

Research and management
of Chilean Jack Mackerel
(*Trachurus murphyi*) exploited
in the South East Pacific Ocean



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Introduction

Records of Chilean catches of jack mackerel began being kept in the 1950s. In national terms, they start to become important in the early 1970s. At present, jack mackerel is Chile's main industrial fishery. Catches made by Chile represent 86% of the total recorded by FAO for statistical area 87.

The Chilean fleet fishes for *Trachurus murphyi*, a species whose habitat is in the South Pacific Ocean, between the subtropical front and the southern boundary of the West Wind Drift, where the Humboldt Current system is produced. Distribution of jack mackerel reaches, in the north, as far as parallel 1° 38' N around the Galapagos Island and to the south, it goes as far as 56° S (the southernmost area of Chile). To the west, its projection reaches the Sea of Tasmania. Studies show that at least the operations of the Chilean and foreign fleets are based on a single stock which, because it is spread out inside and outside the Chilean EEZ, is classified as a straddling species.

Important processes in the life history of jack mackerel —such as feeding and breeding— as well as a significant part of the fisheries developed in association with its availability are linked to the continental border of the South East Pacific Ocean. Jack mackerel shows a clear pattern of movement towards the open sea outside the EEZ, with reproductive purposes, to then return and remain for the most part close to the coast for trophic purposes.

The increase in the jack mackerel population in the mid 1970s gave rise to the development of this fishery in the South East Pacific Ocean. However, a significant reduction in recruitment in the late 1980s, together with a simultaneous increase in landings, gave rise to a major overexploitation. This translated into one of the biggest fishing crises experienced by Chile. Starting in 1998 and as a result of a series of drastic conservation and management measures adopted by the Fisheries Authorities, together with favorable recruitment in the period 1996 - 2002, this overexploitation was reversed. At present, the jack mackerel stock is in a state of relative stability and full exploitation.

The importance of jack mackerel fishing is evidenced by the priority status that the Chilean State grants to regulating jack mackerel and also to research on the subject. In the past few years, the state has funded over 67 research projects on jack mackerel, including two annual programs conducted uninterruptedly since 1980: namely, the monitoring of the fishery and its direct assessment through hydroacoustic methods. A significant number of studies are also conducted by universities and private research institutions.

This paper offers the main background data on fisheries research carried out by Chile. This provides a pool of scientific knowledge on the identity, biology and characteristics of the stock that form the underpinnings for the management of jack mackerel by the fisheries authorities in the South East Pacific.

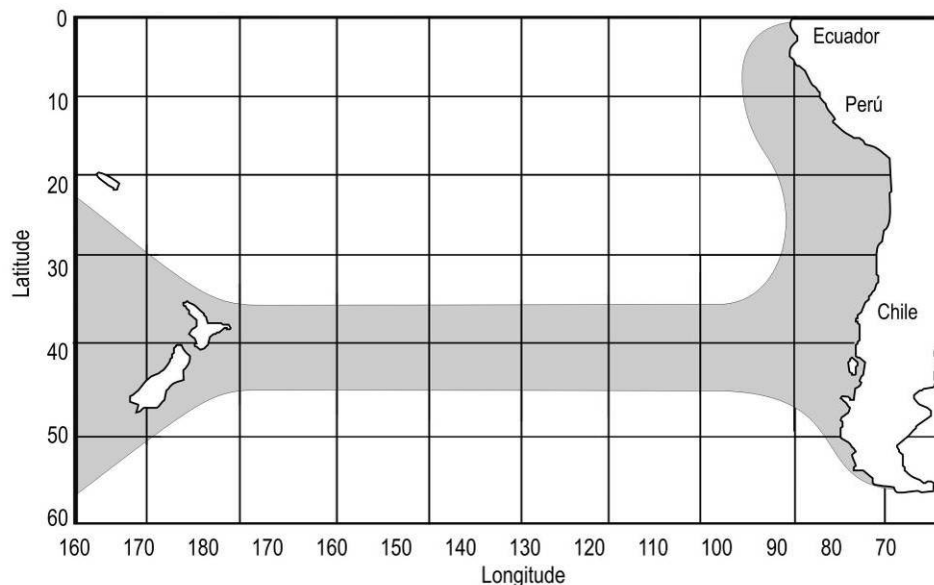
Development of the Chilean Jack Mackerel Fishery

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1.1 Jack mackerel in the South Pacific Ocean

Jack mackerel (*Carangidae*) is a widely distributed resource in all oceans and it is the mainstay of major fisheries around the world. Commercial catches of the *Trachurus* genus rose from around one million tons in 1960 to over 6.5 million tons in 1995. Catches then dropped to 2.5 million tons in 1999. Since the early 1970s, most world catches (20% to 75%) have been composed of Chilean jack mackerel (*Trachurus murphyi*, Nichols, 1920) fished in the South East Pacific Ocean. (Figure 1).

Figure 1:
Distribution of jack mackerel (*Trachurus murphyi*) in the South Pacific Ocean

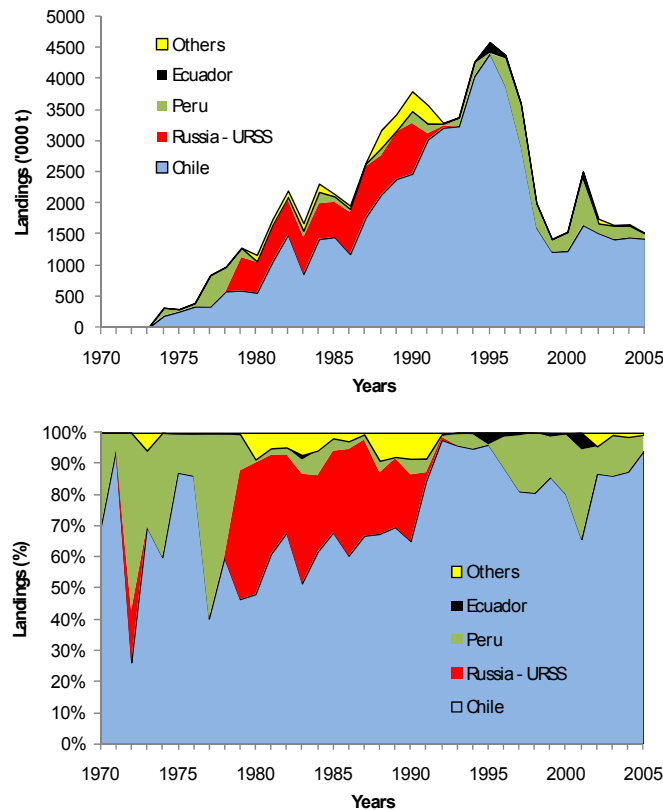


Source: IFOP

In the South East Pacific (FAO Area 87), Chilean jack mackerel catches became significant in the mid 1970s. They mainly consist of catches made by Chile, countries that were part of the former Soviet Union, and Peru. Together, in the late 1980s, they accounted for around four million tons of jack mackerel landings. Throughout the entire life of the fishery, Chile has held a major share, reaching an average of 96% in the period 1992 - 1995 when the highest catches were recorded, bordering on 4.5 million tons. The share caught by the former Soviet Union's fleet is also worth mentioning: during its operations in the period 1978 - 1992 it landed 22% of the total (Figure 2).

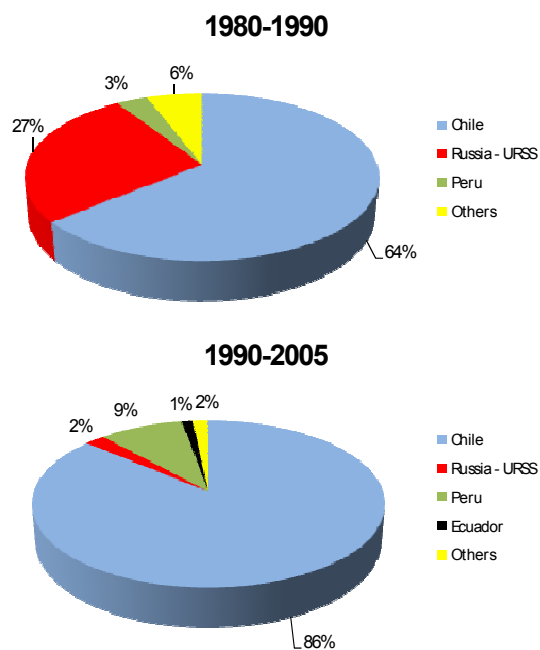
In the past 16 years, average annual Chilean catches have amounted to 86% (Figure 3) of the landings recorded in FAO statistical area 87. It is the main industrial fishery in Chile and it accounts for over 45% of the total fish landed.

Figure 2:
Evolution of Chilean jack mackerel landings in the South East Pacific Ocean, by country, 1970 - 2005



Source: FAO

Figure 3:
Ratio of Chilean jack mackerel catches reported
in FAO statistical area 87 (South East Pacific), by country, 1980 - 2005



Source: FAO

1.2 History of Landings and Fishing Effort

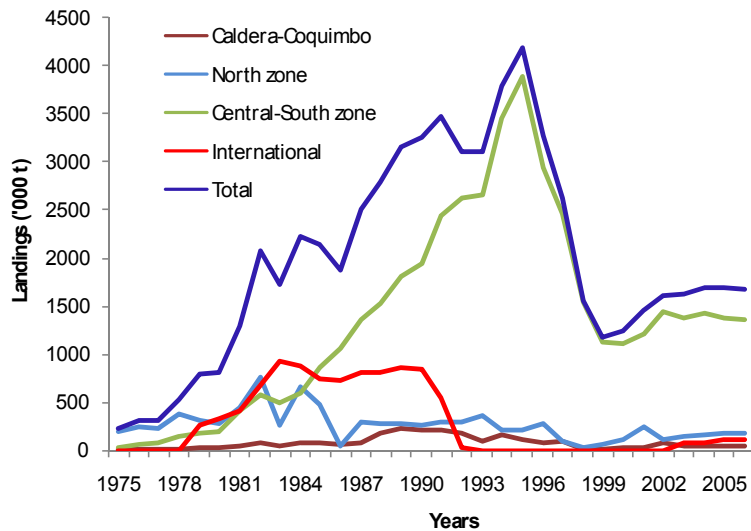
Jack mackerel is exploited by the Chilean fleet mainly in two fishing areas: in the north (roughly the area extending from Chile's northern border and parallel 26° 03'S) and the center-south area (i.e. between parallels 32° 10'S and 43° 30'S). The fleet operating in the latter area operates both in Chile's 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 (26° 03'S - 32° 10'S). Records for that area in the period 1988 - 1996 show average annual landings of 140 thousand tons.

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). At the same time, from 1978 to 1992, long-distance fishing vessels began operating—particularly the former Soviet Union's fleet—in the area adjacent to Chile's EEZ, from 20°S and 52°S up to 105°W. However, the former USSR fleet fished preferably off the center-south area identified above. 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. This was due to the fisheries regulations implemented as a result of the crisis experienced by the fishery due to

overexploitation and decreased recruitment. Regulations played an important role in decreasing catches in the period 1997-2000.

Figure 4:
Jack mackerel landings, by area.
Chilean fleet and international fleet, 1975 – 2006.



Source: SERNAPESCA

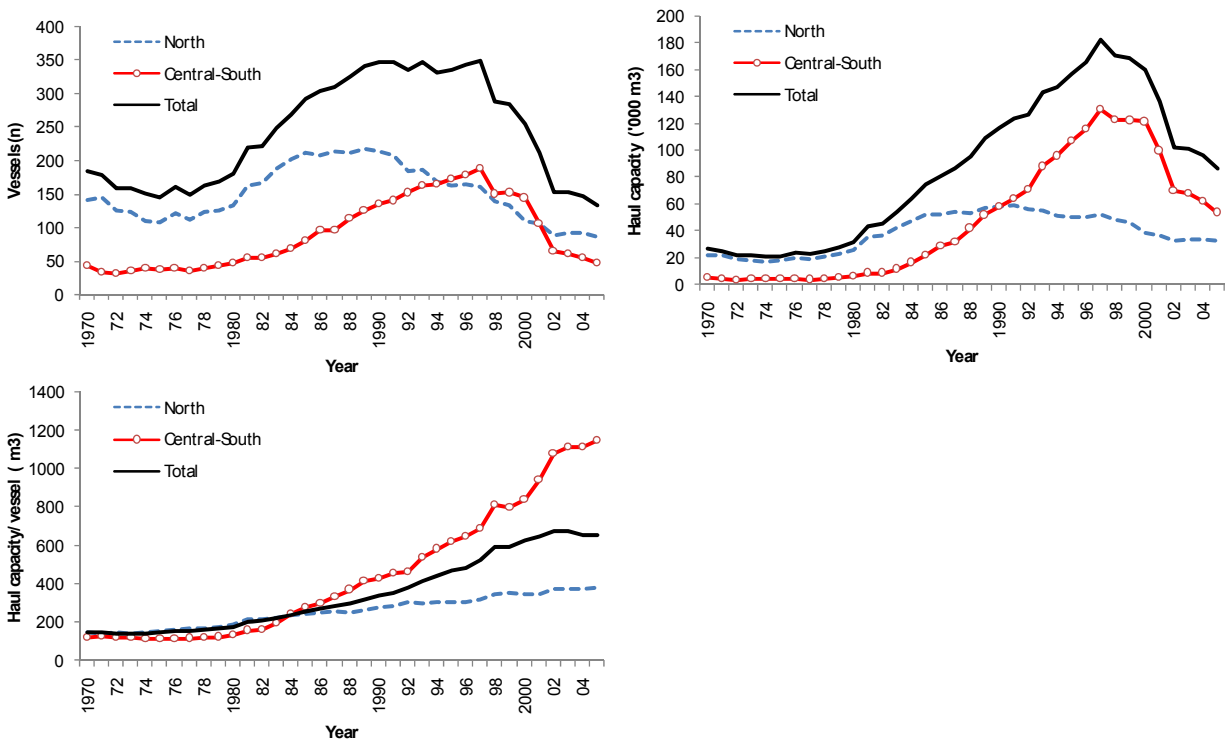
In the period 1999 – 2000, total annual catches were of the order of 1.2 million tons. As of 2001, catch levels stabilized at around 1.5 million tons per year, as a result of the maximum allowable catch quotas established by the fisheries authorities. At the same time, new operations –by a fleet from the People’s Republic of China– began in the international fishery outside the Chilean EEZ.

Jack mackerel quota 1999-2006

Year	Maximum Annual Catch Quota
1999	2,000,000 ton
2000	No quota
2001	1,425,000 ton
2002	1,625,000 ton
2003	1,475,000 ton
2004	1,475,000 ton
2005	1,483,500 ton
2006	1,400,000 ton

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 5, 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.

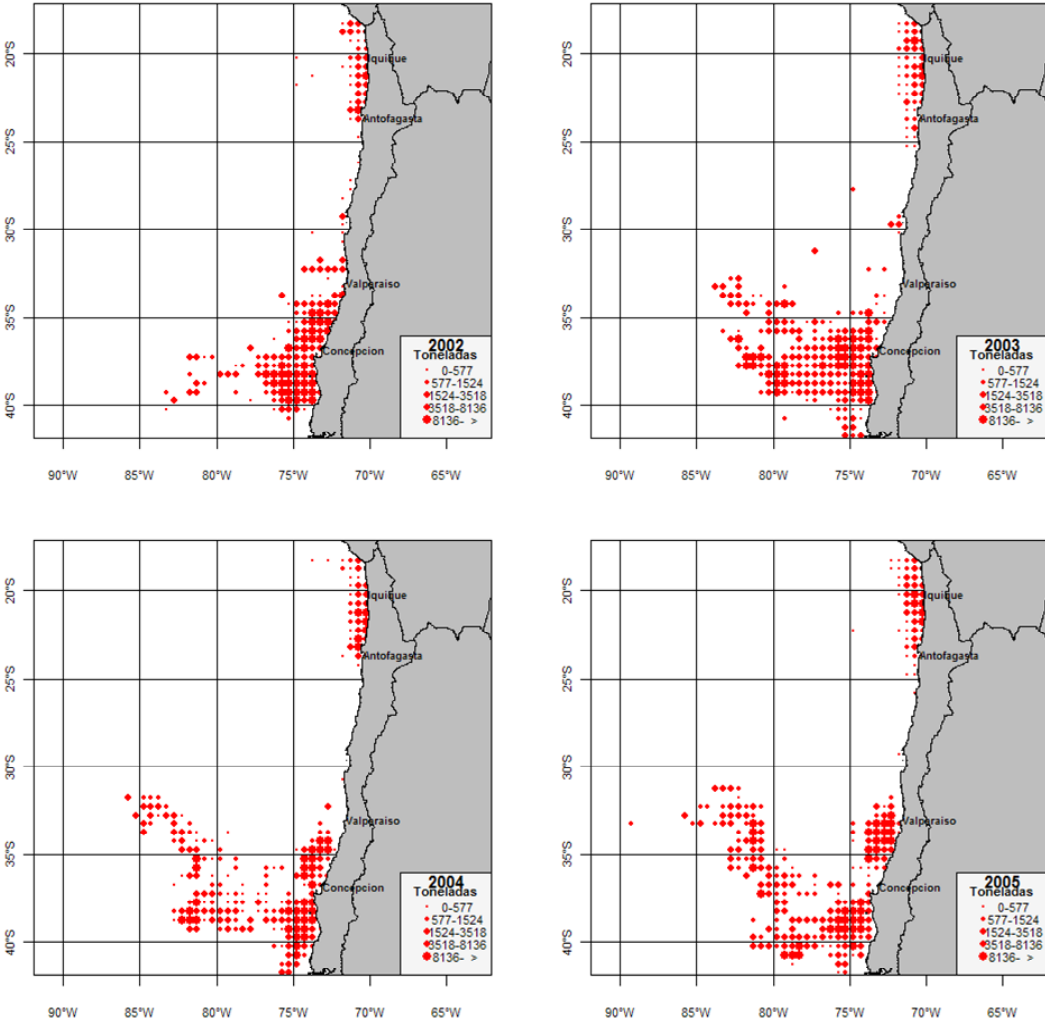
Figure 5:
Evolution of the fleet in the north and center-south area of the fishery, 1970 - 2005



Source: IFOP

Changes in spatial coverage by the fleet are also worth mentioning. These are directly related to the availability of the resource. Jack mackerel exploitation beyond the first 100 nautical miles (n.m.) 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 (Figure 6)

Figure 6:
 Time-space distribution of jack mackerel catches by the
 Chilean industrial purse-seine fleet, 2002 - 2005



Source: IFOP

In the period 1993 - 2005 alone, over 67 research projects on jack mackerel have received funding. These studies range from population structure to stock assessments, including the monitoring of reproductive conditions, acoustic evaluation and monitoring of reproductive conditions (see Annex). Two annual research programs stand out in this context: (i) the monitoring of national fisheries, to gather biological and operational data on all fishing activities; and (ii) stock assessment and estimates of the Total Allowable Catch (TAC), used to make a diagnosis on the status of jack mackerel and recommendations for allowable catches.

