Proceedings of the Sardine Symposium 2000

May 23-25, 2000

Held at the

Scripps Institution of Oceanography and the National Marine Fisheries Service's Southwest Fisheries Science Center La Jolla, California

Symposium Sponsors

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Table of Contents

SESSION ONE: POPULATION DYNAMICS AND COAST-WIDE SURVEYS
MODERATOR: JOHN HUNTER, NATIONAL MARINE FISHERIES SERVICE

I. PREFACE AND SUMMARY

The rapid expansion of the Pacific sardine and concomitant decline of the anchovy on the West Coast of North America present a great opportunity to describe and assess the consequences of a major shift in the California Current ecosystem. The Pacific sardine biomass has been growing at about 30% per year for the last 15 years, from only 6,000 tons to approaching a million tons. This increase, and geographical expansion, occurred during one particular state of the Pacific/North American Pattern, an index of large-scale climate. Today the anchovy has nearly vanished from the coastal waters of Oregon and Washington, while the sardine population is the most abundant forage fish from Baja California to British Columbia and sardine larvae have been found as far north as the Aleutian chain. High-resolution paleo-oceanography has shown that equally dramatic changes in these species have occurred over the past 2 millennia. The re-appearance of sardine populations in the north California Current ecosystem adds a major forage base and consumer input to the system, with large expected changes in trophic structure. If one takes the concept of ecosystem management of fisheries seriously, we must understand how the presence, absence and/or replacement of millions of planktivorous fishes affects the system.

In recent years the sardine expansion has also fueled a growth in the fishery for sardine off California and Mexico. Some limited fisheries have also occurred farther north off Oregon, and British Columbia.

There has been a need for coast-wide cooperation in the collection and analysis of sardine data, including coordination of sampling for age determination. Data on environmental properties related to (i.e., hypothesized to cause) the sardine's expansion also needed re-examination. In addition, stock assessment data from Mexico is needed for managing the species, especially with an expanding fishery.

To address these needs a jointly funded and organized workshop and retrospective review was held May 23-25, 2000 at Scripps Institution of Oceanography and the National Marine Fisheries Service's Southwest Fisheries Science Center. The objectives of the meeting were to:

1. To draw attention of fisheries management entities (e.g., Pacific Fishery Management Council) and the public to the importance of increased sardine abundance, and the associated ecosystem changes.

2. To evaluate the effect of the sardine outburst on key fishery stocks of the California current ecosystem including salmon, hake, pelagic rockfish, marine mammals, birds; as well as the impact of the sardine population on competing zooplanktiverous fish.

3. To establish a cooperative network for monitoring sardine abundance and age structure throughout its range and thereby provide information needed to sustain present high biomass levels.

4. To discuss the economic potential of the sardine outburst with ecosystem concerns.

5. To assess, as far as possible, the relations between expansion/contraction of the sardine and climate cycles in the North Pacific, so that prediction of future population changes is possible.

The symposium's plenary session included speakers from the United States, Canada and Mexico. These speakers had expertise in fisheries science, fisheries economics, marine mammals, marine birds, biological oceanography, and general ecology with experience in ecosystem dynamics and change. The plenary session also included a fishing industry panel, which was composed of:

Jay Bornstein, Bornstein Seafood, Bellingham Washington
Heather Munro, West Coast Seafood Processors Association, Portland, Oregon
Don Pepper, Pacific Sardine Association, British Columbia, Canada
Joe Cappuccio, Del Mar Seafoods, Salinas, California
Darrell Kapp, Bellingham, Washington
Sal Tringali, Monterey Fish Company, Salinas, California

Following the plenary session, the symposium broke into two workgroups with the following terms of reference:

Stock Assessment: Develop recommendations on the formation of a coastwide network for modeling the dynamics of the sardine and monitoring their movements, geographic variation in vital rates, age structure, and abundance.

Ecosystem Consequences: Evaluate the potential ecosystem effects of the sardine outburst and determine the optimal research strategy for estimating the consequences of shifts in ecosystem dominance of sardine.

WORKSHOP RECOMMENDATIONS

The recommendations from the two workgroups are as follows:

Stock Assessment and Management Workshop

1) Convene first meeting of Forum for International Sardine Collaboration and Information Exchange (FISCIE).

The goal of the first meeting shall be to identify and implement collaborative data collection for coast-wide stock assessment of sardine. The meeting shall be convened in 2000 and shall:

- Elect a chair and establish meeting procedures.
- Hear views of INP and Mexican sardine industry regarding joining FISCIE.
- Inventory all west coast sardine data sources.
- Identify and set priorities for new information collection.
- Implement a coast-wide (US, Mex., and Can.) data collection initiative for 2001.
- Establish an electronic reporting and information system.
- Present and discuss latest stock assessments.
- Exchange information on trends and events in the fishery.

2) Implement coast-wide collection of oil yield data. The oil yield of sardines routinely estimated by processors, could provide a valuable time series for monitoring the condition of the stock, if the data were routinely archived, and the methods presently employed were intercalibrated. Steps shall be taken to begin this process.

Ecosystem Consequences Workshop

I. Convene a National Center for Ecological Analysis and Synthesis (NCEAS) workshop addressing development of an Individual Based Model (IBM) for examining the relative importance of temperature and advection (regime shifts), predation, and the fishery in bringing about expansion and contraction of the E. Pacific sardine population. The benefits of having an NCEAS sponsored working group coordinating model development are:

- We will develop a format and protocol for data sharing; currently the data have been collected by a variety of organizations and are not easily transportable;

- We will set standards for future data needs and help design experiments to fill in major areas of missing data;

- We will coordinate research efforts now done separately and piecemeal by researchers from Mexico to Canada;

- We will pursue a coordinated effort to obtain funding to code and run the model;

- We will develop (specify) the model in the context of existing ideas about the expansion and contraction of the sardine population and will provide a framework for examining the implications of the various hypotheses;

- We will specify model scenarios and discuss model output in workshop format;

- The model might be used as a basis for a comparative study of sardine populations around the Pacific Rim. One important question it might address was why the NE. Pacific sardine population did not expand its range north in during the 1970's, in conjunction with expansions in range of the other Pacific sardine populations.

II. Add-ons to existing sampling programs or ships of opportunity

We suggest the addition of several new procedures to be done with existing sampling programs (BPA, GLOBEC, NMFS triennial, bait fishery, Mexican juvenile surveys) including:

- Collecting samples for micro-satellite genetic comparisons of stocks, including comparison with the 1940's NE Pacific Sardine stock;
- Record tissue and gonad condition, in addition to weight and length, in port sampling protocols. This would help with improve the migration component of an IBM and provide useful information related to reproductive activity;
- Stable isotope analysis of samples, including historic samples to provide insight in possible changes in diet of sardines during the expansion or contraction phases;
- Obtain forage fish energy content and condition factor over a range of species. This would provide information on the importance of energetics and food resources to changes in sardine population abundance;

An important recommendation of the Sardine Symposium 2000 was to form an International Sardine Forum to implement and coordinate data collection to permit coast-wide stock assessments covering the current expanded range of the sardine population extending from British Colombia south to Baja California. Following through on this recommendation, the first meeting of the International Sardine Forum, hosted by Instituto Nacional de Pesca (INP) and El Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE) will be held November 29 through December 1, 2000, in Ensenada, Baja California, Mexico.

