pauly, Tsukayama, I.), No.15. ICLARM Studies and Reviews, Manila, 276–293.

Nakamura, I., Inada, T., Takeda, M., Hatanaka, H., 1986. Important fishes trawled off Patagonia. Japan Marine Fishery Resource Research Center, Tokyo. 369 p.

Nesterov. A.A., Chur, V.N., Kolomeyko, F.V., 2007 . Russian fishery and researches in the Southern Pacific Ocean in 1978-1991 and 2002-2003. Presented In: The jack mackerel fishery in the South Pacific Meeting. March 22, 2007, Talcahuano, Chile. Atlantic Research Institute of Marine Fisheries and Oceanography (AtlantNIRO), Kaliningrad, Russia

Oliva, M., 1999. Metazoan parasites of the jack mackerel *Trachurus murphyi* (Teleostei, Carangidae) in a latitudinal gradient from South America (Chile and Peru). Parasites, 6, 223-230.

Ovaskainen, O., Hanski, I., 2004. From individual behavior to metapopulation dynamics: unifying the patchy population and classic metapopulation models. American Naturalist 164(3), 364-377.

Petitgas, P., Secor, D.H., McQuinn, I., Huse, G., Lo, N., 2010. Stock collapses and their recovery: mechanisms that establish and maintain life-cycle closure in space and time. ICES Journal of Marine Science, 67, 1841-1848

Poulin, E. L. Cardenas, C.E,. Hernández, I., Kornfield, F., Ojeda, P., 2004. Resolution of the taxonomic status of Chilean and Californian jack mackerels using mitochondrial DNA sequence. Journal of Fish Biology, 65, 1160-1164.

Riede, K. 2004 Global register of migratory species - from global to regional scales. Final Report of the R&D-Projet 808 05 081. Federal Agency for Nature Conservation, Bonn, Germany. 329 p.

Santander, H., Flores, S. 1983. Los desoves y distribución larval de cuatro especies pelágicas y sus relaciones con las variaciones del ambiente marino frente al Perú. FAO. Fish Rept. N° 291 (3), 835-867.

Sepúlveda, A., Cubillos, L., Arcos, D. 2008. Pesquerías pelágicas chilenas: una síntesis sobre la incertidumbre biológica, 91-107. In: Las actividad pesquera y de acuicultura en Chile. (Ed. E. Yáñez). Pontificia Universidad Católica de Valparaíso.

Sepúlveda, A., Alarcón, R., González, C. 2007. Evaluación de la biomasa de jurel con embarcaciones de la flota pesquera 2005. Doc. Téc. Inst. Invest. Pesq. (IIP), Talcahuano, 14(4), 1-52.

Sepúlveda, A., Alarcón, R., Núñez, S., Aguayo, M., Escobar, P., Vargas, R., Correa, M., González, C. 2009. Evaluación directa del jurel con naves de la flota. Pre-Informe Final Proyecto FIP 2007-24. 211 pp.

Sepúlveda, A., Cubillos, L., Grechina, A., Peña, H., Vilugrón, L., Hernández, A., Miranda, L., Serra, R., Braun, M., Böhm, G., Galleguillos, R., Montoya, R., Quiñones, R., 1998. Migración del jurel dentro y fuera de la ZEE de Chile. Informe final FIP96-15, Instituto de Investigaciones Pesqueras, Instituto de Fomento Pesquero y Universidad de Concepción, 256 p + anexos y figuras.

Serra R (1991). Important life history aspects of the Chilean jack mackerel, *Trachurus symmetricus murphyi*. Investigaciones Pesqueras 36, 67–83

Sifeddine, A., Gutiérrez, D., Ortlieb, L., Boucher, H., Velazco, F., Field, D., Vargas, G., Boussafir, M., Salvatteci, R., Ferreira, V., García, M.,Valdes, J., Caquineau, S., Mandeng Yogo, M., Cetin, F., Solis, J., Soler, P., Baumgartner, T., 2008. Laminated sediments from the central Peruvian continental slope: A 500 year record of upwelling system productivity, terrestrial runoff and redox conditions. Progress in Oceanography 79, 190-197.