2.1 Monitoring the Main Chilean Fisheries

The Chilean Government, through the Fisheries Development Institute (IFOP), conducts the research program “National Fisheries Monitoring” since 1980. The program is dedicated to collecting all the biological and fishing data related to the activities of the Chilean fleet. The data are used to generate indicators pertinent to fisheries management and also to provide input for the jack mackerel stock assessment.

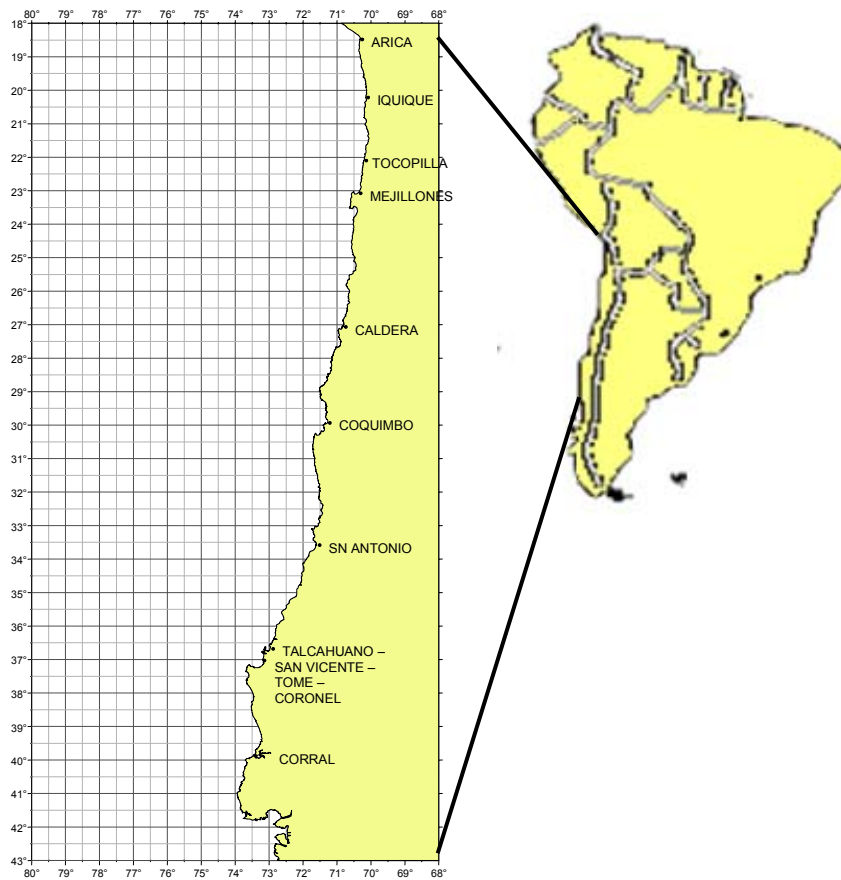
2.1.1 Monitoring Program Structure

Regarding pelagic fisheries, the sampling efforts of this study are aimed at two major areas of fishing activity in Chile: the north, covering the area that runs from Chile's northern border and parallel 32°10'S (Regions I through IV); and the center-south area, from parallels 32°10'S to 43°30'S. On a national level, these are the main fishing areas for jack mackerel. A permanent sampling network is in operation for data collection activities. It covers the main landing ports in the north, i.e. Arica, Iquique, Tocopilla, Mejillones, Caldera and Coquimbo; and San Antonio, Talcahuano, San Vicente, Coronel, Tomé and Corral, in the center-south area (Figure 7). Biological data is also collected on board fishing ships. This is done by scientific observers posted permanently on board the vessels.

Data collection from the fleet includes updates on the technical features of the ships as well as information on operational variables. A daily record is kept of the fishing operations conducted by each vessel. Thus, data is collected on landings (by date, time, port and species), catches (by zone and/or coordinates and species) and fishing effort in terms of the trips made (total trips, with or without fishing). Data are supplemented with information collected on board the ships and recorded in a Log Book System kept by IFOP. Samples are taken on land, every day, at the landing sites, following a statistical stratified bi-stage design. A tri-stage sampling design is applied on

board the ships. In this case, the first stage covers the fishing trips, the second the reflects the sets, and the third the group to be sampled.

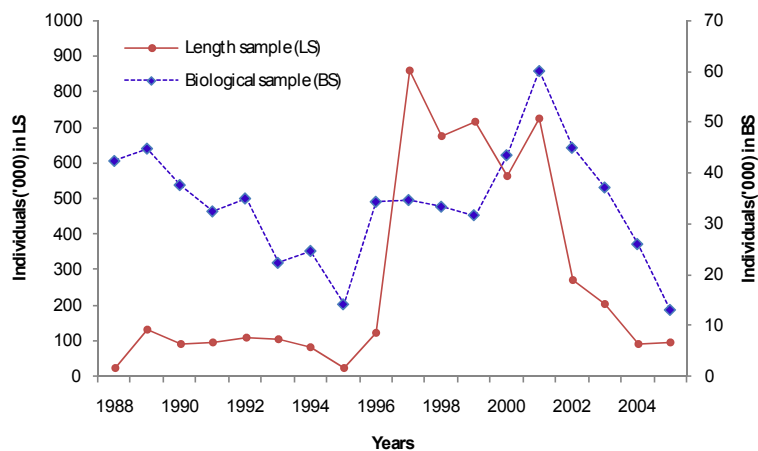
Figure 7:
Sampling points for jack mackerel on a national level



Source: IFOP

Length sampling on a national level currently amounts to approximately 100 thousand specimens per year, out of which, around 10% are subjected to full biological sampling. Nevertheless, sampling was intensified in the period 1997 - 2001, with emphasis on monitoring the capture of recruits, so as to monitor the biological state of jack mackerel during the crisis that affected the fishery (Figure 8). Table 1 shows sampling sizes for the years 2004 and 2005. The sampling port or center is also identified. Table 2 shows the number of otoliths measured in the period 1975 - 2005, which are essential to build age-length keys.

Figure 8:
Number of specimens measured in the period 1988 - 2005.
Length and biological samplings.



Source: IFOP

Table 1
Number of specimens measured,
by port and type of sampling, 2004 – 2005

Port	Biological samples		Length samples	
	2004	2005	2004	2005
Arica	169	50	1417	4634
Iquique	2499	2049	16911	32857
Tocopilla	646	123	5438	4141
Mejillones	633	545	11972	5705
Caldera	3305	1118	9983	10589
Coquimbo	2878	728	5760	1188
Talcahuano	1484	820	5398	9340
San Vicente	11611	6147	27457	25527
Coronel	970	601	4870	2687
Corral	1809	889	3818	1835
Total	28008	15075	95028	100508

Source: IFOP

Table 2
Number of jack mackerel otoliths read in the period 1975 - 2005

Year	Arica-Coquimbo	San Antonio - Valdivia	Total
1975	2498	356	2854
1976	3351	918	4269
1977	3406	799	4205
1978	3917	1941	5858
1979	2743	1000	3743
1980	3362	993	4355
1981	3735	1011	4746
1982	3690	2953	6643
1983	3902	1888	5790
1984	6562	2067	8629
1985	3793	1818	5611
1986	2955	1813	4768
1987	4625	2666	7291
1988	3868	2182	6050
1989	4258	2132	6390
1990	4566	3084	7650
1991	5188	2148	7336
1992	5932	2310	8242
1993	4360	2853	7213
1994	3809	3102	6911
1995	3006	4151	7157
1996	4367	3075	7442
1997	4537	4327	8864
1998	2899	2987	5886
1999	3119	2539	5658
2000	3910	2343	6253
2001	4137	3187	7324
2002	4059	3803	7862
2003	2273	2132	4405
2004	2929	2533	5462
2005	2155	2062	4217
TOTAL	117911	71173	189084

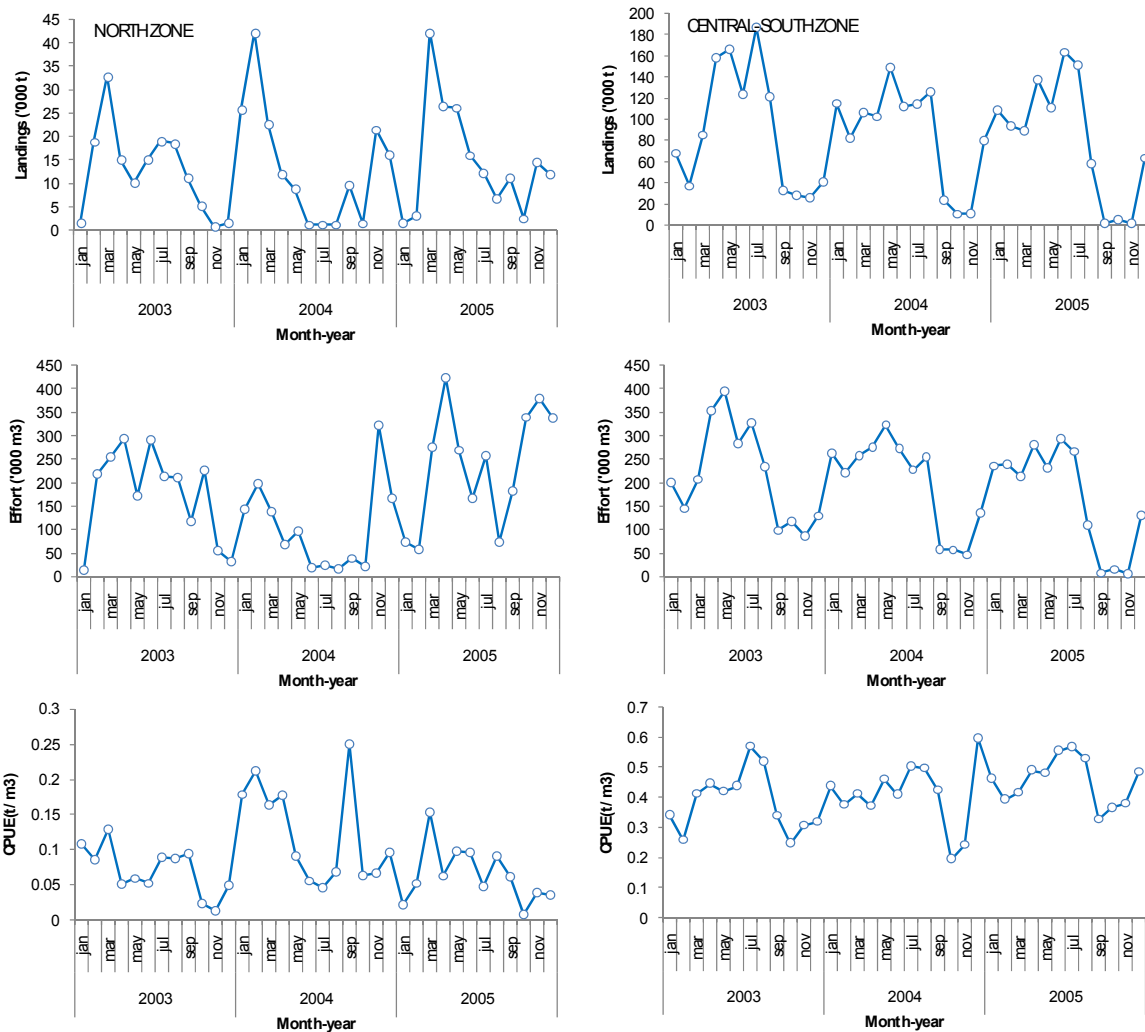
2.1.2 Results of the Fishery Monitoring Program

Information generated by the annual fishery monitoring program provides important data on the main changes in the jack mackerel population exploited off the coast of Chile and its projection outside the EEZ. Population changes are marked by changes in the age and length composition of the catches and also by changes in the temporal and spatial patterns of the fleet.

Seasonality is a characteristic feature of this fishery as a consequence of its reproductive emigration to the high seas (outside the EEZ) and its subsequent immigration for trophic purposes towards neritic zones. In the north, peak landings have been recorded in the month of March, with an average of 32 thousand tons. The latter amount decreases significantly as the month of October approaches with average volumes under 5

thousand tons (Figure 9). Catches in the center-south area also show a clear seasonal pattern, with a significant increase in landings starting in December, when jack mackerel begins its return—or immigration—from the high seas to the coastal feeding grounds. Peak catches are obtained in the period April through July (first semester). Average landings during this period reach 130 thousand tons, thereby concentrating 65% of the annual catches. (Figure 10).

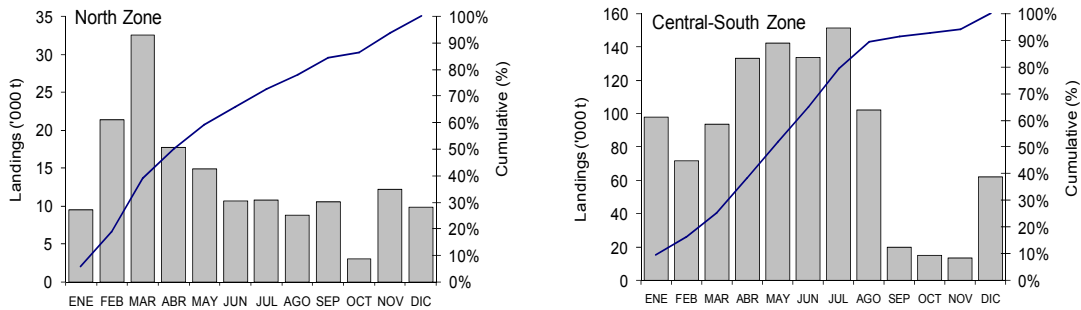
Figure 9:
Catches, hold displaced by the fleet (m^3) and monthly yield (t/m^3),
2003 - 2005; a) north area and b) center-south area



Source: IFOP

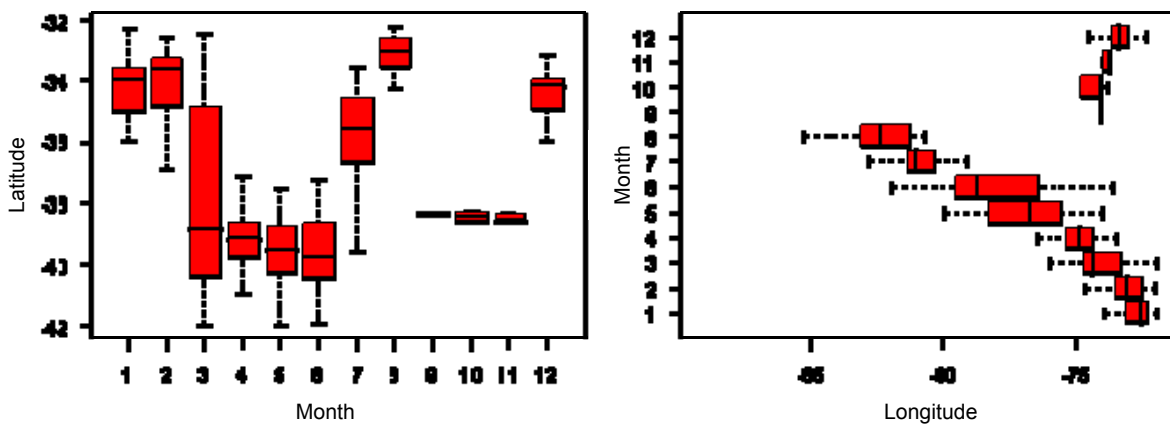
The seasonality of the fishery is also reflected in the spatial behavior of the fleet in the center-south area. Early in the year, it operates mainly close to the coast and gradually moves seaward in subsequent months. It reaches its maximum independence around 80°W - 85°W towards the month of August. By the end of the year, operations are once again coastal and centered—in latitudinal terms—around parallel 38°S (Figure 11).