II. PLENARY SESSION

Coast-Wide Stock Assessment

Kevin T. Hill, California Department of Fish and Game, La Jolla, California

Pacific sardine landings for the directed fisheries off California and Baja California reached the highest in recent history during the 1999 calendar year with a combined total of 115,051 metric tons (mt) harvested (Table 1, Figure 1). California landings for 1999, limited by a State of California management quota, were projected to be approximately 60,315 mt, 47% higher than 1998. The Ensenada, Mexico fishery experienced a 14% increase from the previous year, with final harvest projected to be 54,735 mt. The Ensenada fishery was not limited by a management quota.

For calendar year 1999, the Director of California Department of Fish and Game allocated a sardine quota of 120,474 mt to California's sardine fishery. This quota was based on a July 1, 1998, 'inside area' biomass estimate of 1,073,091 mt (Hill et al. 1999). As of October 31, 1999, the California fishery had landed 47,993 mt, with 72,481 mt of the quota remaining for November and December 1999. Off southern California, market squid availability was high during semester 1, 1999. This availability remains high, and the late-fall squid fishery has resumed. The wetfish fleet, which harvests sardine, continues to concentrate effort on market squid, a more profitable species.

Pacific sardine biomass (age 1+ as of July 1, 1999) was estimated using an integrated stock assessment model called CANSAR-TAM (Catch-at-age ANalysis for SARdine - Two Area Model; Hill et al. 1999), which is based on the original CANSAR model described by Deriso et al. (1996). CANSAR-TAM was developed to account for the expansion of the Pacific sardine stock northward beyond the California bight to include waters off the whole northwest Pacific coast. CANSAR and CANSAR-TAM are age-structured analyses using fishery-dependent and fishery-independent data to obtain annual estimates of sardine abundance, year-class strength, and age-specific fishing mortality for 1983 through the first semester of 1999. Non-linear least-squares criteria are used to find the best fit between model estimates and input data. Biomass estimates were adjusted by the model to better match the fishery-independent (survey) indices of relative abundance, including: aerial spotter sightings (Lo et al., 1992), CalCOFI egg and larval data, spawning area, and spawning biomass estimated using the daily egg production method (DEPM; Lo et al. 1996). The assessment model is based on a semi-annual time increment (Jan-Jun, semester 1, and July-Dec, semester 2) and now includes seventeen years of data. CANSAR-TAM recalculates biomass for all years in the time series. Bootstrap procedures were used to estimate 95% confidence limits and CV's for biomass and recruitment point estimates.

The CalCOFI, spawning area, and DEPM spawning biomass surveys indicate a steady increase in sardine relative abundance over the entire time series, with all three reaching their highest levels in 1999. (Table 2, Figures 3,4, 6). The CalCOFI proportion positive index had undergone considerable saturation in recent years due to the higher frequency of positive stations as the sardine stock expanded throughout and beyond the Southern California Bight. This problem was addressed in the current assessment by expanding the offshore range of CalCOFI stations included in the index. In addition, the survey was fit with an exponent (□=0.3547) to accommodate the assumption that the index was a non-linear function of sardine egg production.

Unlike the other fishery-independent surveys, the aerial spotter index has displayed a dramatic downward trend since 1995, with 1999 relative abundance values as low as those projected for 1989 (Table 2, Figure 5). Reasons for this downward trend are uncertain, but may be related to the spotter index covering a relatively small portion of the total sardine distribution. Spotter pilot effort tends to be nearshore, southerly, and within the range of the wetfish fleet. Sardine sightings are primarily concentrated in nearshore areas where the majority of spotter and fishing effort occurs. Based on our knowledge of sardine egg distribution in 1996 through 1999, it is highly likely that the area of the stock extends well beyond the area of the spotter survey. We accommodated spotter index saturation in our model by assuming a nonlinear function to sardine biomass, applying an exponent of □=0.4585.

Relative influence of survey data on biomass estimates from CANSAR-TAM can be controlled by specifying weighting factors ($□_r$) for each data type. For the 1999 assessment, surveys were differentially weighted based on the relative amount of area 'sampled' by each index. GIS methods were used to estimate total area covered by each of the four indices, with the assumption that DEPM and spawning area indices covered 100% of the total survey area (i.e., $□_r$=1.0). Based on this method, the CalCOFI index was down weighted to $□_r$=0.7 and the spotter index was down weighted to $□_r$=0.15.

Based on CANSAR-TAM, we estimate the July 1,1999 total age 1+ biomass to have been 1,581,346 mt (Table 3, Figure 8). This estimate includes a bias correction based on 2,000 bootstrap runs. This estimate provides an approximation of coast-wide population biomass. Sardine biomass has increased dramatically from 1983 to 1999 (Table 3, Figure 8). Age composition data and model outputs provide preliminary indication of a strong 1998 year class (Table 3), which dominated catch off southern California during semester 2, 1998. The 1998 year class contributed to the increase in total population biomass between 1998 and 1999.

U.S. Harvest Guideline for 2000

To calculate the harvest guideline for 2000, we used the MSY control rule defined in Amendment 8 of the Coastal Pelagic Species-Fishery Management Plan (Option J; Table 4.2.5-1 in the CPS FMP, PFMC 1998). This formula should theoretically perform well at preventing overfishing and maintaining relatively high and consistent catch levels over the long term. The Amendment 8 harvest formula for sardine is:

$$\mathbf{H_{t+1} = (BIOMASS_t\text{-}CUTOFF) \times FRACTION \times DISTRIBUTION}$$

where H_{t+1} is the total U.S. coast wide harvest guideline, CUTOFF is the lowest level of estimated biomass at which harvest is allowed, FRACTION is an environmentally-dependent fraction of biomass above CUTOFF that can be taken by fisheries, and STOCK DISTRIBUTION is the fraction of total $BIOMASS_t$ in U.S. waters. $BIOMASS_t$ is the estimated biomass of fish age 1+ for the whole stock at the beginning of season t. Resultant values for the 2000 fishery are as follows:

TOTAL BIOMASS	CUTOFF	FRACTION (F_{msy})	U.S. DISTRIBUTION	HARVEST GUIDELINE
1,581,346	150,000	15%	87%	186,791 mt

FRACTION in the MSY control rule for Pacific sardine is a proxy for F_{msy} (i.e., the fishing mortality rate for deterministic equilibrium MSY). FRACTION depends on recent ocean temperatures because F_{msy} and productivity of the sardine stock is higher under ocean conditions associated with warm water temperatures. An estimate of the relationship between F_{msy} for sardine and ocean temperatures (T) is:

$$F_{msy} = 0.248649805\ T^2 - 8.190043975\ T + 67.4558326$$

where T is the average three season sea surface temperature at Scripps Pier, California during the three preceding seasons. Under Option J (PFMC 1998), F_{msy} varies between 5% and 15%. F_{msy} will be equal to 15% under current oceanic conditions (T_{1999} = 18.04 degrees C; Figure 7).

Literature Cited

Deriso, R. B., J. T. Barnes, L. D. Jacobson, and P. J. Arenas. 1996. Catch-at-age analysis for Pacific sardine (*Sardinops sagax*), 1983-1995. Calif. Coop. Oceanic Fish. Invest. Rep. 37:175-187.

Hill, K. T., L. D. Jacobson, N. C. H. Lo, M. Yaremko, and M. Dege. 1999. Stock assessment of Pacific sardine (*Sardinops sagax*) for 1998 with management recommendations for 1999. Calif. Dep. Fish Game, Marine Region Admin Rep. 99-4. 94 p.

Lo, N. C. H., L. D. Jacobson and J. L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49:2515-2526.

Lo, N. C. H., Y. A. Green Ruiz, Merecedes J. Cervantes, H. G. Moser, R. J. Lynn. 1996. Egg production and spawning biomass of Pacific sardine *(Sardinops sagax*) in 1994, determined by the daily egg production method. CalCOFI 37:160-174.

PFMC 1998. Amendment 8 (to the northern anchovy fishery management plan) incorporating a name change to: the coastal pelagic species fishery management plan. Pacific Fishery Management Council, Portland, OR.

Pacific Sardine Fishery:

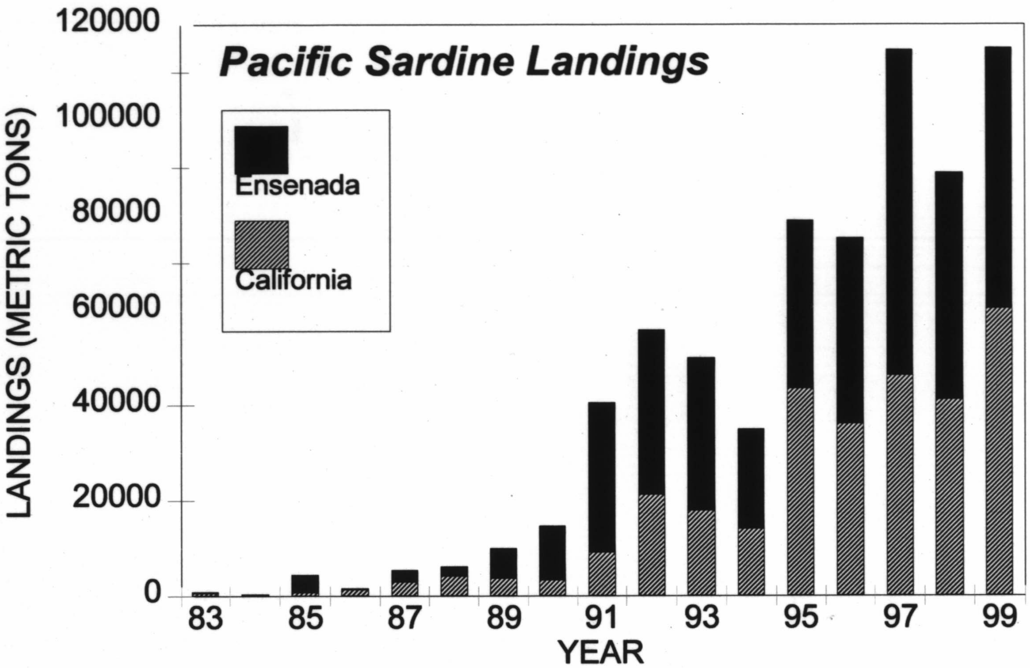

Figure 1. Annual Pacific sardine landings in California and Ensenada.

Table 1. Pacific sardine landings (metric tons) in California and Baja California, 1983-1999.

	CALIFORNIA			ENSENADA			
YEAR	semester 1	semester 2	CA TOTAL	semester 1	semester 2	MX TOTAL	CA-MX TOTAL
83	245	244	489	150	124	274	762
84	188	187	375	0	0	0	375
85	330	335	665	3,174	548	3,722	4,388
86	804	483	1,287	99	143	243	1,529
87	1,625	1,296	2,921	975	1,457	2,432	5,352
88	2,516	1,611	4,128	620	1,415	2,035	6,163
89	2,161	1,561	3,722	461	5,761	6,222	9,945
90	2,272	1,033	3,305	5,900	5,475	11,375	14,681
91	5,680	3,354	9,034	9,271	22,121	31,392	40,426
92	8,021	13,216	21,238	3,327	31,242	34,568	55,806
93	12,953	4,889	17,842	18,649	13,396	32,045	49,887
94	9,040	5,010	14,050	5,712	15,165	20,877	34,927
95	29,565	13,925	43,490	18,225	17,169	35,394	78,884
96	17,896	18,161	36,057	15,666	23,399	39,065	75,121
97	11,865	34,331	46,196	13,499	54,941	68,439	114,636
98	21,841	19,215	41,055	20,239	27,573	47,812	88,868
99	31,745	28,570	60,315	34,760	19,975	54,735	115,051

Pacific Sardine Survey Indices:

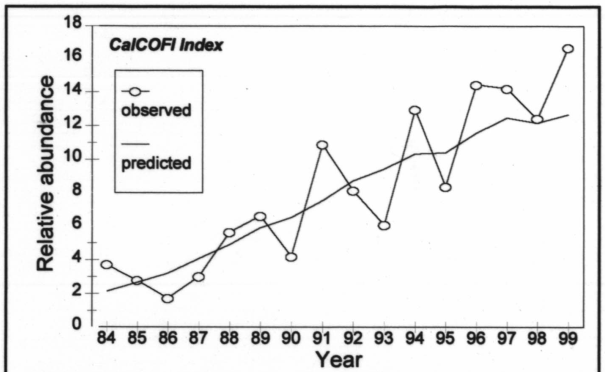

Figure 3. Relative abundance (proportion positive stations) of Pacific sardine eggs and larvae off southern California based on CalCOFI bongo tows, 1984-1999. Model was fit with an exponent of 0.3547. Survey was weighted to lambda = 0.70 based on relative proportion of total area sampled.

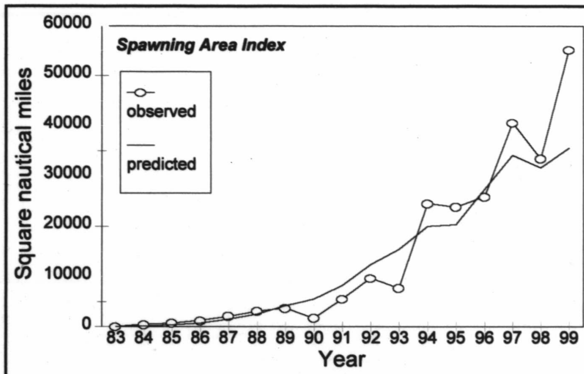

Figure 4. Relative abundance Pacific sardine spawners off California based estimates of spawning area (Nmi²), 1983-1999. Model was fit with an exponent of 1.0. Survey was weighted to lambda = 1.0.

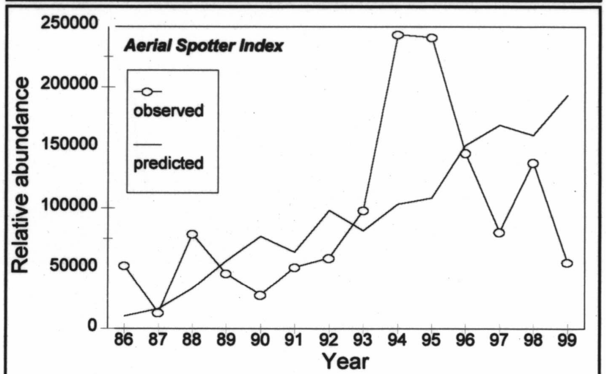

Figure 5. Relative abundance of Pacific sardine off California based on aerial spotter pilot sightings, 1986-1999. Model was fit with an exponent of 0.4585. Survey was weighted to lambda = 0.15 based on relative proportion of total area sampled.