Figure 10:
Average Monthly Landings, 2003 - 2005



Source: IFOP

Figure 11:
Location of jack mackerel fishing areas in the center-south area of Chile, by geographical position and month, 2003 - 2005



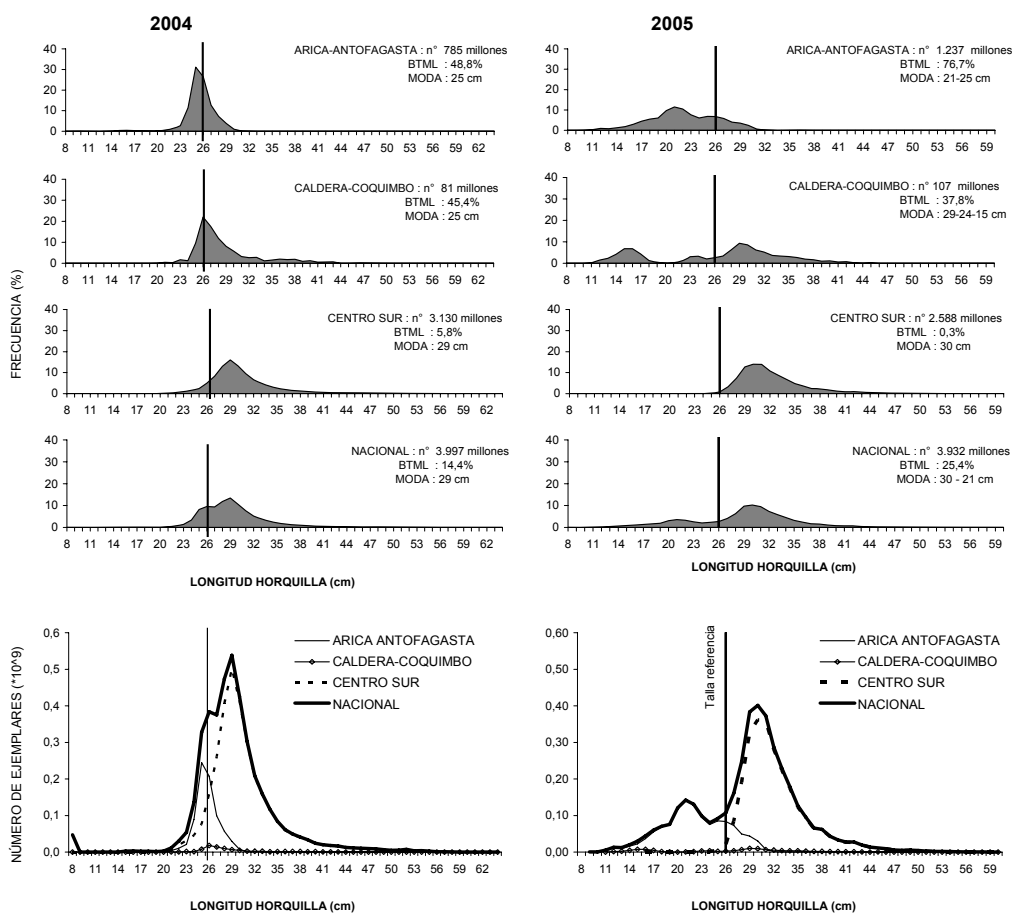
Source: IFOP

On the other hand, the age and length compositions of jack mackerel account for the main processes of its population dynamics: growth, mortality and recruitment. It is worth emphasizing that, while in the north there is a partial view of the recruitment dynamics, in the center-south area, changes in abundance among the adult portion of the population are more clearly visible. This is due either to a decrease in the number of specimens with a higher reproductive value caused by mortality, or due to the failure or success of recruitment noticed early on in the northern area of Chile. In period 2004 - 2005, the length composition of jack mackerel catches were characterized, on the one hand, by the growth of individuals of 30 cm of modal length that characterized the national fishery in 2004; and, on the other hand, by a significant increase in the number of specimens under 26 cm of fork length (LH) in 2005, particularly in the northern area. The latter is indicative of good recruitment by the fishery, whose magnitude should be measured on the basis of its progression through the fishery in the center-south area in the coming years (Figure 12).

Historical data on the age composition of jack mackerel catches is also illustrative. It reflects the main changes experienced by the population over time. Up to the early 1990s, the population of jack mackerel grew, reflecting the important recruitment that had taken place in the mid- 1980s which was noticeable through a strengthening in the age composition, primarily in the center-south area with specimens over age 8. Subsequently, and as a result of the overfishing of the resource in the 1990s and the decrease in recruitment levels, the age composition of the population weakened considerably, reaching its most critical levels in 1998 and 1999, with catches based on 2 annual classes, age 3 and age 4. (Figure 13). In the past 5 years, as a result of the restrictions imposed on catches and the passing of strong annual classes —such as those of 1998 and 1999— a significant recovery of the resource's age composition has been achieved (from age 4.1 to age 7.6 in 2006). Notwithstanding the above, data on the age composition also shows that, in recent years (2001-2005) recruitment levels for the adult stock have been low (age 4-5) in the center-south area.

Figure 14 shows a summary of relevant indicators for the fishery. Changes in catch seasonality over time and the reproductive condition of jack mackerel stand out. The latter involves measuring the gonad somatic index (IGS) and the ratio of mature females. In general, reproductive indicators show that the pattern of intra-annual variability does not change significantly. However, the increase showed as the second semester of each year approaches is noticeable as a result of their higher reproductive activity.

Figure 12:
Jack mackerel catch in numbers by size, by the Chilean fleet (Arica -Chiloé),
total for the fleet, by macro-area , 2004 – 2005.



Source: IFOP

2.2 Direct Assessment of the Resource

The direct assessment of jack mackerel in Chile is carried out by two different programs: acoustic surveys and monitoring surveys to determine reproductive conditions.

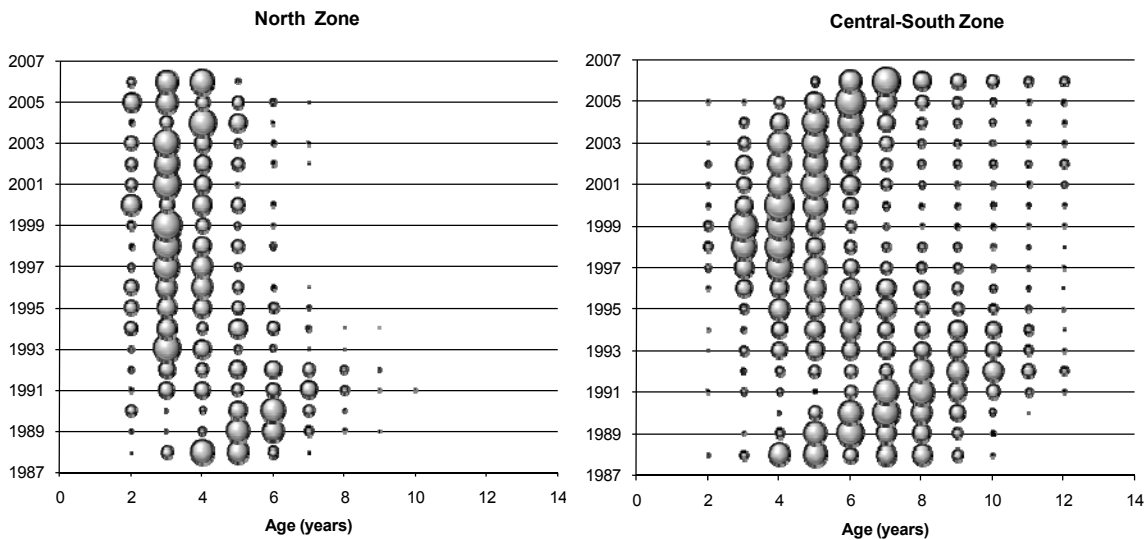
2.2.1 Acoustic surveys

Since 1980, the Chilean State has conducted fisheries surveys in the area of distribution of Chile's main pelagic resources: *Trachurus murphyi*, *Engraulis ringens* and *Sardinops sagax*. These studies –carried out by IFOP– are intended to estimate the abundance, spatial distribution and age composition of the stocks evaluated using acoustic systems (econtegration). The studies also seek to determine the bio-oceanographic conditions present in the areas surveyed.

The number of studies carried out has been linked to the development of fishing in the main areas where pelagic resources are fished in Chile. From 1980 to 1990, fisheries surveys focused on the north of Chile, covering the area that extends from Chile's northern border and parallel 30°00'S, up to a maximum distance of 200 nautical miles measured from the coast. As of 1991, as a result of the jack mackerel fishery's greater significance in the center-south area, the fisheries survey program included –on a regular basis– jack mackerel in the area ranging from parallel 33°00'S to parallel 42°00'S, the western boundary of which has been extended in some sectors up to 500 nautical miles from the coast.

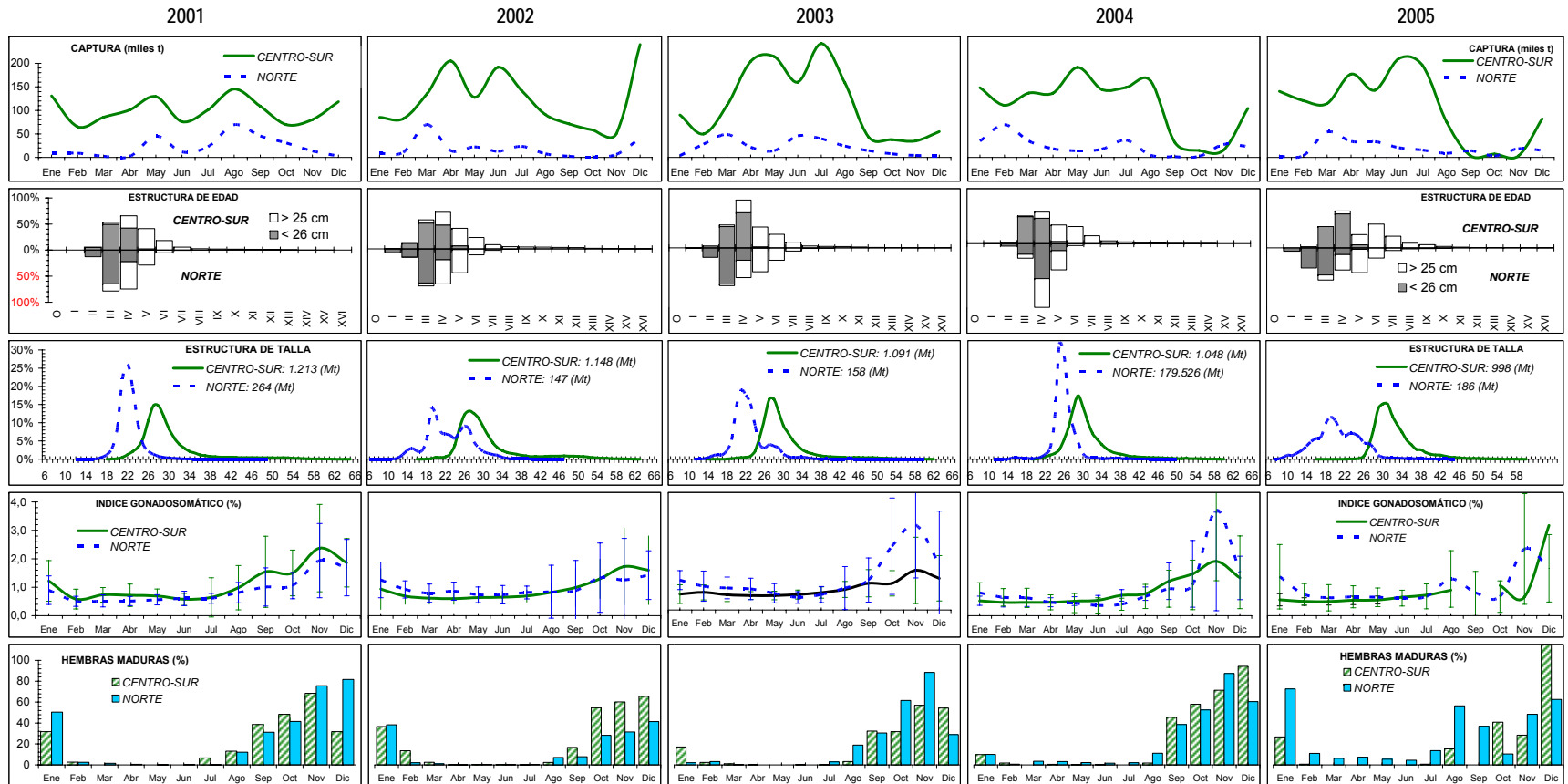
In the period 1980 – 2006, 55 survey were conducted (Table 3) in which jack mackerel was the target species. The surveys involved a total of 1,852 days/ship. Of the total surveys, 38 were made in the area that extends from Chile's northern border to parallel 31°00'S up to a maximum distance of 200 nautical miles from the coast. The remaining 17 surveys were made in an area extending from parallels 32°S and 42°S up to a distance of 500 nautical miles from the coast (Figure 15).

Figure 13:
Bubble diagram of age compositions of jack mackerel catches, 1987 – 2006.
North and center-south area of Chile



Source: IFOP

Figure 14:
Evolution of main biological indicators for jack mackerel,
north and center-south area of Chile, 2001 - 2005



Source: IFOP

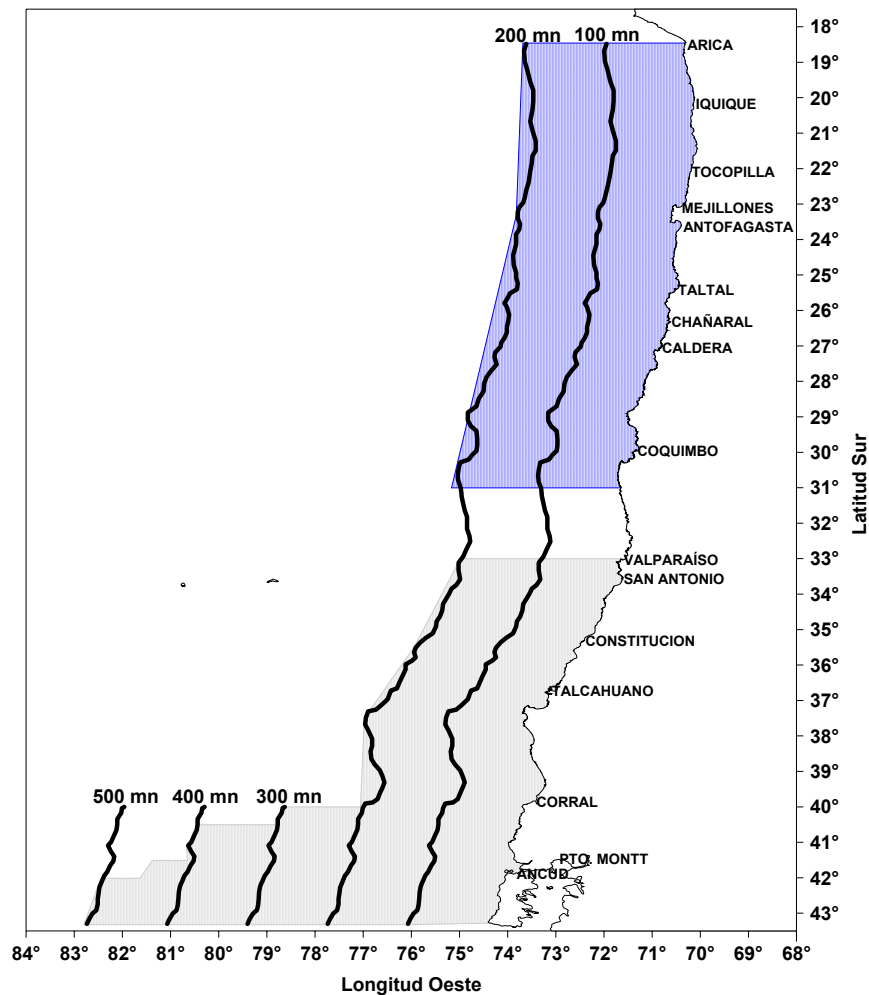
Table 3
Acoustic surveys of Chilean jack mackerel

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

Hydroacoustic detection methods were used in all the surveys to quantify the biomass and abundance of the resources under study. Transect sampling was employed in a general east-west direction, separated by distances varying from 10 to 30 nautical miles (Figure 16). The sampling area to the west of the Chilean coast has remained fairly constant in the sector located north of latitude 30°S. However, towards the south, the area under study has changed in accordance with the spatial distribution of jack mackerel. In the period 1991-2002, the area under study was concentrated inside the EEZ. However, as of 2003, together with acoustics surveys and fishing explorations, the area under study has been adjusted to the distribution of jack mackerel. This has meant increasing the coverage up to 43° of latitude south and a distance in excess of 500 nautical miles from the coast (Figure 16).