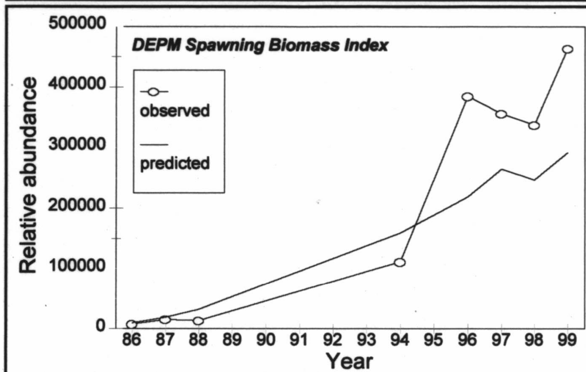

Figure 6. Relative abundance of Pacific sardine spawning biomass off California based on daily egg production method estimates, 1986-1999. Model was fit with an exponent of 1.0. Survey was weighted to lambda = 1.0 based on relative proportion of total area sampled.

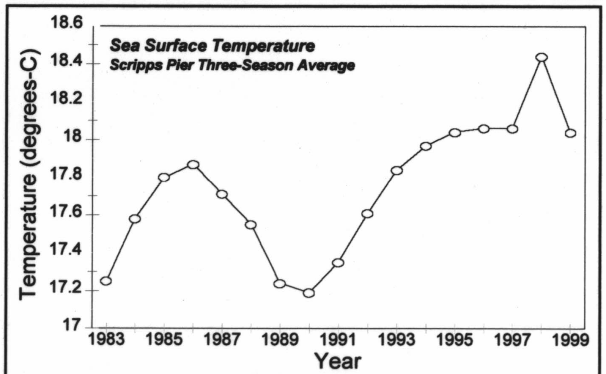

Figure 7. Sea surface temperature (SST) at Scripps Pier. Three-season running average was calculated as described in Jacobson and MacCall (1995). SST is used by CANSAR-TAM to model the spawner-recruit relationship. SST is also used to scale FRACTION in the harvest formula.

Table 2. Pacific sardine survey indices, 1983-1999.

Year	CalCOFI	DEPM	Spawning Area	Spotter	SST
1983	--	--	40	--	17.25
1984	3.727	--	480	--	17.58
1985	2.771	--	760	--	17.8
1986	1.729	7,659	1,260	52,426	17.87
1987	3.008	15,705	2,120	13,490	17.71
1988	5.639	13,526	3,120	78,674	17.55
1989	6.615	--	3,720	45,857	17.24
1990	4.202	--	1,760	28,072	17.19
1991	10.895	--	5,550	51,225	17.35
1992	8.140	--	9,697	58,984	17.61
1993	6.084	--	7,685	98,270	17.84
1994	12.963	111,493	24,539	243,585	17.97
1995	8.367	--	23,816	241,220	18.04
1996	14.453	384,694	25,889	145,772	18.06
1997	14.229	356,300	40,592	80,270	18.06
1998	12.424	337,596	33,447	137,711	18.44
1999	16.667	463,213	55,173	55,437	18.04

Pacific Sardine Biomass:

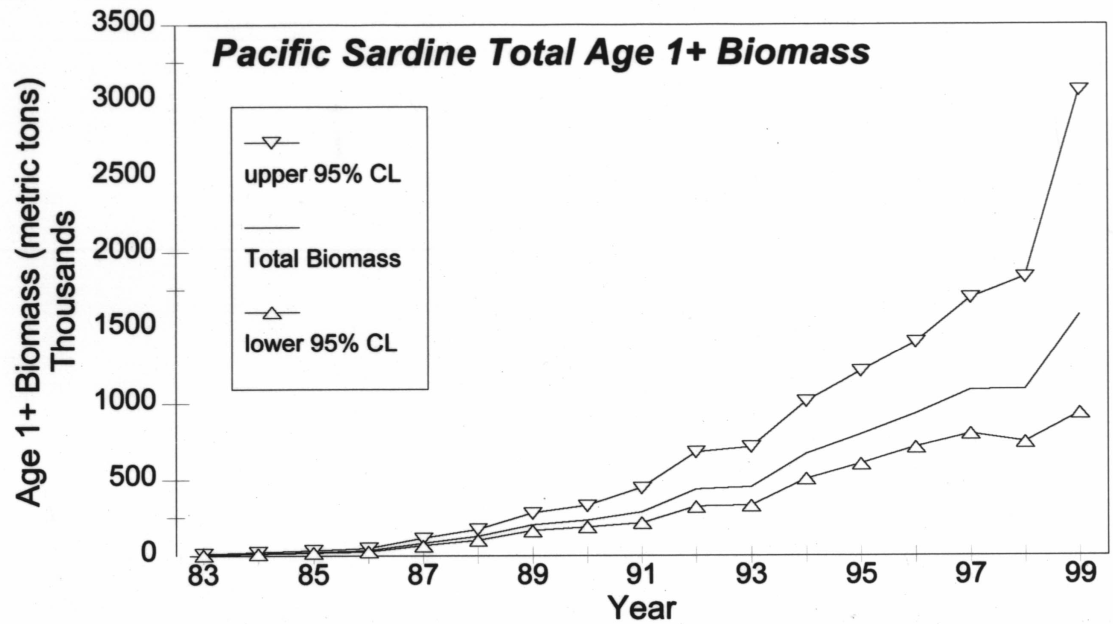

Figure 8. Pacific sardine age 1+ biomass for July 1 of each year, based on CANSAR-TAM.

Table 3. Pacific sardine biomass (age 1+, metric tons) and recruitment (age 0) estimated for July 1 of each year estimated by CANSAR-TAM model. Harvest guideline recommendations for 2000 are based on the 'Total' biomass estimate, which theoretically represents the coast-wide stock.

	Age 1+ Biomass (mt)				Age 0 Recruitments (1x10^3)		
Year	Inside	**Total**	Lower 95%	Upper 95%	Number	Lower 95%	Upper 95%
83	5,480	**5,480**	3,470	10,396	134,717	89,352	229,798
84	13,597	**13,659**	9,754	22,237	213,707	147,396	347,297
85	21,711	**22,174**	16,809	34,602	216,821	159,990	341,237
86	31,626	**33,130**	26,375	49,177	835,851	618,070	1,238,498
87	77,881	**81,302**	64,847	114,953	851,061	622,096	1,231,753
88	116,013	**125,457**	102,696	171,243	1,518,592	1,115,741	2,312,449
89	181,430	**200,474**	163,224	278,683	1,160,920	842,744	1,840,353
90	198,051	**231,939**	187,548	328,360	4,649,454	3,191,278	7,833,995
91	245,702	**282,620**	213,260	443,835	5,407,115	3,538,532	9,147,414
92	368,123	**434,562**	318,997	678,379	3,891,349	2,535,671	6,797,570
93	345,032	**448,744**	327,303	713,306	8,870,328	6,059,673	14,489,479
94	517,804	**665,697**	501,336	1,013,750	11,433,918	8,076,900	18,422,161
95	583,373	**791,535**	601,469	1,211,808	8,304,507	5,453,404	13,872,792
96	664,949	**931,083**	710,499	1,404,155	10,435,547	6,179,839	18,690,581
97	748,297	**1,087,303**	797,411	1,693,166	10,135,553	5,894,169	18,706,601
98	694,530	**1,090,656**	743,239	1,833,076	23,680,928	13,633,699	48,863,615
99	1,058,807	**1,581,346**	933,155	3,060,895	11,255,893	5,849,691	25,967,093

The Small Pelagic Fisheries in Baja California and the Gulf of California Mexico

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Small pelagic fisheries from the North American Pacific, whose populations develop in the California Current system and Gulf of California, constitute one of the associations characteristic of the margins of coastal upwelling of the great oceanic gyres.

The Pacific sardine and northern anchovy fisheries in Mexico are of national importance because their landings volume in several years has represented more than 50% of the national fishing catch. They are of regional importance because they support a great part of the fishing industry of the northwestern part of the country, since they are used for direct human consumption in several products, and as raw material for the elaboration of balanced food for the poultry and porcine industry. In the matter of marketing, in the last years, the exporting of canned products has been encouraged, although there has been the need for the import of fish meal, due to the fall in the anchovy catch in Ensenada (from which up to a 98% was dedicated to the production of fish meal), and to the low production of oleaginous, besides the increase in the demand of this product.

The fishery of small pelagic in Mexico, is characterized by being multi-specific, in which a group of species is caught, highlighted by its volume the Pacific sardine (*Sardinops caeruleus*), the northern anchovy (*Engraulis mordax*), three species of herring (*Ophistonema* spp), mackerel (*Scomber japonicus*) and with less participation the bocona sardine (*Cetengraulis mystycetus*), the Japanese sardine (*Etrurneus teres*) and the "charrito" jack mackerel (*Trachurus symmetricus*).

The main areas for catch are located in the Gulf of California and the western coast of the peninsula of Baja California, the landings ports are; Guaymas and Yavaros in the State of Sonora, Ensenada and Cedros Island in the State of Baja California, San Carlos in the State of Baja California Sur, and Mazatlan in State of Sinaloa.

Due to the fact that the pacific sardine is the species that supplies the greatest volumes of catch, it constitutes also the most important resource for the canning industry for direct human consumption. Comparatively, the rest of the species that make up the group of small pelagics, play a role of less importance in this matter, although they constitute a substitute of the pacific sardine in the periods of its low abundance; however, its main use is as raw material for the production of fish meal and fish oil.

CHARACTERISTICS OF THE RESOURCE

In Mexico, the Pacific sardine fishery started in the port of Ensenada, Baja California, Mexico in the year of 1929, recording low catch levels due to the small consumption demand and scarce carrying capacity of the fleet. In the middle of the decade of the 1940's, there is a fall of the fishery in the coasts of North America as a consequence of sharp changes in the environmental factors, and of an excess in the fishing effort, causing a severe economics crisis in the industry of the United States. During the years 1960's, this fall has an effect in the Mexican coasts of Baja California, which caused its virtual disappearances of the northwestern coast of the Mexican Pacific; however, since a catch was kept at very limited levels in the area of Cedros island and Bahia Magdalena, and due to the discovery of other pacific sardine stocks in the Gulf of California, a portion of the Ensenada fleet was displaced towards the Gulf of California; forming the base of what is now the Mexican pacific sardine fishery, whose base ports are in Guaymas and Yavaros, Sonora, whish have developed greatly, with a numerous fleet and the most important industrial plant in the country, assigning 85% of the production to the elaboration of fish meal and fish oil, and canning the rest 15% (Pedrin, et al, 1978 and Lluch, et al 1987).

With respect to the northern anchovy fishery, it started in the 1950's, also in the port of Ensenada, Baja California with very low catch records, which were assigned to human consumption, mostly canned. With some fluctuations, these catch levels are kept until the beginning of the decade of the 1970's in which, due to the fall of the Peru anchovy production, wide markets were opened to the Mexican anchovy as a virtual substitute of the Peru anchovy in the national market, as food in its form of fish meal (Garcia, et al 1991).

At the beginning of the years 1970's, the Pacific sardine and the northern anchovy fisheries had a parallel development, since a great portion of the fleet acted upon both resources, in the northern anchovy catch in the Pacific, as well as in Pacific sardine mainly in the Gulf of California.

In the western coast of Baja California, the fall of the northern anchovy fishery, which started in the beginning of the 1980's reaching its peak in 1990, was caused by unfavorable conditions and an excess in the catch. Parallel to the disappearance of the northern anchovy, a moderate “increase” of the Pacific sardine and Pacific mackerel is recorded, as it is indicated by the evaluations of the biomass using the Egg Production Methods (EPM) (Lo, et al. 1996).

In the Gulf of California, the anchovy fisheries beginning in 1993 after the fall of the Pacific sardine fisheries, recorded, in the 1990 and 1991 seasons, the Pacific sardine catch tends to increase, showing high recruitment in a consistent manner up to date, due to which there is a consensus in the sense that the Pacific sardine population shows a tendency for growth in the mid-term in this area of its distribution. (Cisneros, et al. 1995) indicates that from 1975 to 1985 the number of spawns increased slowly, and during the 1986-1987 fishing season, the spawning biamass increased up to 1.159 million tons.

PRESENT SITUATION AND PERSPECTIVES

The short term panorama is relatively optimistic, since the Pacific sardine populations, in both coasts, offer possibilities of maintaining or increasing moderately their biomass and availability. Experience indicates that the recovery of this type of resource often is so spectacular, in terms of velocity of growth and of volumes of production, similar to the collapses.

The dynamics of the interspecific and intraspecific interactions of the community, such as depredation, cannibalism, the competition is very high. This indicates that the changes in the environment affect it as a whole, and to each one of the components of this system, as a function of the ecological characteristics of each species. The different periods in which the variability operates, give as a result dynamic distribution changes (expansions and retreats) in the different time scales, from the seasonal to the geological changes (Lluch, et al 1997).

The extreme limits in which the presence of small pelagic is recorded, offer to us an schematic image of the distribution between the extreme areas in which each species is detected, and the usefulness of this information with biogeocraphical purposes, associated to systematic aspects.

The changes in distribution and abundance given in these resources, are extremely marked and are shown as a result of variations in the environment, and as a consequence of the interactions between the elements that form the association upon which the fishery acts. This makes it necessary to consider the distribution in more dynamic terms, both for understanding the mechanisms involved, as well as in reference to the availability in the fishing resources (Lluch, et al 1994).

The fishery developed in the Gulf of California, varies within seven species: five sardine and two anchovy. However, historically, the greatest catches are obtained on the Pacific sardine, while in the northern Pacific, up to 1989, the catch was sustained almost exclusively in northern anchovy, and from 1990 and beyond, the Pacific sardine and Pacific mackerel support the fishery.

From the Pacific sardine caches documented during all this century in the western cost of North America and the Gulf of California, the expansions and retreats recorded during the history of this fishery are shown, observing a retreat from north to south during the first half of the past century, with a peak precisely on the 30’s years of this century, while since the middle of the decade of the 1970's, an expansion of this fishery is recorded again, which is kept up to date (Figure 1).