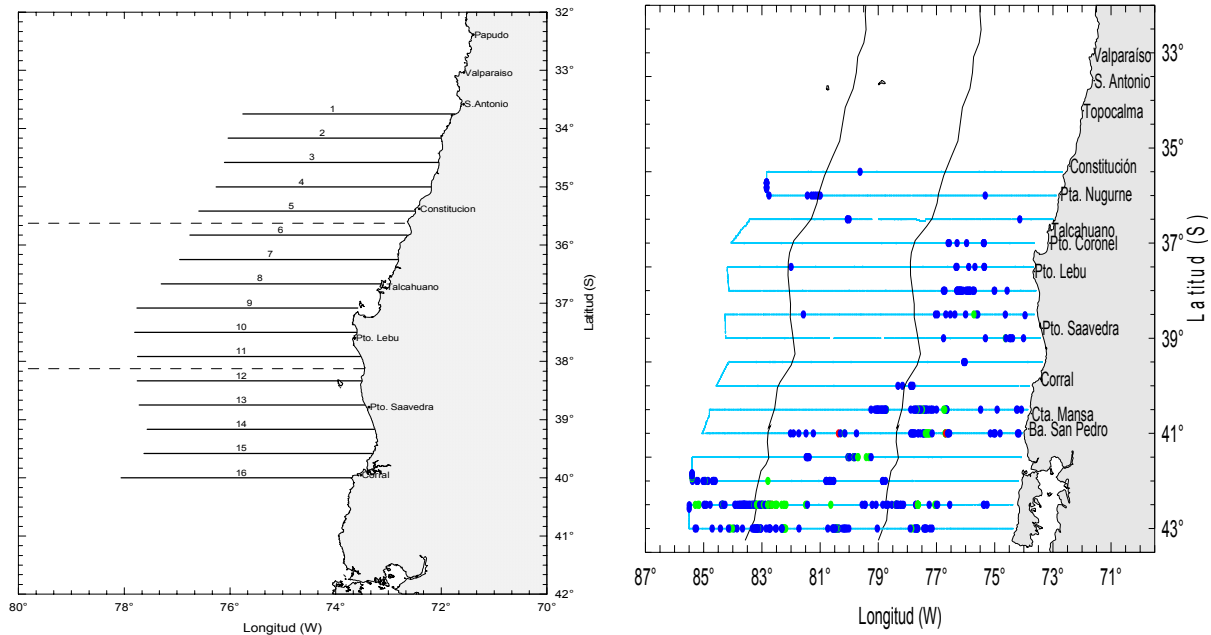
Figure 15:
Jack mackerel areas surveyed in Chile, 1981 - 2006



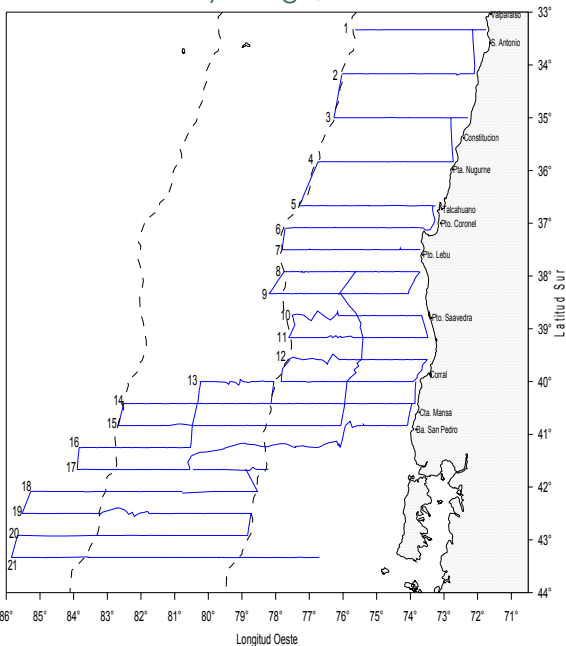
Source: IFOP

The first estimates of jack mackerel stock conducted in the north of Chile show high levels of the biomass in the early 1980s, recording a maximum of 8 million tons (Figure 17 and Table 4). As of 1983, high biomass levels dropped drastically to values that did not exceed one million tons. Values such as those recorded when the acoustic surveys began (1981-1983) have never been recorded again.

Figure 16:
Design of acoustic surveys employed in the center-south area



Survey Design, 1992-2002

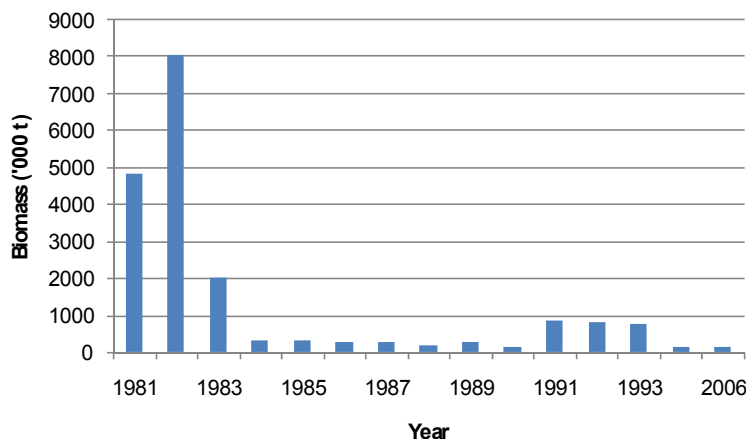


Survey Design, 2003-2006

Ecosurvey Design, 2003-2006

Source: IFOP

Figure 17:
Jack mackerel biomass estimates in northern Chile (18 21'S – 31 00'S)



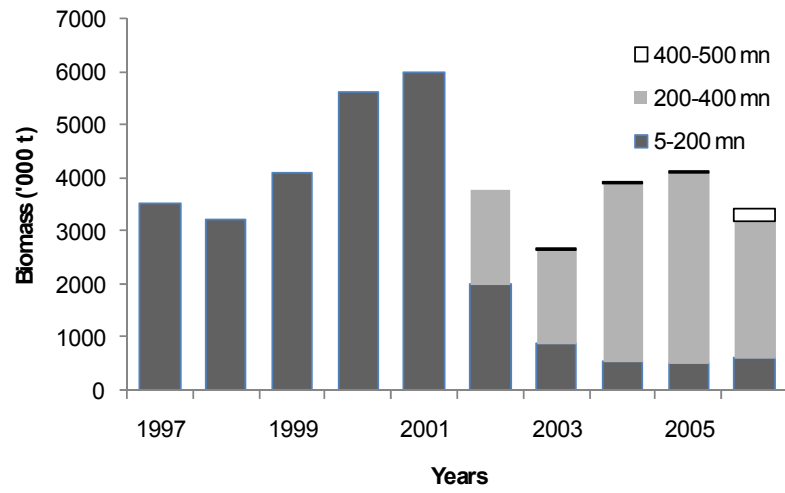
Source: IFOP

As a result of the increasing importance acquired by the Chilean fishery off the center-south area, from 1991 the acoustic surveys concentrate on this area. Biomass estimates showed a sharp decline from 1997 to 1998, followed by a partial recovery until 2001. Since 2002 the trend was reversed and the biomass inside the first 200 n.m. dropped to substantially lower levels than those recorded in previous years. From 2003 and together with an expansion of the study area, changes in the gravity center of the resource distribution have been noticed (Figure 19).

Table 4
Jack mackerel biomass estimates by
acoustic surveys, 2001 - 2006

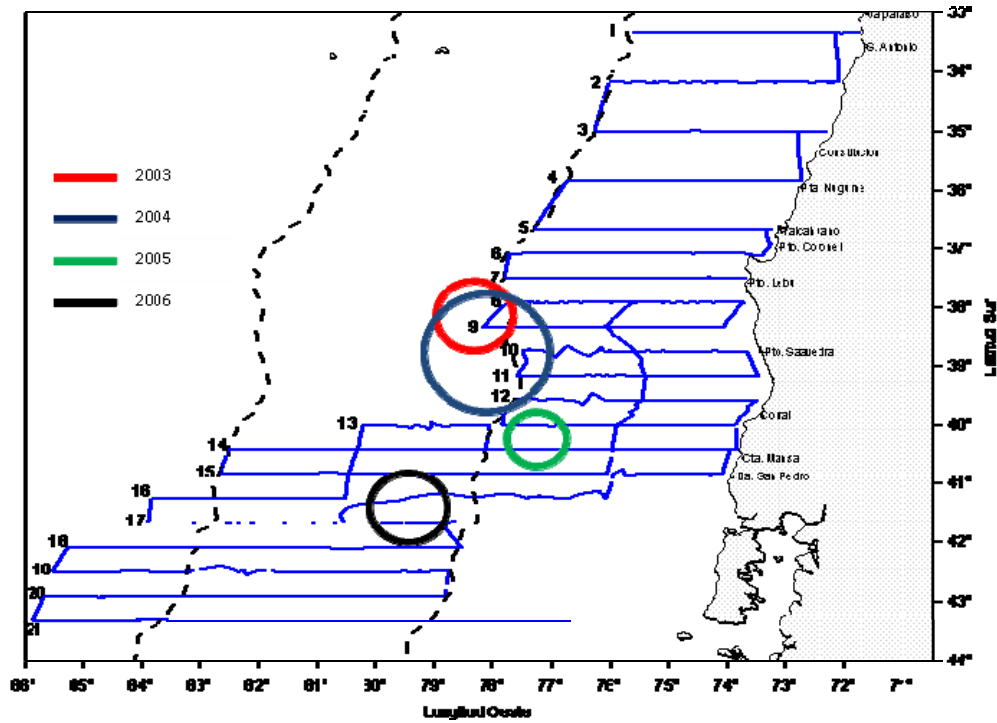
Biomass ('000 t) by nautical interval			
Year	5-200 nm	200-400 nm	>400 nm
2001	5970		
2002	1990	1800	
2003	881	1795	0.7
2004	540	3380	0.9
2005	510	3600	0.9
2006	597	2596	238

Figure 18:
Jack mackerel biomass estimates by acoustic surveys
in the center-south area of Chile (33 00'S – 43 00'S)



Source: IFOP

Figure 19:
Spatial position of the centers of gravity of jack mackerel (surveys), 2003 - 2006



Source: IFOP

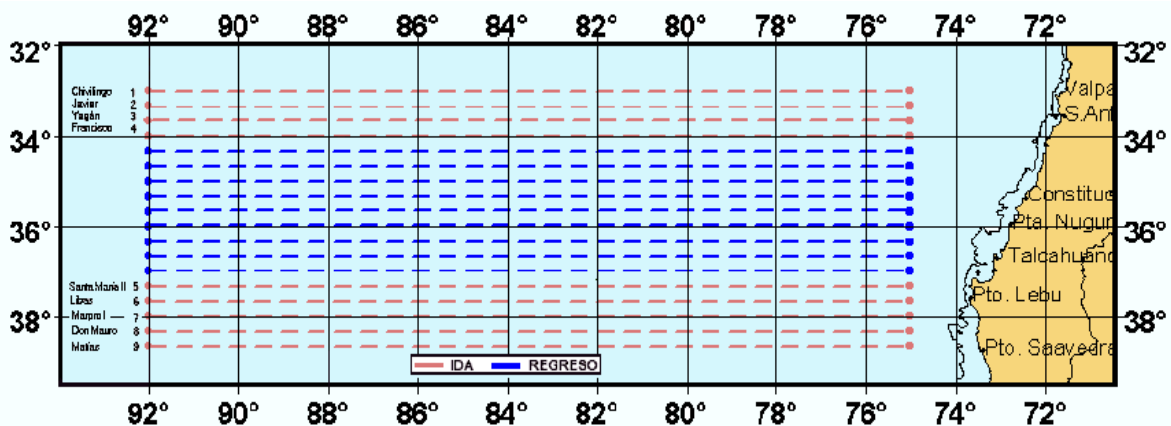
2.2.2 Monitoring of Reproductive Conditions

At spawning time, jack mackerel forms low density, disperse aggregations that are not easily detected by acoustic equipment. Therefore, and as a supplement to hydroacoustic assessments, Chile began to monitor reproductive conditions of Chilean jack mackerel in 1997. This program is conducted by the Institute for Fisheries Research, Region VIII (INPESCA), the University of Concepción and IFOP. Monitoring is used to estimate the relative abundance indices of jack mackerel eggs and larvae in the center-south ocean area of Chile and thus characterize reproductive aggregations in time and space. The results of this program provide relative estimates of the spawning biomass using the Daily Egg Production Method (DEPM) (Lasker, 1985). The spawning biomass thus estimated is used as a calibration index for stock assessment.

The monitoring program is conducted simultaneously and synoptically (8 days) both inside and outside the EEZ up to a distance of 1000 nautical miles (parallel 92°W) of Chile's central area. The sampling area and the period are determined by considering, as a scientific premise, that the extension and location of the spawning nuclei are determined primarily by the distribution of water masses with temperatures typically ranging from 15 to 19°C. These masses show inter-annual latitudinal shifts depending on the development of cold or warm periods or due to the enhancement or weakening of the West Wind Drift.

Surveys are carried out in the second half of November, i.e. the period of highest reproductive activity (see Part 3.3). The area under study extends over a quadrant defined by parallels 31°40'S and 38°S and meridians 75°W and 92°W. Ten to 12 fishing vessels are used to perform 20 transects perpendicular to the coast separated by a distance of 20 nautical miles (n.m.) (Figure 20). They take samples every 18 n.m. In total, the study collects samples of ichthyoplankton in over 700 oceanographic stations in the area under analysis (Tables 5, 6 and 7)

Figure 20:
Transect sampling system used in surveys to monitor
Chilean jack mackerel reproductive conditions



Source: INPESCA

Table 5
Operational background data of the sampling in surveys to monitor Chilean jack mackerel reproductive conditions

Date	Latitude (°S)	Longitude (°W)	Area (nm ²)	Vessels	Desing	D. Transect.
Nov 1997	36°00'-40°00'	74°54'-84°07'	108.078	4	Zig-Zag	30 nm
Dec 1998	33°00'-39°00'	75°00'-86°00'	231.34	5	Zig-Zag	75 nm
Nov 1999	33°06'-38°12'	75°00'-92°00'	284.526	9	Lineal	18 nm
Dec 1999	35°03'-38°24'	74°00'-86°00'	114.917	6	Lineal	18 nm
Nov 2000	32°06'-37°48'	75°00'-92°00'	261.815	10	Lineal	18 nm
Nov 2001	31°48'-36°54'	75°00'-92°00'	257.28	9	Lineal	18 nm
Nov 2003	33°00'-38°00'	75°00'-92°00'	317.568	8	Lineal	20 nm
Nov 2004	31°40'-38°00'	75°00'-92°00'	403.98	10	Lineal	20 nm
Nov 2005	33°00'-38°40'	75°00'-92°00'	356.32	9	Lineal	20 nm

Source: INPESCA

Table 6
Results of the sampling of eggs and larvae recorded in surveys to monitor Chilean jack mackerel reproductive conditions

Eggs	1997	1998	1999-n	1999-d	2000	2001	2002	2004	2005
Stations	66	173	751	363	880	660	694	910	784
Stations +	34	125	546	212	660	477	419	658	326
%	52	72	73	58	75	72	60	72	42
Density (D)	109	318	562	266	444	640	132	374	98
Var(D)	507	1903	2717570	401	364251	1175956	67713	694352	68926
Dpos	211	440	773	456	592	886	219	517	237
Var(Dpos)	65895	456706	3576544	249700	398045	1410027	93262	886664	133222
Dmin	26	30	35	35	35	35	35	35	35
Dmax	1176	3918	26844	3501	5199	11353	2900	14465	4421
Larvae	1997	1998	1999-n	1999-d	2000	2001	2002	2004	2005
Stations	66	173	751	363	880	660	694	910	784
Stations +	18	101	501	207	678	503	270	483	367
%	27	58	67	57	77	76	39	53	47
Density (D)	38	243	193	152	266	243	50	98	87
Var(D)	62	1131	98	135	131454	108322	13332	39907	35358
Dpos	139	416	289	267	345	318	128	184	186
Var(Dpos)	15725	336377	220	85908	143287	118071	24241	59351	57231
Dmin	21	30	35	35	35	35	35	35	35
Dmax	425	2803	2794	2157	3395	2865	1379	1698	2122

Source: INPESCA

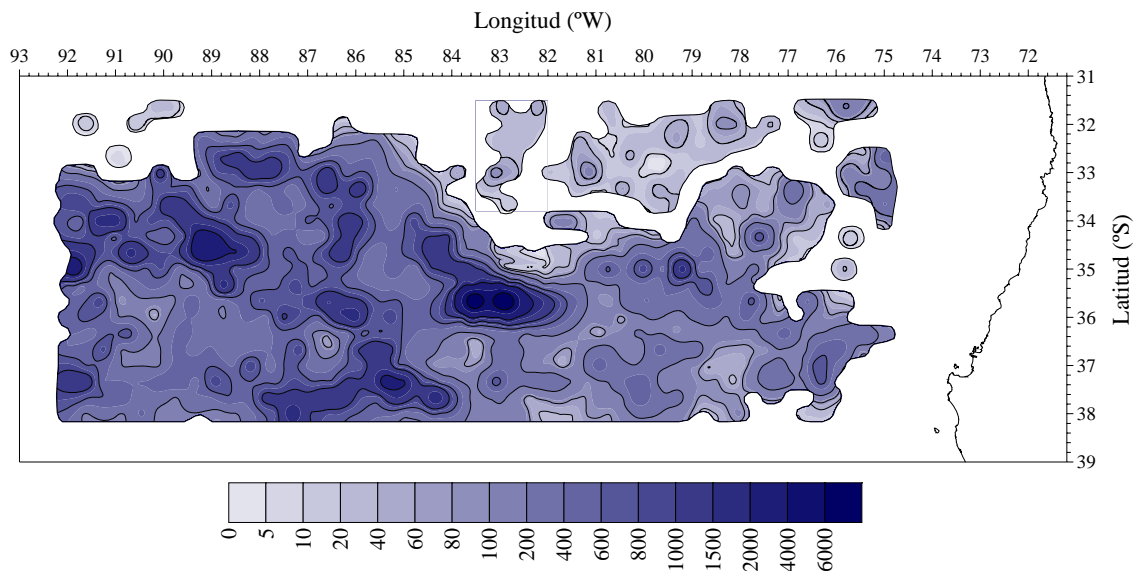
The results show that, in November 2005, no significant relationship was found ($p > 0.05$) between the density of jack mackerel eggs and larvae and sea surface temperatures (SST) and the speed of ocean current speeds. Furthermore, a degree of environmental preference was established (significant associations) for wind speeds in excess of 6.3 m/s and 6.7 m/s for eggs and larvae, respectively and turbulence values higher than 350 m³/s³ (only in the case of larvae). The main densities of eggs and larvae were found above 85° W and these are interrupted above 91° W (Figures 21, 22 23 and 24). A historical analysis (1998 - 2005) shows the SST environmental preferences which shows that eggs and larvae prefer warm waters with temperatures above 16.2°C (eggs) and 16.9°C (larvae). On the contrary, integrated data for the period 1998 - 2005 showed no

significant association with the variables 'wind intensity' and 'turbulence index'. The spawning biomass estimated through DEPM in 2005 was 1.043 million tons, i.e. the lowest estimate in the historical series and very similar to the one reported in 2003.