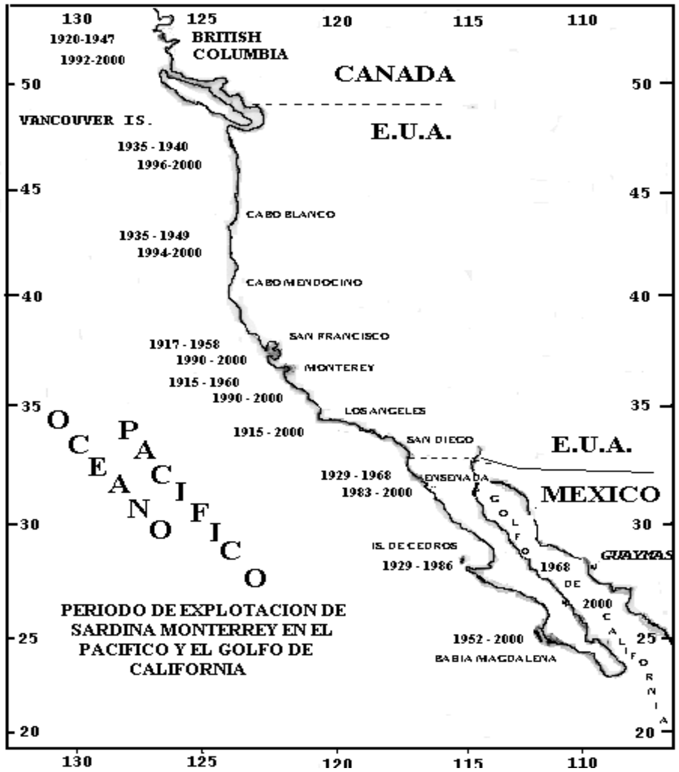

Figure 1

The general behavior of the Pacific sardine catches in the western coast of Baja California Figure and the Gulf of California compared to the northern anchovy, has always corresponded to the dominant species, except in the years between 1968-81 (Figure 2).

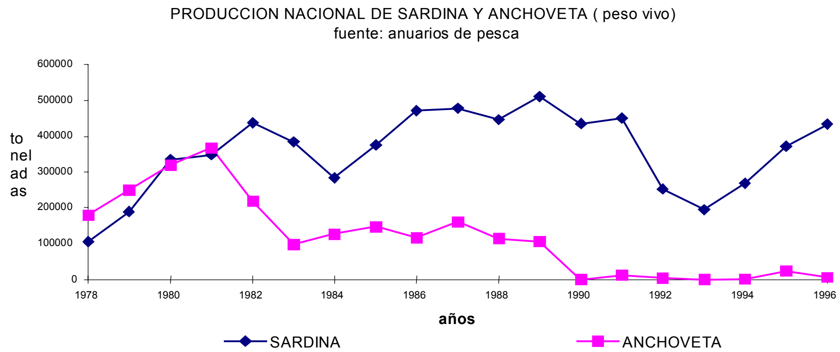

Figure 2

From the landings recorded in Baja California in the last 22 years, a transition is observed between the dominant species (northern anchovy for Pacific sardine) starting in the fishery since 1983, with the drastic fall of northern anchovy catches (of around 50%) and its collapse in 1990 (with a catch of only 90 metric tons), while Pacific sardine and Pacific mackerel, constitute the dominant species in this region of Mexico (Figure 3).

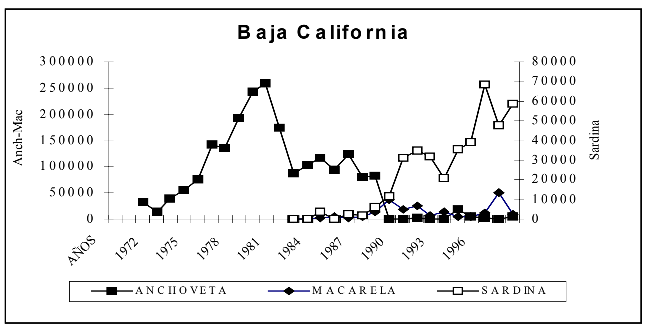

Figure 3

In the western coast of Baja California Sur (Bahia Magdalena region) the catches of these two species show a behavior very similar to that observed in Ensenada, although an out of phase condition is recorded in the catch volume in each one of these regions, which suggests to us a sliding (from south to north and vice versa) of the stocks regulated by the effects caused by environmental conditions; this is, during warm periods a sliding of the population is recorded towards north of its distribution. On the contrary, during cold events, the sliding is from north to south (Figure 4).

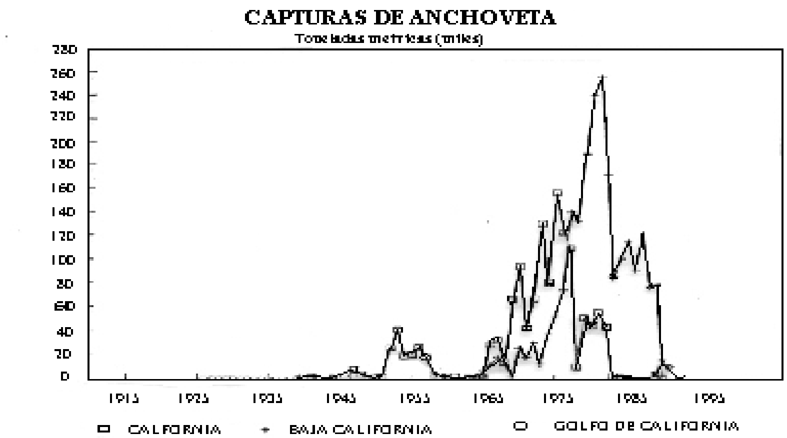

Figure 4

Finally, the behavior of the small pelagic populations in the Gulf of California shows a different condition to that recorded in the western coast of Baja California, since the dominant species, with some exceptions, has always been the Pacific sardine, except in the 1990-1991 and 1991-1992 seasons as indicated, in which the species that supported the catches were the northern anchovy and the Pacific sardine (Figures 5).

The catch of small pelagic has been obtained historically by a fleet reaching the 202 boats with a carrying capacity oscillating between 20 to 300 metric tons of hold capacity (Ponce, 1988), which have operated in the ports of Guaymas and Yavaros in Sonora; Puerto San Carlos,

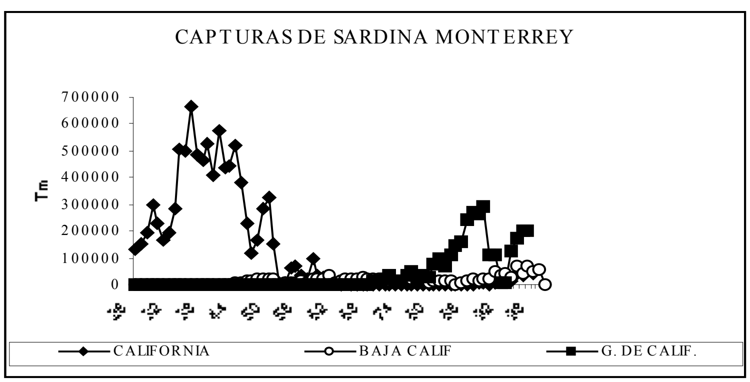

Figure 5

in Baja California Sur and Isla de Cedros and Ensenada, in Baja California. Constituting in this manner, what is known mainly as the Pacific sardine fishery (*Sardinops caeruleus*) and the northern anchovy (exclusively *Engraulis mordax*). At present, the fleet is made up of around 65 boats in both coasts.

MECHANISMS THAT EXPLAIN THE VARIABILITY IN THE POPULATIONS OF SMALL PELAGICS

The mechanisms that have been proposed for explaining these variations, have been based mainly in three different points of view; the first one is based in assuming that the fishing exploitation is the main cause of variation, since it is considered that exploitation is the main factor in the increase of mortality, due to which the magnitude of exploitation, determines the success or failure of the populations for maintaining their capacity for replenishment (Clark and Marr, 1955).

However, different authors have thought that the variability in abundance is of such a magnitude, that it is not possible to explain it only by the effect of the fishery (Clark and Marr, 1955; Redovich, 1982) even when there is a consensus in the sense that fishing may accelerate a collapse or it may delay its recovery (Lluch, et al 1994).

The second point of view is based on what is named as the problem of recruitment, based in the hypothesis by Hjort (1914), which has been and is one of the statements in which the work of a great number of researchers has been based, and that is supported by the fact that differential survival between the egg and larvae stage determines in a great manner the success of recruitment; and therefore, the size of the population.

In this proposal, there is an implicit recognition that the oceanographic conditions play a main role in the variations of the abundance present in the populations. Lasker and McCall (1983) carried out a review of the mechanism proposed by different authors, for explaining the variations on survival, and came to the conclusion that a critical element is the availability of food at the moment of larvae spawning. Lluch et al. (1991) establish that the ratio of eggs and larvae (reflected by the number of positive seasons) is practically constant between years, and that the variability is not present during the development of egg to larvae, but spawning is variable, demonstrating the proposal by Alhstran (1965).

The third point of view, proposed by (Lluch, et al. 1989) and based on the idea that global climatic changes are the mechanisms that regulate the distribution, abundance and behavior of the populations and which has been documented in all the regions in the world in which great oceanic gyres are present, such as South America (Peru and Chile), Asia (Japan), South Africa and the western coast of the North Pacific (California, Baja California and the Gulf of California) (Lluch, et al., 1994).

Evidently, the climatic changes at the global level constitute one of the main factors that determine the great changes in distribution and abundance of the populations of these species (Pacific sardine and northern anchovy) which has been reinforced when analyzing the scales in laminated sediments in front of California and in front of Guaymas, Sonora in the Gulf of California (Soutar and Isaacs, 1974; Baumgartner, et al., 1992), these authors have established that the populations suffer considerable variations in their abundance in time, in a cyclic manner in the absence of fishing; however, it is recognized that at present, part of the variability is due to the effects of the environmental conditions and the effects of fishing.

We have asked ourselves if under conditions of low abundance, it is possible to continue the exploitation of these resources, and we have arrived to the conclusion that even when the response to this depends on several factors, there is no reason to stop the fishing activity at short or mid term, at least with respect to the state of the resource. The present situation of low abundance of some of the species of small pelagics, is probably due more to the natural variations of the system than to a probable inadequate exploitation, which has been pointed out for other fisheries in the world (Lluch, op. cit.).

The recognition of the variability of the system, must contribute to changing the traditional scheme with regard to the point of view giver to the research and to the administration of the fishing resources, for which it is necessary to integrate the research of the physical and biological aspects, and to give it an orientation towards goals that allow us to elaborate forecasts of both the resource as well as the environment, and that this contributes to the optimum use of the pelagic species that make up the system, proposing administrative measurements which can be applied in a dynamic manner for administrating their exploitation.

The characteristics of the system, its variability, its complexity and its present condition, in a great manner without precedent, makes indispensable the interaction of the different sectors that conform this fishery, due to which it is also necessary to give it a multidisciplinary focus that may contribute with new elements.

The catch of the species exploited by these fisheries has decreased in the last years. This tendency started in 1982 with the decline of northern anchovy in the western coast of Baja California. In the Gulf of California, although the Pacific sardine decreased in an important manner in the 1983-1984 and in the 1990-1991 and 1991-1992 seasons as we mention, it has remained and it is the main support for the catches recorded in this region. It is pointed out that the fluctuations on the abundance of these species are due to variations in the environment; however, recent studies indicate that maybe the drastic changes were caused as a consequence of the combined action of climate and exploitation; up to this moment, there is no consensus on the relative weight of each component.

PROBLEM TO BE RESOLVED

At present, it is evident that the current state of research and of the aspects on knowledge of the fishery as a whole, far from clearing doubts, new questions arise, which answers depend in great manner on the future development of scientific activities, as well as on the fishery.

In this context, we believe that it is necessary to integrate all the lines of research that make up the project, and the different institutions that develop it, considering new lines of research which include both the environmental component, as well as the biological, as an essential instrument for explaining how the system functions.

In general, it is evident that there is a serious problem for industry. The great variability present in the Pacific sardine and northern anchovy catches in the Pacific and in the Gulf of

California, proposes the urgent necessity of seeking out options for the industrial plant installed, with the purpose of keeping it in operation as possible as the resources permit.

On the other hand, as an alternative for providing raw material there are other species; however, the technical information available is very scarce and in some cases there is none, which makes it necessary to generate this information for being able to take dynamic administrative measurements that secure an optimum exploitation, guarantees the least possible effort with the maximum yield and with the maximum social effect.

LITERATURE CITED

Ahlstrom, E. H., 1965. A review of effects on the environment of the pacific sardine. ICNAF Spec. Publ., 53-76

Baumgartner, T.R., A. Soutar and Ferreira -Bartrina (1992) Reconstruction of the history of pacific sardine and northern anchovy population over the past two millennia from sediments of the Santa Barbara Basin, California. Calif. Coop. Oceanic Fish Invest. Rep. 33:24-40

Cisneros-Mata , M.A., A.G. Montemayor-Lopez and O. Nevaárez-Martínez. 1996. Modeling deterministic effects of edge structure, density dependence, environmental forcing, and fishing in the population dynamics of sardinops sagax caeruleus in the Gulf of California. Calif. Coop. Oceanic Fish Invest. Rep. 37: 201-207.

Clark, I.N. and J. C. Marr, 1955. Populations dynamics of the pacific sardine. CalCOFI Progress Rep. 4-52.

García, F.W., A. Cota V., A. Barrera M., J. Luna F. y F .J. Sánchez R. 1991. Análisis de la pesquería de anchoveta (*Engraulis mordax*, Girard 1856) durante la temporada de 1988. Ciencia Pesquera Inst. Nal. De la Pesca Dpto. de Pesca México (8): 23-33 p

Hort, J. 1917. Fluctuations in the great fisheries of Northern Europe viewed in the light of biological research. Cons. Perm. Int. Explor. Mer. Rapp. And Proc. Verb., 20, 228 pp.

Lasker, R. And A. D. McCall, 1983. New ideas in the fluctuations of the clupeoid stocks off California. In C.N.C./SCOR Proc. Of the joint oceanographic Assembly 1982-General Symposia, Ottawa, Can.: 110-120

Lluch Belda, D., S. Hernandez – Vázquez and R. A. Swartzlose 1991. A hypothetical model for fluctuation of the California sardine populations (S*ardinops sagax caerulea*). In long term variability of pelagic fish populations and their enviroment, T Kawasaki et al., eds, Pergamon Press, pp.293-300.

Lluch Belda, D., R. J. M. Crawford, T. Kawasaki, A.D.McCall, R.H. Parrish, R.A. Schwartzlose and P.E. Smith. 1989. World wide fluctuations of sardine and anchovy stocks: the regimen problem. S. Afr. J. Mar. Scin. 8:195-205.

Lluch Belda, D., R. J. M. Crawford, F.J. Magallon and, R.A. Schwartzlose. 1997. Preliminary evidence linking regional climatic variability to recent and dramatic collapse of the Mexican sardine fishery. (Abstract) Proceedings of the thirteenth Annual Pacific Climate (PACLIM) Workshop Asilomar, California. April 14-17, 1996.