Table 7
Results of the Daily Egg Production Method (DEPM) in surveys to monitor Chilean jack mackerel reproductive conditions

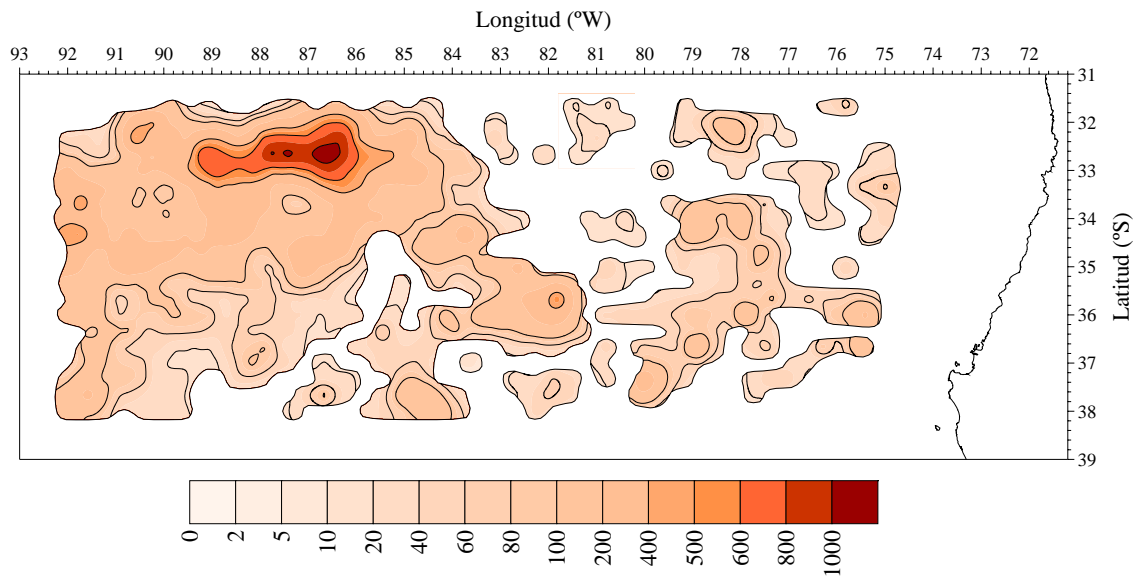
Year	Mean weight (g)	Partial fecundity (n° oocytes)	Spawning frequency	Sexual proportion	Eggs production (eggs·m ⁻² ·d ⁻¹)	Spawning Area ('000 Km ²)	Spawning Biomass ('000 t)
1999	191.8	26610	0.13	0.43	65275	664	5724
2000	211.0	26069	0.15	0.47	49163	823	4688
2001	223.7	27150	0.10	0.39	46217	600	5627
2003	394.7	39846	0.09	0.48	9204	648	1388
2004	412.1	39957	0.19	0.48	27318	1054	3287
2005	364.7	40463	0.14	0.47	9940	774	1043

Figure 21:
Contour diagram (isolines) showing the spatial distribution of the density of jack mackerel eggs (eggs 10m⁻²) in spawning grounds. November 2004.



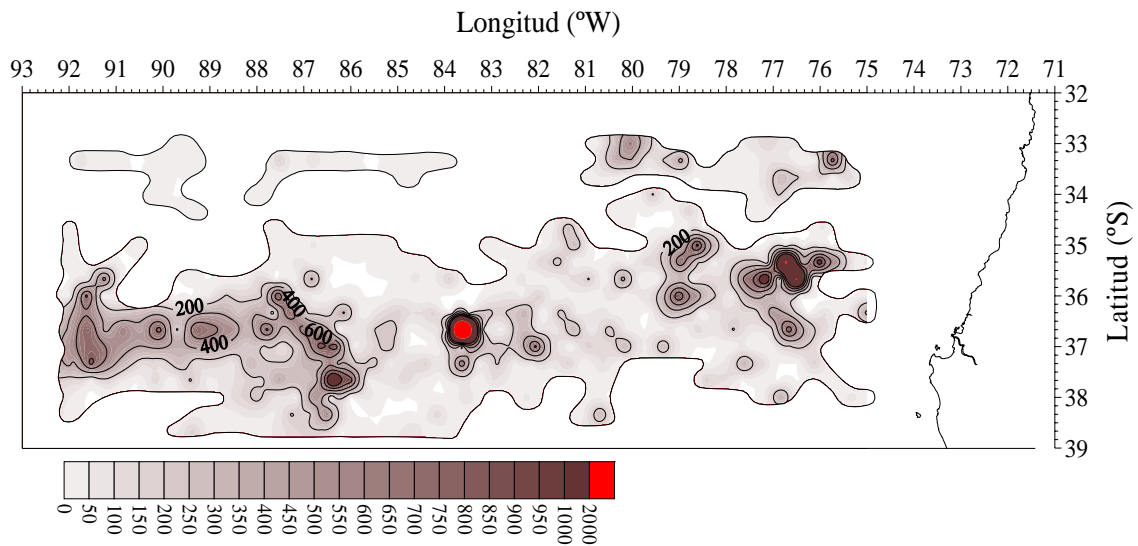
Source: INPESCA

Figure 22:
Contour diagram (isolines) showing the spatial distribution of the density of jack mackerel larvae (larvae 10m⁻²) in spawning grounds. November 2004.



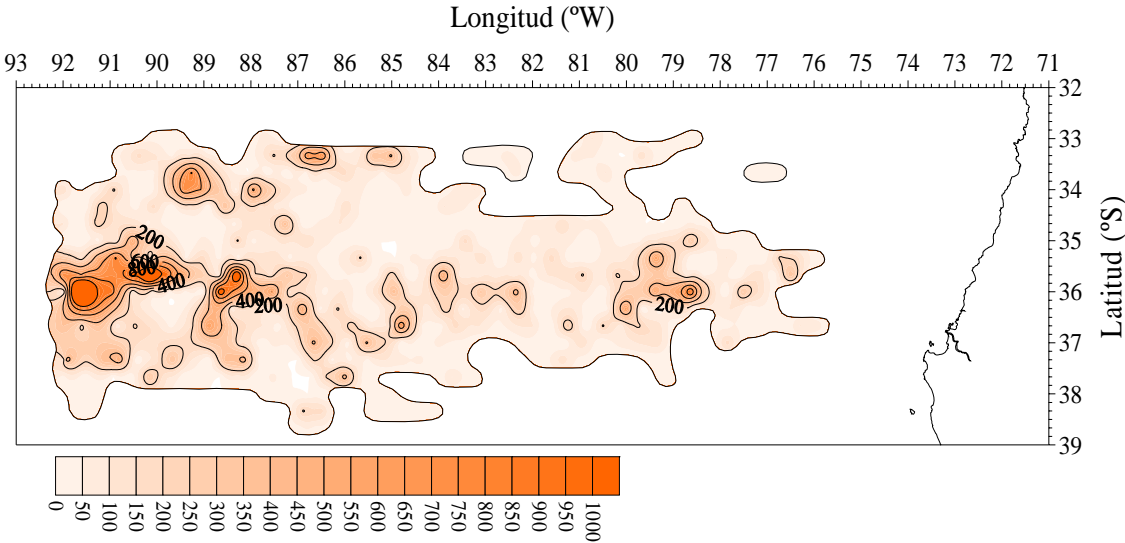
Source: INPESCA

Figure 23:
Contour diagram (isolines) showing the spatial distribution of the density of jack mackerel eggs (eggs 10m⁻²) in spawning grounds. November 2005.



Source: INPESCA

Figure 24:
Contour diagram (isolines) showing the spatial distribution of the density of jack mackerel larvae (larvae 10m⁻²) in spawning grounds. November 2005.



Source: INPESCA

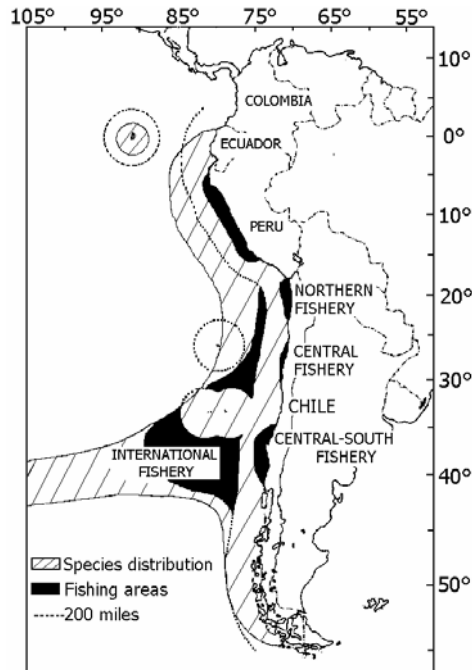
3.1 Identity and distribution of the stocks

The genus *Trachurus* is one with the broadest distribution of the Carangidae family that inhabits the Atlantic, Indian and Pacific Oceans and the Mediterranean Sea.

According to Poulin et al. (2004), two *Trachurus* species inhabit the Pacific Ocean: *Trachurus symmetricus*, in the North Pacific, and *Trachurus murphyi*, in the South Pacific. The authors base their conclusion on genetic studies which show that both species exhibit significant differences in their mitochondrial DNA. This work changes the results obtained by Stepien and Rosenblatt (1996) who, based on electrophoretic studies of allozymes, concluded that genetic differences between northern and southern hemisphere jack mackerel were not significant and that they should therefore be classified as a single species.

T. murphyi represents, together with *T. Symmetricus* and *T. Picturatus*, one of the most apomorphic groups (Ben Salem, 1988). It has developed an outstanding neritic-oceanic behavior, which explains its vast distribution in the high seas and the development of its life cycle in both systems. According to Chirichingo (1974) and Chirichingo et al. (1982), jack mackerel can be found in the north from 1° 38' N, around the Galapagos islands, to 56° S (southernmost area of Chile). To the its west projection reaches the Tasmanian Sea, forming what Russian researchers called in the early 1990s, the "jack mackerel belt" (Figure 25). According to Serra (1991), jack mackerel stock apparently expanded its distribution and abundance in the 1970s through a process of colonization along the West Drift Current. Evidence of jack mackerel presence near New Zealand was reported in the mid 1980s (Evseenko, 1987 and Bailey, 1989) and subsequently in Tasmania. According to Kasahara et al. (1988, In: Taylor, 2002), jack mackerel in New Zealand was first reported in 1987. The most recent work done by Cárdenas et al. (2005) involving molecular phylogenetic analysis through sequences of the cytochrome b gene, and also in the Control Regions for mitochondrial DNA of individual jack mackerel specimens collected off Chile (Iquique and Valdivia) and New Zealand (Tauranga), found no genetic differences among the samples analyzed.

Figure 25:
Distribution of Chilean jack mackerel and the main fisheries in the South East Pacific



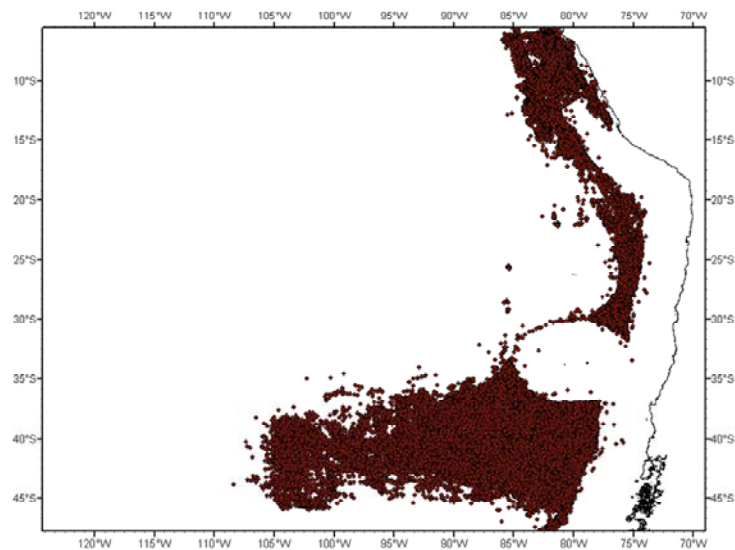
Source: Serra, 1991

3.2 The Chilean Stock

Studies aimed at identifying stock units of jack mackerel (*Trachurus murphyi*) in Chilean waters began in the 1990s by analyzing life patterns and studying morphometric, meristic, parasitological and genetic aspects (Serra, 1991; George-Nascimento, 2000), in addition to genetic variability studies (Alay et al., 1994; Galleguillos & Torres, 1988; Astorga & Galleguillos, 1998; Galleguillos et al., 1998; Poulin et al., 2004; Cárdenas et al., 2005). These studies allow concluding that, at least in the current and historical operating area of the national and foreign fleets in the area adjacent to the EEZ, the fishery is supported by a single stock, named “Chilean jack mackerel stock” (Figure 26).

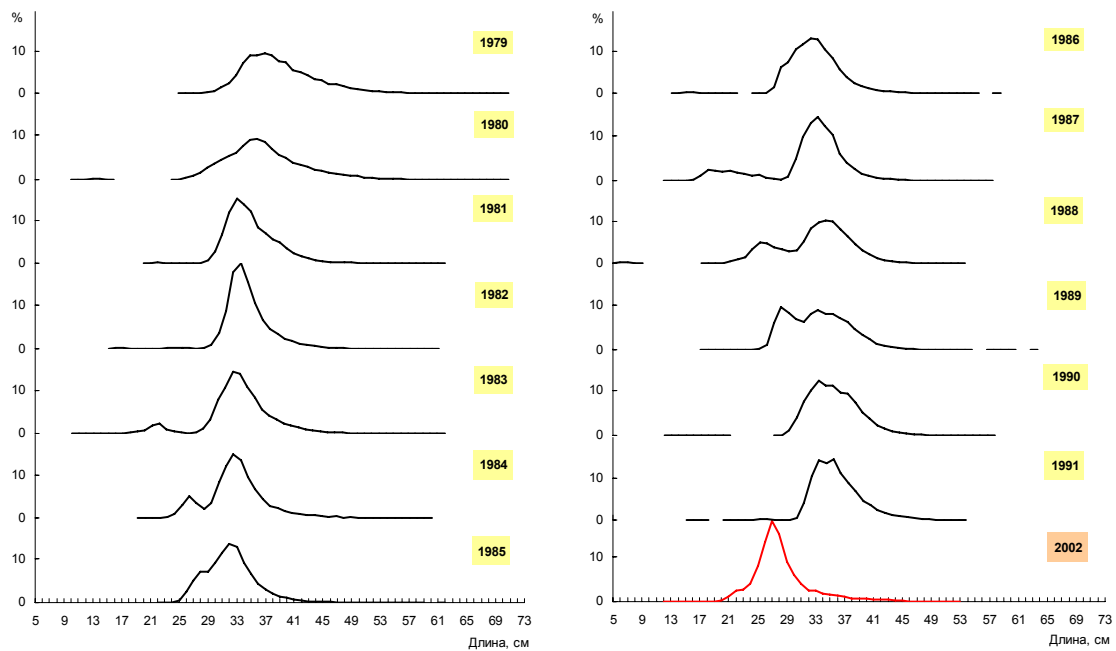
Supplementary evidence confirming the result of the above studies is provided by the size sampling data from catches made in the period 1979 - 1991 by the Chilean fleet and that of the former URSS. The data not only demonstrate the same size composition, but also show important recruitment to the fishery in 1982, 1986 and 1987 (marked by arrows). A similar analysis can be made regarding the size composition of the catch in northern Chile for the same period, proving the existence of a single stock unit off the Chilean coast and its projection onto the high seas beyond the EEZ (Figures 27, 28 and 29).

Figure 26:
Space distribution of fishing catches from the most representative fleet of the former URSS between 1986 - 1991



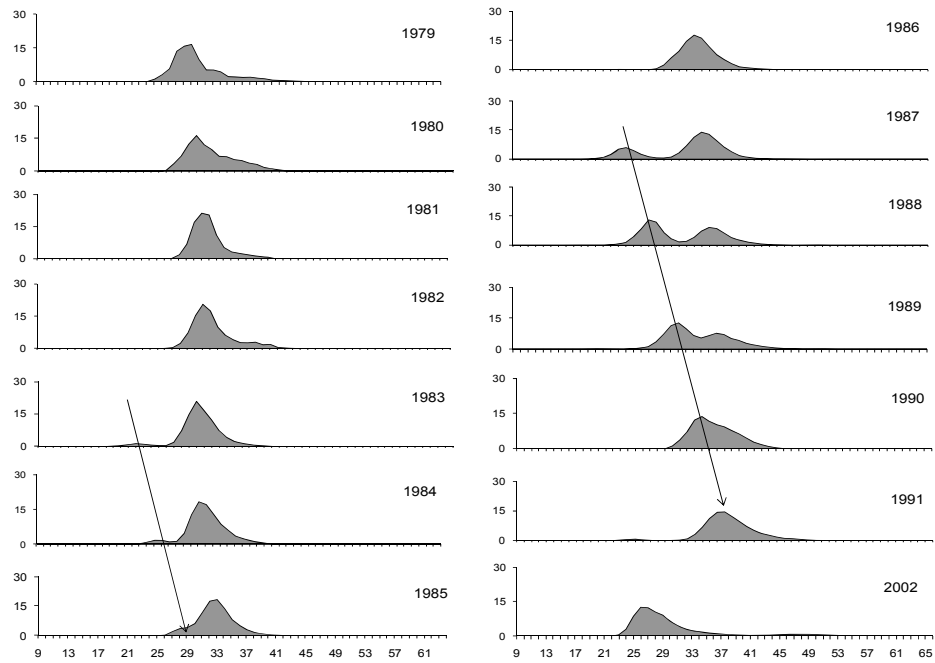
Source: Greshina, 2006

Figure 27:
Composition of the sizes caught by the former URSS fleet that operated outside the EEZ between 1979-1991, and the Russian Federation during 2002



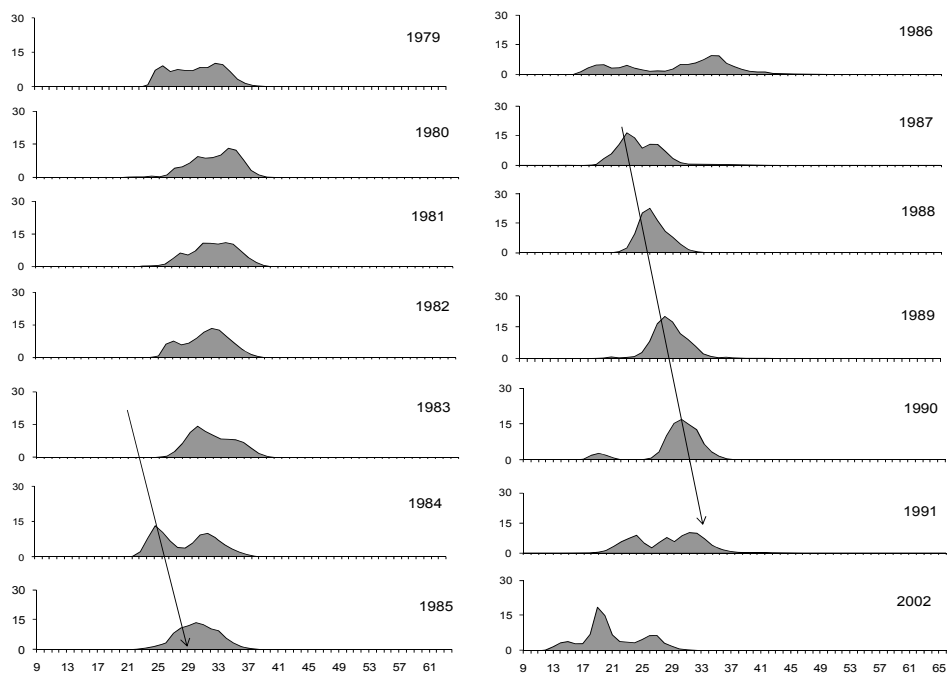
Source: Nesterov, 2007

Figure 28:
Composition of the sizes caught by the Chilean fleet that operated inside the EEZ in the Central-South Zone between 1979 and 1991, and in year 2002



Source: IFOP

Figure 29:
Composition of the sizes caught by the Chilean fleet that operated inside the EEZ in the Northern Zone between 1979 and 1991, and in year 2002



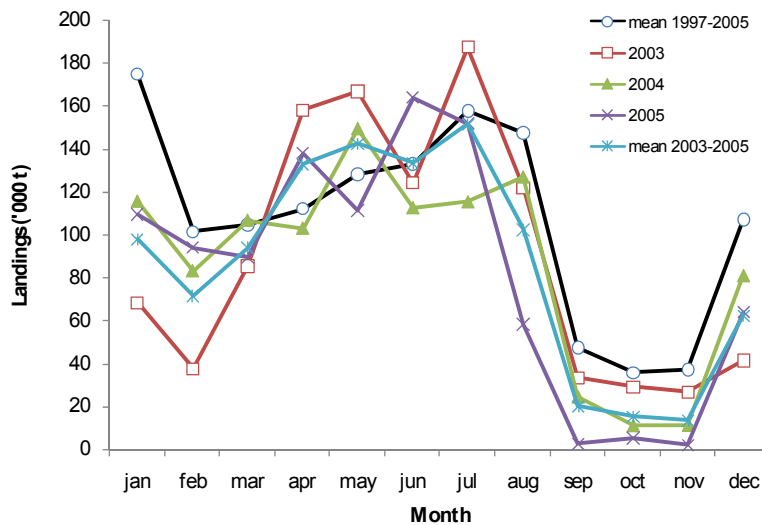
Source: IFOP

coincides with statements made by Serra et al. (1979) and Arancibia & Cubillos (1993). Adrianov (1994) and Grechina et al. (1994) state that jack mackerel migrates for reproductive purposes to the northeast and west starting in October, and that its main spawning area is located between meridians 78° W and 105° W and parallels 38° S and 42° S. These boundaries are determined by the position adopted by the 16°C isotherm (Dejnik & Nevinskiy, 1994; Grechina et al., 1994).

The marked seasonal pattern shown by jack mackerel, reflected in the changes in stock availability inside and outside the EEZ —which determines the operation of the Chilean fleet— has been also reported by Corten (2007). The author indicates that the Dutch fleet operating in the high seas area adjacent to the Chilean EEZ in 2005 concentrated its operations in the first semester in areas adjacent to the EEZ (jack mackerel feeding near the coast), while in the second semester catches concentrated in areas further away from the coast. (Figure 32).

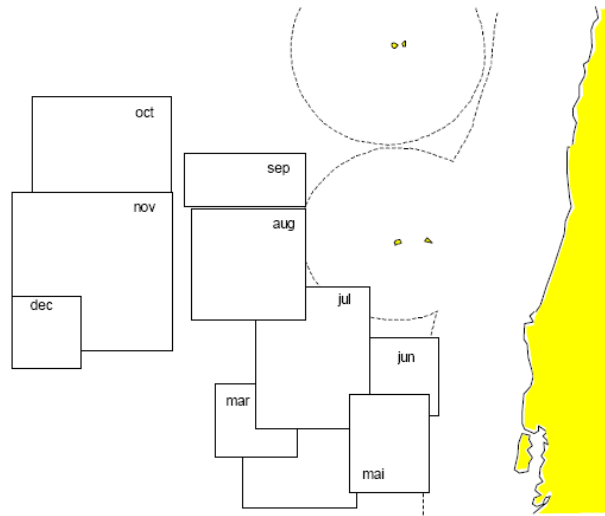
Immigration towards the Chilean EEZ and migration away from it, described above, not only confirm the existence of a single stock unit —they also define Chilean jack mackerel as a straddling stock.

Figure 31:
Seasonal landings of jack mackerel (*Trachurus murphyi*) in the 35° S – 40° S zone



Source: IFOP

Figure 32:
Monthly areas of operation of the Dutch fleet that catches Jack Mackerel during 2005

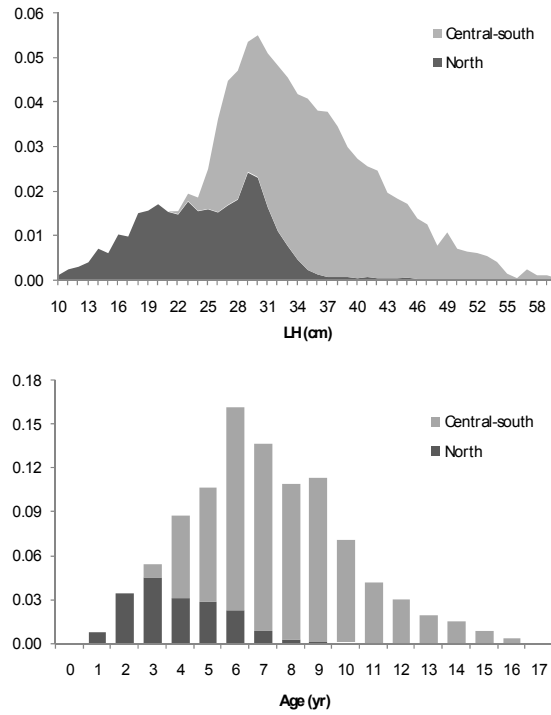


Source: Corten, 2007

3.4 Breeding Grounds

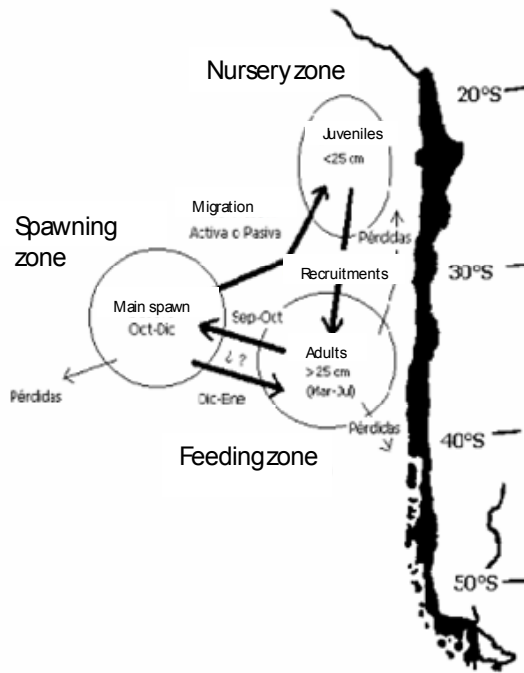
Catch composition data show that Chilean jack mackerel has a marked size and age segregation along the coast. In northern Chile, catches consist mainly of immature individuals. To the south (35° S and 40° S) there is a bigger ratio of larger individuals (Figure 33). Based on this evidence, Arcos et al. (2001) hold that the main breeding area for jack mackerel is found in northern Chile –preferably inside the EEZ. On the other hand, the center-south area, including the oceanic projection outside the EEZ, is an area for feeding and spawning (Figure 34). Newer studies provided by Nesterov (2007) strengthen this statement, in the sense that areas where age 1 individuals predominate are located north of 30° S. Although this is partial information collected outside the EEZ, it allows inferring that the larger concentration of pre-recruits (aged 1 year old) apparently extends inwards to the Chilean EEZ and northwards from that same area, as suggested by the continuity of the distribution presented in Figure 35.

Figure 33:
Composition of sizes and ages of the Chilean jack mackerel 2005



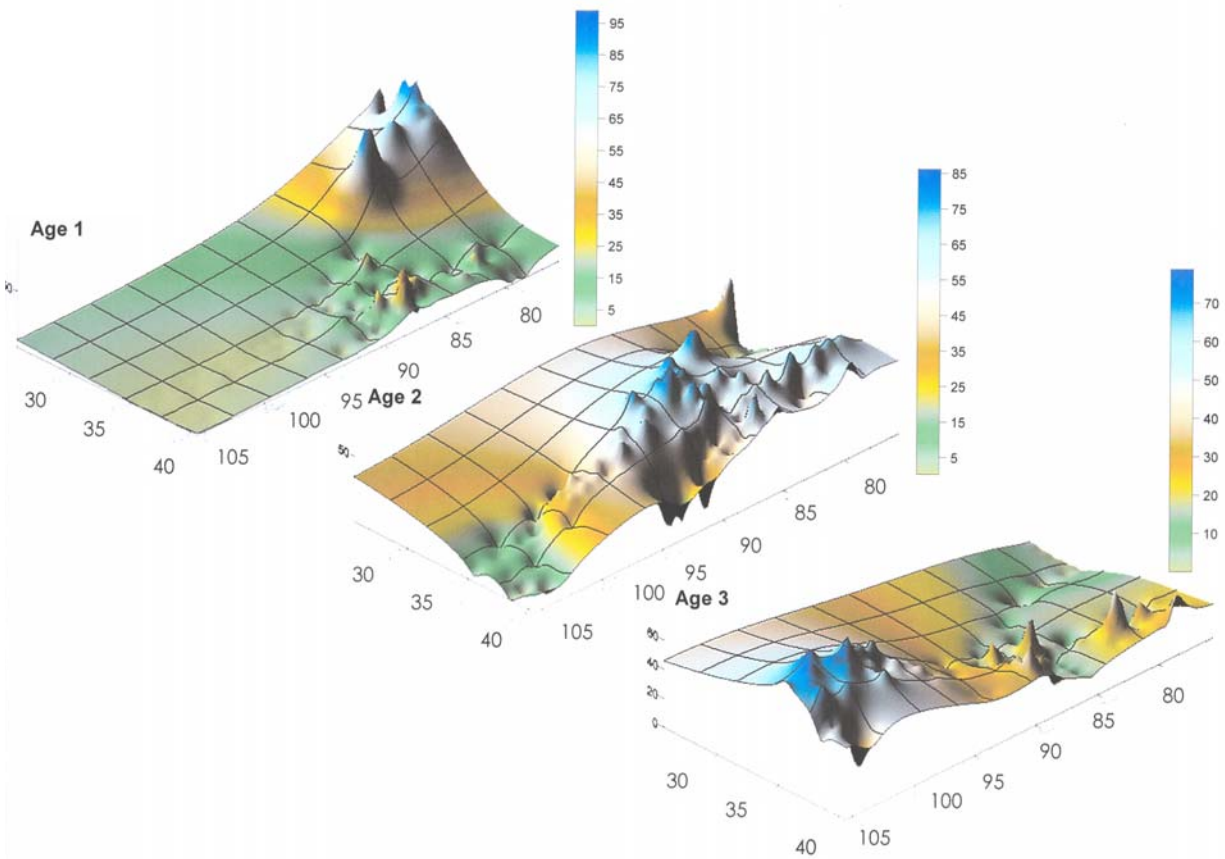
Source: IFOP

Figure 34:
Jack mackerel model of migrations proposed by Arcos et al (2001)



Source: Arcos et al, 2001

Figure 35:
Space distribution of the jack mackerel abundance
2002-2003 between 1 and 3 years old outside the EEZ



Source: Nesterov, 2007

3.5 Reproduction and growth

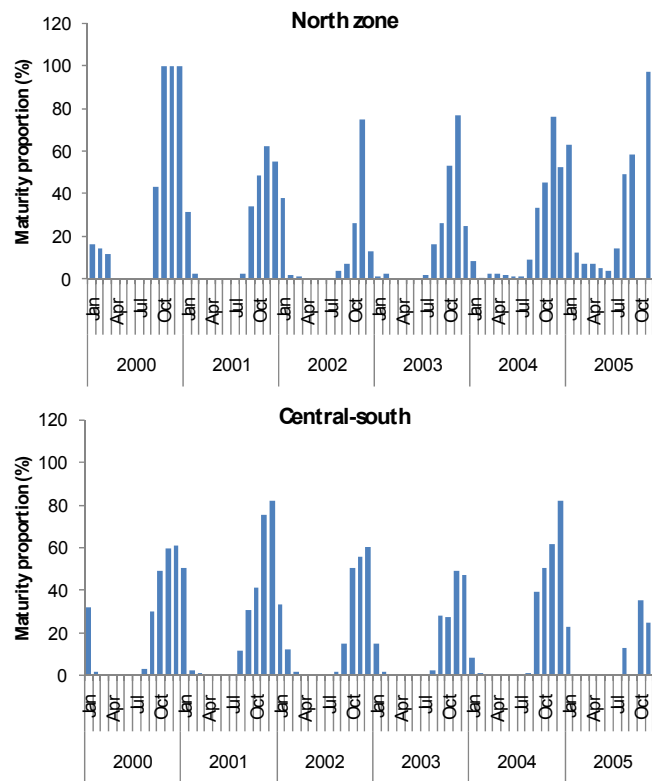
Jack mackerel reaches maturity around age 4 and 25 cm FL (Fork Length). It is a multiple spawner, which means that a female produces several spawning batches in the reproduction season. Estimates made in the center south zone of Chile indicate that during the most intensive reproduction period, 10% to 15% of the females spawn each day. The length of the spawning and the most intensive reproduction period is believed to be limited by the existence of favorable hydrobiological conditions (Andrianov, 1990, 1994). By analyzing the gonad somatic index (GSI), Oyarzún et al. (1998) and Aracena et al. (1998) found that the period of maximum reproduction activity occurs in late spring and summer (November-December of each year), which is also reflected in the ratio of sexual maturity of females indicated in Figure 36.

Life expectancy for jack mackerel (95% of L_{∞}) is estimated at 22 years, but in the catches, age groups do not exceed age 16. Cubillos et al. (1998) reviewed 22 works,

establishing more realistic growth parameters, shown in Table 8. Accordingly, jack mackerel is a medium-sized fish with moderate growth.

Age readings from the catches have allowed establishing age 2 as the recruitment age to the fisheries, i.e. fish between 15 cm and 21 cm FL. At present, in northern Chile, jack mackerel older than age 4 is less available for fishing. Its sexual maturity begins at this time and it is recruited to the adult stock which is mainly distributed off the center-south area between 35° S – 40° S.

Figure 36:
Evolution of the jack mackerel sexual proportion between 2000 and 2005



Source: IFOP

Table 8
Main length-at-age growth
parameters of the jack mackerel

Parameter	Value range
L _∞	73,7 – 78,5 cm FL
K	0,111 – 0,161 años ⁻¹
T ₀	-0,098 – 0,0186 years

3.6 Environmental characteristics of the jack mackerel

The main feature of the eastern half of the South Pacific Ocean is the establishment of the Anticyclonic Subtropical Gyre, which involves the South-equatorial currents towards the West (north of 25° S), from the South Pacific towards the East (between 30-40° S) and the Chile-Peru Current that flows along the coast towards Ecuador (Bernal et al., 1983; Leth, 2000; Chaigneau & Pizarro, 2005).

Furthermore, the meteorological system with the greatest influence in the South East Pacific Ocean is the Subtropical Anticyclone of the Pacific (South Pacific Anticyclone). It regulates the winds along the coasts of Peru and Chile (Strub et al., 1998; Chaigneau & Pizarro, 2005; Rutland et al., 2004). There, masses of air descend in a cell of atmospheric circulation making the predominant winds in the summer flow towards Ecuador, and makes them weaker or inverts their direction in the autumn and winter (Saavedra, 1980). The result is an upwelling process, which—in the center of Chile— shows a marked seasonal fluctuation that takes place mainly in the spring and summer, reaching its peak in December and January (Arcos, 1987; Peterson et al., 1988; Leth, 2000; Blanco et al., 2001; Rutland et al., 2002).

In the center-south area (33-43° S) and in the autumn-winter period, jack mackerel is distributed mainly at 50 m to 150 m deep, inhabiting environments dominated by sub-Antarctic waters with temperatures ranging from 10 to 14° C, salinity under 34.3 and a moderate oxygen content (> 3 ml L⁻¹). However, it is frequently found at greater depths, inhabiting cooler Sub-surface Equatorial waters, that are saltier and have a low content of dissolved oxygen (< 1ml L⁻¹). In recent years, jack mackerel has been found in more oceanic waters and towards the southernmost area of its distribution (39-41° S), inhabiting, in general, cooler, less saltier and well oxygenated (> 5ml L⁻¹) waters, marked by greater deepness in the mixing of layers and the thermocline.

On the other hand, the large main spawning area of the Chilean stock is located in the coastal and oceanic sector off center-south Chile (33-40° S) coinciding with waters of the Subtropical Front. It is mainly associated with water temperatures of 16-19° C, moderate wind magnitudes (4-8 m s⁻¹), low turbulence (<150 m³ s⁻³) and low thermal gradients (<0.3° C 10 km⁻¹). Significant associations (p<0.05) have been established between jack mackerel eggs with sea surface temperatures (SST) and wind magnitudes in the spawning area. Evidence of a link between positive anomalies in the SST and variations to the south of the geographic position of the 15°C isotherm have been established in connection with the presence of specimens smaller than 26 cm in Chile's center-south area. This suggests a favorable situation for the survival and abundance of jack mackerel. There also is recent evidence on a spatial-temporal connection between jack mackerel (determined by catch data and acoustic biomass information) and the presence of mesoscale eddies and meander currents in the fishing grounds off center-south Chile. The former also appears to be valid for the distribution of eggs and larvae of jack mackerel in the vast ocean spawning region off center-south Chile.

Stock assessment

4.1 Methodological aspects.

Chilean jack mackerel stock was assessed by IFOP using a statistical catch-at-age model based on a Bayesian estimate approach (Fournier and Archibald, 1982; Deriso et al., 1985; Hilborn, 1990b; McAllister and Ianelli, 1997, Maunder et al., 2000; Hilborn et al., 2003; Ianelli and Lamberson, 2003). This methodological approach is considered state of the art in modern stock assessment. The advantage it offers is its flexibility to include different types of information, test hypotheses and evaluate the implications of different uncertainties.

Considering the studies and information presented in Paragraph 3.2 of this report, the stock assessment suggests that jack mackerel found along the Chilean coast—inside and outside the EEZ—is a single stock unit. For these purposes, the model uses data collected from the fishery as of 1975. Fishing inside and outside the EEZ is considered; with regard to the latter the catch of the former URSS fleet between 1979 and 1992, and the People's Republic of China is also included. The relevant information considered in the analysis include the age composition of the catches by zone or fleet, landings, and series of indicators such as the biomass obtained through hydroacoustic surveys and spawning biomass using the Daily Egg Production Method (DEPM).

The stock assessment model (Serra, Canales y Caballero, 2006) assumes an error in the age composition of the catches, landings and abundance indices. Catch age composition errors are modeled using multinomial probability distribution with small size samples, whereas for the remaining sources, lognormal distributions are employed with variation coefficients of less than 30%. Similarly, different *a priori* distributions are considered to restrict the domain of certain parameters such as those related to the exploitation patterns of the different fleets and biomass availability coefficients for acoustic surveys and spawning biomass. In a manner consistent with changes in availability by age groups along the coast, for the Chilean fleet operating in the northern area a "dome shape" selection pattern is applied. In the center south fishery—including the former URSS catch—a logistic model is used.

The model has 106 parameters which are resolved minimizing the negative sum of the log probabilities identified to model the information error and the *a priori* log distributions considered for some parameters. This is equal to maximizing the *a posteriori* distribution from a Bayesian perspective. In this sense, and in order to measure the risk level for the pertinent variables, uncertainty analysis is done by integrating the *a posteriori* distribution using the MCMC (Markov Chain Montecarlo) re-sampling technique.

4.2 Data.

Table 9 contains the catch statistics of jack mackerel for the different fishing areas and fleets considered in the stock assessment. Information on Chilean catches is based on statistics provided by the Instituto de Fomento Pesquero (IFOP) for 1975 - 2001 and official data provided by the National Fisheries Service for the years 2002 to 2005. Data for the former URRS fleet is based on catch statistics for the period 1978 – 1992. Data for the fleet of the People's Republic of China was obtained from information provided at bilateral meetings with Chile.

The jack mackerel stock assessment for the period 1975 -2005 takes the following information into account:

a) Catches at age matrix by zone.

The catch at age matrix was built by zone, on the basis of information generated through a permanent sampling of fish size and otoliths at landings. The size composition of the Soviet fleet catch (obtained by INPESCA from VNIRO) is also included. This was afterwards converted to age using an age-length key from the center-south fishing area. This is supported by the similarity of the size composition of catches by both fleets and the lack of otolith samples from the Soviet fleet.

b) Mean weight at age matrix, which are obtained considering the mean length at age and the length-weight relationship.

c) Annual landings.

d) Biomass from acoustic surveys 1997-2005 and the corresponding age compositions.

e) Spawning biomass for the years 1999-2001 and 2003-2005 obtained from egg surveys and the daily egg production method (DEPM).

f) Sexual maturity ogive, which considers that specimens of age 3 or less are immature while mature specimens are those of age 6 and more. Specimens of ages 4, 5 and 6 are considered to have a 4%, 50% and 96% of sexual maturity, respectively.

g) Natural mortality rate is assumed to be constant between ages and years, with a value of $M=0.23$ year.

Table 9
Jack Mackerel landings at a national and
international level outside de EEZ (thousands of tons)

	ZN	CC	ZCS	TCH	INT	TSR
1975	187	7	28	222	0	222
1976	238	11	55	303	0	303
1977	226	3	73	301	0	301
1978	368	6	145	518	0	518
1979	312	20	183	515	270	784
1980	267	24	191	482	325	808
1981	435	35	406	876	420	1296
1982	756	64	580	1400	680	2080
1983	259	41	501	801	929	1730
1984	664	77	601	1342	877	2219
1985	472	71	852	1395	739	2134
1986	43	52	1052	1146	731	1877
1987	281	62	1355	1697	819	2516
1988	279	175	1528	1982	812	2793
1989	266	222	1809	2297	857	3154
1990	258	204	1947	2409	852	3262
1991	283	207	2443	2933	540	3472
1992	285	174	2623	3082	36	3119
1993	360	87	2658	3105	0	3105
1994	197	149	3448	3794	0	3794
1995	212	98	3887	4196	0	4196
1996	265	74	2943	3282	0	3282
1997	88	81	2461	2630	0	2630
1998	19	11	1536	1566	0	1566
1999	45	6	1125	1175	0	1175
2000	108	28	1107	1243	0	1243
2001	244	11	1205	1461	0	1461
2002	109	25	1332	1466	76	1542
2003	142	18	1255	1414	96	1510
2004	158	22	1268	1447	130	1577
2005	166	12	1237	1415	130	1545

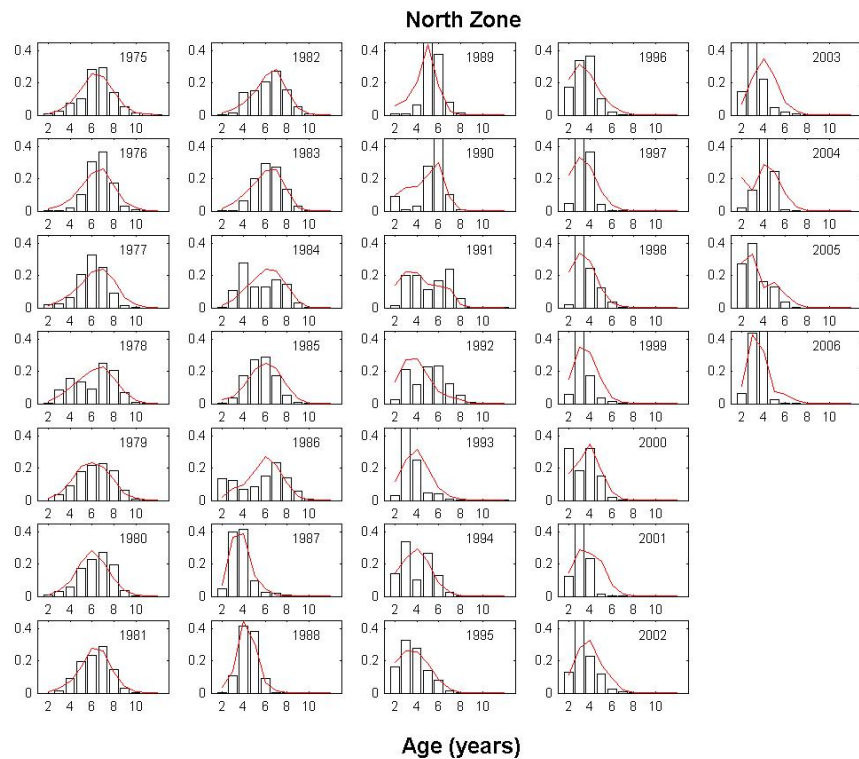
ZN: North zone of Chile
 CC: Caldera-Coquimbo zone of Chile
 ZCS: Central-south zone of Chile
 TCH: Chile total
 INT: Total international fleet
 TSR: Sub-regional total

4.3 Model fit

Figures 37, 38 and 39 show the model fit for relevant information, underlining its ability to suitably reproduce the dynamics of age structures in Chile's north and center-south areas. This result is part of a complex sensibility analysis process in the variation coefficients for each source of error. In this sense, the results of the model are sensitized in terms of the variation coefficients granted to the abundance indices, in ranges that fluctuate between $vc=10\%$ - 30% , while the effective sample size of the age compositions are not modified, and are assessed with values of $n=50$. The model fit for the biomass indices is less satisfactory, because signs of a strong drop in the spawning biomass calculated using the DEPM are not consistent with the enhancement observed in catch age composition and sizes.

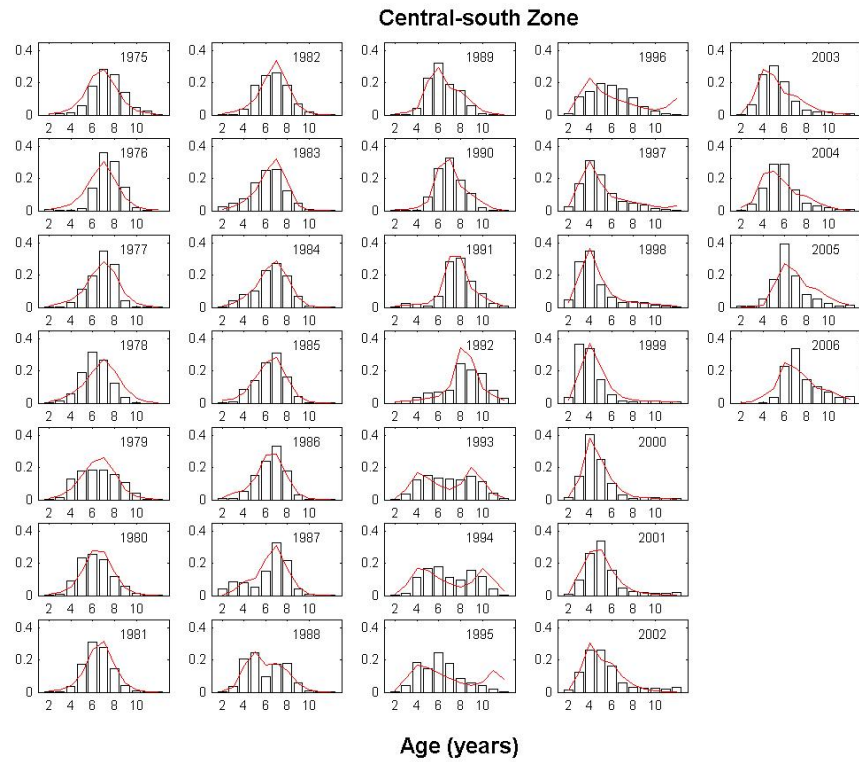
Age data on fleet catches show that exploitation patterns have changed significantly over time and fish age. In general, and after good recruitment periods, the age-specific effect of fishing mortality has been transferred to younger groups in the stock. A noteworthy fact in this respect is that, in the north of Chile, the “dome shape” exploitation pattern shows a strong shift towards younger specimens as of 1985, while the pattern in the center south area is logistic, showing a similar tendency to increased preference for younger specimens, although this began only in 1993 (Figure 40).

Figure 37:
Assessment model fit for age information
of jack mackerel catches in the North Zone of Chile



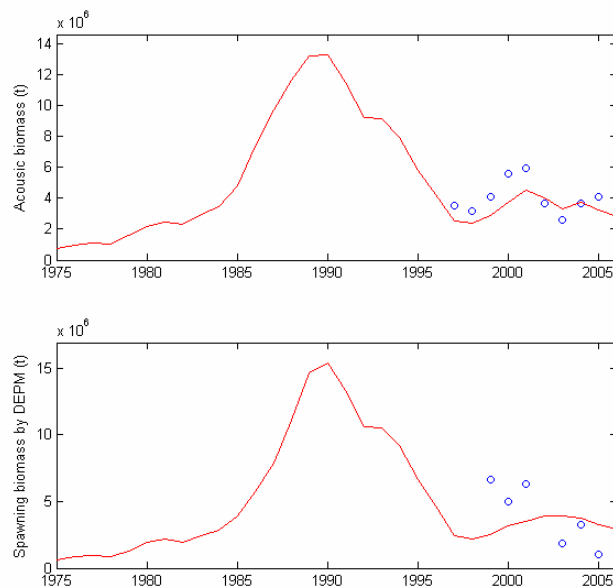
Source:IFOP

Figure 38:
Assessment model fit for age of
jack mackerel catches in Central-South Zone of Chile



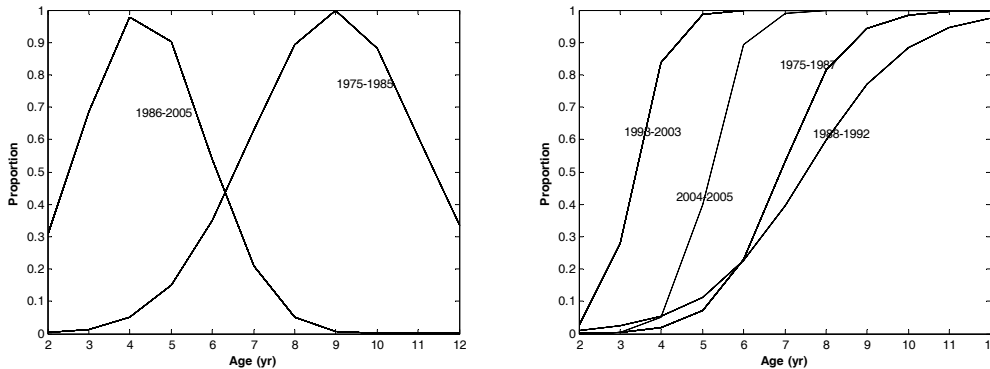
Source: IFOP

Figure 39:
Assessment model fit for biomass indexes
of jack mackerel in the Central-South Zone of Chile



Source: IFOP

Figure 40:
Exploitation pattern of jack mackerel in Chile:
left: North Zone, right: Central-South Zone



Source: IFOP

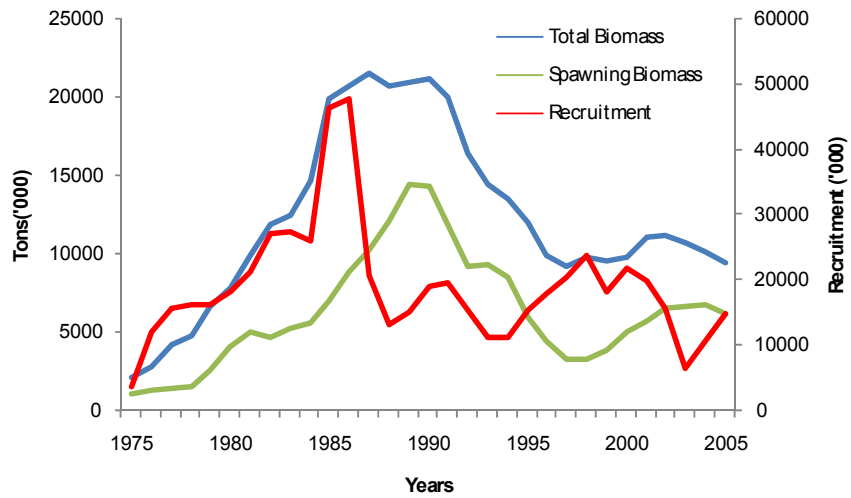
4.4 Results

Historically, jack mackerel biomass grew from 1975 to 1985 as a consequence, firstly, of positive surplus production generated by a sustained growth in recruitment; and secondly, as a result of somatic growth. Increased abundance of jack mackerel in this region is also mentioned by Serra (1991) and Elizarov et al. (1993). Jack mackerel recruitment reached its peak in 1985 and 1986, declining from 1987 onwards. Parallel to this, between 1985 and 1991, landings grew by 88%, a trend that was kept up until it reached a record level of 4.2 million tons in 1995. (Figures 41 and 42).

As a result of decreased recruitment as of 1987 and a simultaneous increase in catches, overfishing occurred. This is demonstrated by catches that exceed the surplus production of the stock, and by excessive exploitation rates (Figure 43). These factors accelerated the decrease in abundance. In this period, the spawning biomass ratio (SBR) dropped strongly to levels of 15%, which is significantly less than the biological target (40%), also indicating the overexploitation of the stock during this period.

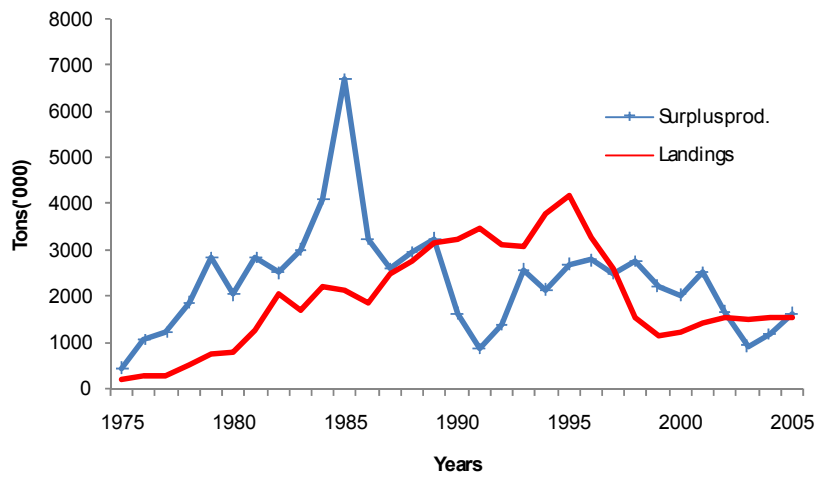
Regarding recruitment estimates, and notwithstanding uncertainties regarding the most recent years, the trend has been a decreasing one since 2001. This has remained the same in the three last stock assessments. It indicates a high likelihood of weakness of the annual classes which entered the fishery at age 2 in 2003 and 2004. This conclusion is supported by the weakening of younger ages (ages 2-4) in the age composition of the catch and the biomass estimated by the hydroacoustic survey. This weakness was accentuated in 2005 and it supports suggestions in previous works describing increased modal age in the age composition of the catch..

Figure 41:
Level and trend of total biomass (TB), spawning biomass (SB)
and recruitment (R) in numbers of Chilean jack mackerel



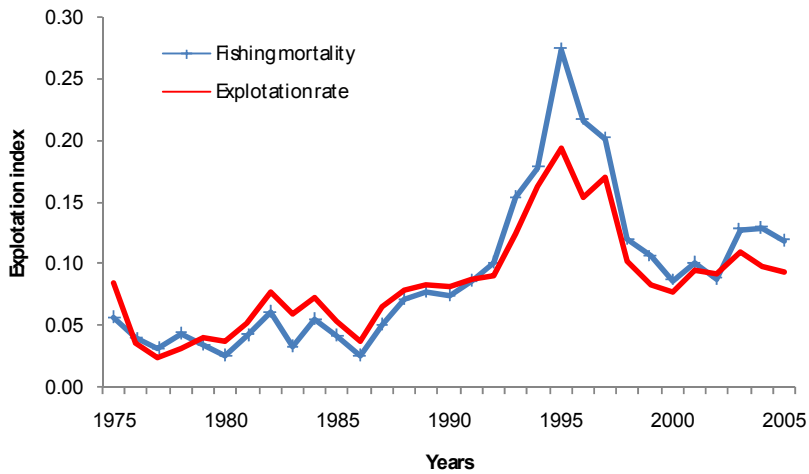
Source: IFOP

Figure 42:
Landings and productive surpluses of the Jack Mackerel



Source: IFOP

Figure 43:
Mortality rate by fishing (F) and exploitation (E)



Source:IFOP

Serra et al. (2005) found a significant effect between the spawning biomass and sea surface temperatures (SST) in connection with recruitment. Low SSTs produce low recruitment whereas the opposite occurs with high SSTs. The SSTs for 2001 and 2002 were low; these are the years in which recruitment that entered the fisheries in 2003 and 2004 took place. This result reinforces the conclusion that it is highly likely that recruitment during these years will be weak compared with the period 1996-2001. The latter was what enabled the partial recovery of the spawning stock up to 2003.

On the other hand, total and spawning biomass appear relatively stable as of 1998. This condition was achieved through strong regulation measures, among which the establishment of catch quotas stands out. This measure was established to avoid further reductions in the spawning biomass below critical conservation limits. A fact that helped to stop the decline in stock was the strong decrease in the size of the fishing fleet, thereby making it possible to adjust fishing efforts to present stock productivity levels. Indeed, in recent years, catch and surplus production have reached similar levels and the spawning biomass increased and remains stable at around 4.5 million tons.

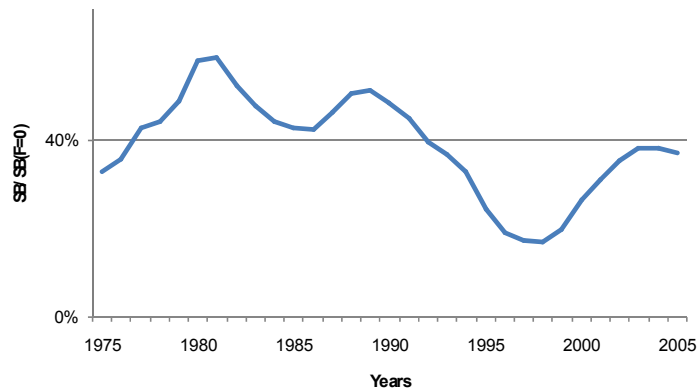
The decreased abundance of jack mackerel in coastal waters (inside the EEZ) made the fleet intensify its fishing operations outside the EEZ. Consequently, the area covered by the cruises—and therefore the stock assessment process—also changed, generating alternative hypotheses (Serra, Canales and Caballero, 2004). The cause of the change in distribution is not evident, since the oceanographic conditions have been normal. However, this hypothesis was included in the stock assessment process. One hypothesis suggests that the reduced biomass found in the last years inside the EEZ reflects changes in availability. According to the alternative hypothesis, this decrease is due to the contraction in stock distribution because of decreased abundance. Preliminary analyses of the latter hypothesis in stock assessments are cause for major concern on the status and prospects for the stock in the medium term.

4.5 Status of the Stock

The status of the stock is analyzed on the basis of the spawning biomass ratio (SBR) defined by Maunder and Watters (2003); the analysis of spawning biomass per recruit (SBR), considering for these purposes the medium theoretical weight and exploitation pattern in the last two years; and finally the surplus production of the stock.

The spawning biomass ratio (SBR) or spawning potential ratio, the size of the Chilean jack mackerel spawning stock is 35% compared to what it would have been without exploitation, with an adequate management target set at 40% for a pelagic fish like jack mackerel. Figure 44 shows that, as of 1992, this goal was not attained as a result of increased fishing mortality. As of 1999, and due to the reduction in landings, the SBR recovered to levels close to 35%; and surplus production was equal to landings. A similar conclusion is obtained by analyzing the biological reference points, given that fishing mortality for fully recruited ages in the last two years reaches values close to $F=0.25$, which slightly exceed the management goal of $F_{40\%}=0.22$.

Figure 44:
Trajectory of the jack mackerel spawning biomass ratio



Source:IFOP

These results allow concluding that the stock is currently in a status of full exploitation. Its spawning biomass shows a temporary stabilization as a result of strong fishing regulations and the entry of important year classes in the period 1996 - 2002. Nevertheless, the spawning biomass level is still considered below desirable limits ($SBR < 40\%$). This requires keeping its evolution under close watch, particularly due to lower and uncertain recruitment levels estimated in recent years.

Current knowledge on jack mackerel allows stating that jack mackerel fished inside and outside the Chilean EEZ is a biologically self sustained single stock. Evidence supporting this conclusion is based on the following:

- ❑ Marked seasonality of the fishery inside and outside the Chilean EEZ, as a result of migration to the high seas for reproduction and subsequent trophic immigration towards the coast.
- ❑ Main spawning ground located off the center area of Chile, a process that begins inside the EEZ and extends towards the high seas.
- ❑ Main breeding grounds located in the north of Chile and inside the Chilean EEZ.
- ❑ Similarity in the size composition of catches by different fleets operating inside and outside the Chilean EEZ.
- ❑ Genetic convergence of specimens taken from inside and outside the Chilean EEZ, as shown by DNA studies.

Fisheries indicators as well stock assessments of Chilean jack mackerel show that the stock is recovering from a state of low abundance and over-exploitation, and that it has reached a condition of temporary stock stability and full exploitation. Its stability depends—in the medium term— basically on controlling fishing mortality and on the recovery of the decreasing trend shown by recruitment. The foregoing statement is based on:

- ❑ Reduced fishing mortality as result of decreased catches and an adjustment in fleet size, which allowed the stock to recover.
- ❑ Current fishing mortality rates are close to the goal of F40%_{SBR} Biological Reference Point.
- ❑ Surplus production equaled by total landings.
- ❑ Present spawning biomass is close to the 40% which would have existed had it not been exploited.

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Annex 1.

List of Government research projects on Jack mackerel developed in Chile between 1993 and 2006

- 1993 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
- 1993 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
- 1993 Bohm G., et al, 1994 Análisis de la captura y del esfuerzo de pesca de las unidades de pesquería de jurel de la zona centro-sur y norte Informe Final Proyecto FIP-IT/93-22
- 1993 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
- 1993 Serra et al, 1994 Investigación evaluación del stock del jurel 1994. Informe Final, Proyecto IFOP/1993
- 1993 Serra R., et al, 1994 Evaluación directa del stock de jurel en la zona centro-sur Informe Final Proyecto FIP-IT/ 93-02
- 1994 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
- 1994 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
- 1994 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
- 1994 Quiñonez 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
- 1994 Serra et al, 1995 Investigación evaluación del stock de jurel 1995. Informe Final, Proyecto IFOP/1994
- 1995 Arcos D., et al, 1996 Evaluación del stock de jurel a nivel subregional Informe Final Proyecto FIP-IT/95-09
- 1995 Barbieri M.A., et al, 1996 Evaluación hidroacústica del recurso jurel en la zona centro-sur (fase crucero metodológico) Informe Final Proyecto FIP-IT/ 95-07
- 1995 Bohm et al, 1996 Investigación situación pesquería pelagica zona centro sur 1995. Informe Final, Proyecto IFOP/1995
- 1995 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
- 1995 Cerda A., et al, 1996 Evaluación bioeconomica de la pesquería industrial de jurel en la zona centro-sur. fase i Informe Final Proyecto FIP-IT/ 95-12

- 1995 Cubillos L., et al, 1996 Validacion de los metodos aplicados en la estimacion de edad y crecimiento, y determinacion de la mortalidad en jurel en la zona centro-sur. Informe Final Proyecto FIP-IT/95-10
- 1995 Martínez et al, 1996 Investigación situación pesquería pelagica zona norte 1995. Informe Final, Proyecto IFOP/1995
- 1996 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 FIP-IT/96-18
- 1996 Cordova J, et al, 1997Evaluación hidroacústica del recurso jurel en las regiones v a ix Informe Final Proyecto FIP-IT/ 96-13
- 1996 Martínez et al, 1996 Investigación situación pesquerías pelagicas zona norte 1996. Informe Final, Proyecto IFOP/1996
- 1996 Sepulveda A., et al, 1997 Migración de jurel desde y hacia la zee de chile central Informe Final Proyecto FIP-IT/ 96-15
- 1996 Serra et al, 1996 Investigación situación pesquerías pelagicas zona centro sur 1996. Informe Final, Proyecto IFOP/1996
- 1996 Serra et al, 1997 Investigación evaluacion del stock de jurel 1997. Informe Final, Proyecto IFOP/1996
- 1996 Serra R.,et al, 1997 Bases biológicas para prevenir la sobreexplotación en el recurso jurel Informe Final Proyecto FIP-IT/ 96-16
- 1997 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
- 1997 Martínez et al, 1996 Investigación situación pesquería pelagica zona norte 1997. Informe Final, Proyecto IFOP/1997
- 1997 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 FIP-IT/97-06
- 1997 Serra et al, 1998 Inves. evaluacion del stock de jurel 1998 Informe Final, Proyecto IFOP/1997
- 1997 Serra et al, 1998 Investigación situación pesquería pelagica zona centro sur 1997. Informe Final, Proyecto IFOP/1997
- 1998 Aranis et al, 1999 Inves situación pesquería pelagica zona centro sur 1998. Informe Final, Proyecto IFOP/1998
- 1998 Barría P., et al, 1999 Monitoreo de las capturas de jurel en la zona centro-sur Informe Final Proyecto FIP-IT/ 98-01
- 1998 Cordova J, et al, 1999Evaluación hidroacústica del recurso jurel en la zee de chile Informe Final Proyecto FIP-IT/ 98-11

1998 Martínez et al, 1996 Inves. situación pesquerías pelágicas zona norte 1998. Informe Final, Proyecto IFOP/1998

1998 Serra et al, 1999 Inves. evaluación del stock de jurel 1999 Informe Final, Proyecto IFOP/1998

1999 Aranís et al, 2000 Inv. situación pesquería pelágica zona centro sur 1999. Informe Final, Proyecto IFOP/1999

1999 Barría P., et al, 2000 Monitoreo de las capturas de jurel, 1999 Informe Final Proyecto FIP-IT/ 99-02

1999 Cordova J, et al, 2000 Evaluación acústica del recurso jurel en la zee de Chile. Informe Final Proyecto FIP-IT/ 99-03

1999 Martínez et al, 1996 Inv. situación pesquería pelágica norte 1999 Informe Final, Proyecto IFOP/1999

1999 Sepulveda A., et al, 2000 Condiciones biológicas del jurel en alta mar. Informe Final Proyecto FIP-IT/ 99-14

2000 Aranís et al, 2001 Investigación situación pesquerías pelágicas zona centro sur 2000. Informe Final, Proyecto IFOP/2000

2000 Barría P., et al, 2001 Monitoreo de las capturas de jurel, año 2000 Informe Final Proyecto FIP-IT/2000-02

2000 Cordova J, et al, 2001 Evaluación hidroacústica de jurel en la zee de Chile, año 2000. Informe Final Proyecto FIP-IT/ 2000-03

2000 Cubillos L., et al, 2001 Condición biológica de jurel en alta mar, año 2000. Informe Final Proyecto FIP-IT/ 2000-10

2000 Martínez et al, 1996 Investigación situación pesquería pelágica norte 2000. Informe Final, Proyecto IFOP/2000

2000 Serra et al, 2001 Investigación ctp jurel 2001 Informe Final, Proyecto IFOP/2000

2001 Aranís et al, 2002 Inves. situación pesquería pelágica zona centro sur 2001. Informe Final, Proyecto IFOP/2001

2001 Cordova J, et al, 2002 Evaluación hidroacústica de jurel en la zee, marzo 2001. Informe Final Proyecto FIP-IT/ 2001-02

2001 Cubillos L., et al, 2002 Condición biológica de jurel en alta mar, año 2001. Informe Final Proyecto FIP-IT/ 2001-12

2001 Martínez et al, 2002 Inves. situación pesquería pelágica zona norte 2001. Informe Final, Proyecto IFOP/2001

2001 Serra et al, 2002 Inves. ctp de jurel 2002 Informe Final, Proyecto IFOP/ 2001

- 2002 Aranís et al, 2003 Inves. situación pesquería pelágica zona centro sur 2002. Informe Final, Proyecto IFOP/2002
- 2002 Cordova J, et al, 2003 Evaluación hidroacústica de jurel en la zee, año 2002. Informe Final Proyecto FIP-IT/ 2002-02
- 2002 Cubillos L., et al, 2003 Condición biológica de jurel en alta mar, año 2002. Informe Final Proyecto FIP-IT/ 2002-12
- 2002 Martínez et al, 2003 Inves. situación pesquería pelágica zona norte 2002. Informe Final, Proyecto IFOP/2002
- 2002 Serra et al, 2003 Inves. ctp de jurel 2003 Informe Final, Proyecto IFOP/2002
- 2003 Aranís et al, 2004 Investigación situación pesquería pelágica centro-sur 2003. Informe Final, Proyecto IFOP/2003
- 2003 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
- 2003 Martínez et al, 2004 Investigación situación pesquería pelágica zona norte 2003. Informe Final, Proyecto IFOP/2003
- 2003 Serra et al, 2004 Investigación ctp jurel 2004 Informe Final, Proyecto IFOP/2003
- 2004 Aranís et al, 2005 Investigación situación pesquería pelágica centro-sur 2004. Informe Final, Proyecto IFOP/2004
- 2004 Arcos D., et al, 2005 Condiciones biológicas del jurel en alta mar, año 2004. Informe Final Proyecto FIP-IT/ 2004-33
- 2004 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
- 2004 Martínez et al, 2005 Investigación situación pesquería pelágica zona norte 2004. Informe Final, Proyecto IFOP/2004
- 2004 Serra et al, 2005 Investigación ctp jurel 2005 Informe Final, Proyecto IFOP/2004
- 2005 Aranís et al, 2006 Investigación situación pesquería pelágica centro-sur 2005. Informe Final, Proyecto IFOP/2005
- 2005 Cordova et al, 2006 Evaluación hidroacústica jurel v a x regiones 2005. Informe Final, Proyecto IFOP/2005
- 2005 Martínez et al, 2006 Investigación situación pesquería pelágica zona norte 2005. Informe Final, Proyecto IFOP/2005
- 2005 Sepulveda A., et al, 2006 Condición biológica de jurel en alta mar, año 2005. Informe Final Proyecto FIP-IT/ 2005-11
- 2005 Serra et al, 2006 Evaluación de stock y ctp jurel 2006 Informe Final, Proyecto IFOP/2005

- 2006 Aranís et al, 2006 Investigación situación pesquería pelágica centro-sur 2006. Informe Final, Proyecto IFOP/2006
- 2006 Cordova et al, 2006 Evaluación hidroacústica jurel v a x regiones 2006. Informe Final, Proyecto IFOP/2006
- 2006 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
- 2006 Martínez et al, 2006 Investigación situación pesquería pelágica zona norte 2006. Informe Final, Proyecto IFOP/2006
- 2006 Sepulveda A., et al, 2006 Condición biológica de jurel en alta mar, año 2006. Informe Avance Proyecto FIP-IT/2006-05
- 2006 Serra et al, 2006 Evaluación de stock y ctp jurel 2007 Pre-Informe Final, Proyecto IFOP/2006