Lo, N.C.H., Y. A. Green Ruiz, M.J. Cervantes, H.G. Moser and R.J. Lynn. 1996. Egg production and spawning biomass of pacific sardine (S*ardinops sagax) in 1994 determined by the daily egg production method. Cali. Coop. Fish Invest. Rep. 37:161-174.*

Pedrin, O.A. 1978. Informe sobre la pesquería de sardina monterrey en el Golfo de California en la temporada 1977-1978 y recomendaciones para la reglamentación. I.N.P Serie Informativa. México: 1-23.

Ponce, D. G. Y D. Lluch B. 1990. Análisis de la flota sardinera-anchovetera del noroeste de México. Inv. Mar. CICIMAR Vol. 5 (2) 123-136.

Radovich, J. 1982. The collapse of the California sardine fishery: what have we learned? CalCOFI Rep. XXIII 56-78 P

Soutar, A. And J.D. Isaac. 1974. Abundance of pelagic fish during the 19th. And 20th. centuries as recorded in anaerobic sediments off the California. Fish Bull. 72: 257-273.

Hydroacoustical Observations of Small Pelagic Fish Behavior in the West Coast of Baja California, Mexico

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The use of hydroacoustics for measuring abundance and distribution of pelagic fishes has several advantages over standard sampling techniques. Acoustic instruments, which transmit and receive sound waves, are capable of detecting fish much far beyond the range of the human vision. Thus, the possibility to observe and count what is under the surface without disturbing the environment is one key advantage of underwater acoustics (Brandt, 1996). Moreover, with hydroacoustics it is possible to search a large volume of water in a short time (MacLennan and Simmonds, 1992) and because sound travels in water at approximately 1500 m/s, the entire water column can be sampled quickly with the possibility of obtain detailed maps of fish densities and mean sizes over large bodies of water.

Underwater acoustics is widely used for providing fishery independent estimates of fish abundance (MacLennan, 1990). However, because of the many uncertainties connected with the method, particularly related to fish behavior, the abundance estimates are generally used as relative indices to, for instance, have more specific values of structured assessment model related to stock assessment (Freón and Misund, 1999). The main goal of this presentation is to present results on the behavior of small pelagic in the west coast of Baja California, Mexico using hydroacoustics.

From December 1993 to March 200, fifteen oceanographic surveys have been done to the west coast of Baja California, Mexico board the R/V "El Puma" (Table 1). Two areas are covered, Northern from Punta Colnet to Punta Baja (30° 54', 116° 40' W to 29° 26' N 115° 29' W) and Southern area from Punta Eugenia to Bahia Tortugas (27° 29' N 115° 22' W to 26° 47' N 113° 55' W) (Figure 1). In each zone, seven transects 18 km long were defined in each survey to cover two zones, each about nine km long. A neritic zone, which covers the shallower part of the transect (<80 m depth) and the oceanic zone, the deepest (>200 m depth) and offshore part of the transect. During approximately 12 h, continuous recording of the water column using hydroacoustics was done in odd transects (1,3,5 and 7). The rest of the transects were done during the day and no hydroacoustic data were obtained. Our path started at the neritic station, went to the oceanic, then reversed to the neritic station about three hours later. Ship speed along the transect averaged 11 knots.

HYDROACOUSTIC SYSTEM

A Simrad EY-200 echosounder with a working frequency of 200 kHz was used. For analysis, we used an Hydro Acoustic Data Acquisition System (HADAS, ver. 4.01) developed by Lindem and Houari (1988). The system is based on a combination of hardware and computer software that together give the capability of digitizing and storing hydroacoustic data. This program uses a modification of the Craig and Forbes (1969) algorithm to remove the beam pattern effect. Because we used a time varied gain of 40 LogR, analysis of echo counting for individuals and target-size distribution was done. The unit was calibrated with a 13.7 mm-copper sphere (-45 dB). Pulse duration was set at 0.3 ms. Ping rate was 1.7 pings per seconds and minimum threshold noise level was 400 mV. For analysis we used target strengths (TS) between -44 to -34 dB. According to Love (1971), who collected data on many species, using several echosounders operating from 15 to 1000 kHz, this range of target strength for a 200 kHz transducer means fish body lengths between 11 and 37 cm long. Moreover, this range has been detected with this same hydroacoustic system when anchovies (*Engraulis mordax*) 8 to 14 cm long, have been captured with Isaacs-Kid mid-water nets in the west coast of Baja California [20]. All results are presented with data gathered during night, between 19.00 and 05.00 hours (local time), when fish are more dispersed. This is important because the echo counting analysis is based on the size distribution of single fish echoes (MacLennan and Simmonds, 1992). To evaluate fish distribution the water column was split in two, 5-to 25-m and 25-to 50-m depth. Since a single beam echosounder was used, we were not able to estimate fish density. However, echo counting was used to describe the behaviour and distribution of echoes. To do this, for each cruise, the median of the echo-counting for the selected Target Strength was obtained. Moreover, for each cruise, the number of echograms with no echoes i.e. negative echograms, is expressed as a percentage of the total echograms analyzed. An Isaacs-Kid mid-water net (4 m mouth wide) was used were acoustic information showed the presence of strong echoes.

RESULTS

Table 1 presents the number of echograms analyzed for each area in both strata and region. In the northern area, the median number of echoes in the 5-25 m depth stratum shows a constant decrease, which was accentuated after El Niño 1997. Moreover the percentage of negative echograms increases with time, the exception was in March 200 where a clear reduction of negative echograms occurred (Figure 2). In the 25-50 m depth layer, the median number of echoes and percentage of negative echograms remains steady along the time (Figure 3). Comparing echoes in both strata, results show that before El Niño 1997, the most of the abundance was observed in the upper stratum. However, after this event, abundance is reduced in the upper layer (Figure 4). The percentage of negative echograms shows more or less the same behavior along time (Figure 5). Regarding echo-distribution along the transect, the median of echoes in the oceanic area after El Niño 1997 was significantly reduced (Figure 6). This behavior is also evident when the percentage of negative echograms is analyzed (Figure 7). Results of the midwater trawl show that after 150 trawls, 96% is anchovy (*Engraulis mordax*). Mean total length 11.2 cm (8-15 cm) and 4% sardine (*Sardinops sagax*). Mean total length 18.0 cm (16-21 cm).

Results in the southern area, show a decrease in the number of echoes in the upper stratum. This was more evident after El Niño 1997. In the last cruise (March 2000), the median number of echoes was similar as the observed before El Niño. However, the percentage of negative echograms still remains high (Figure 8). The 25-50 m depth layer showed a very high median of echoes in December 1993. However, since 1994 there is not an evident tendency in both median and percentage of negative echograms (Figure 9). Comparing both strata, results show that after El Niño 1997, the median number of echoes was reduced in the upper layer. This behavior switched in March 2000 (Figure 10). However the percentage of negative echograms in both strata remains high (Figure 11). Echo distribution along the transects show no significant tendency with time in the number of echoes (Figure 12). However, from July 1996 to March 1998 the percentage of negative echograms was lower in the neritic than in the oceanic area. (Figure 13). Results of the midwater trawls show that after 145 trawls, 98% is anchovy (*Engraulis mordax*). Mean total length 12.3 cm (8-14 cm) and 2% sardine (*Sardinops sagax*). Mean total length 17.5 (15-21 cm).

CONCLUSIONS

1. Since 1993 eco-counting has been reduced significantly in both areas.

2. In the northern area, in the 5 to 25 m depth layer, there is no evidence of recovering in the abundance of echoes. However, the reduction in the percentage of negative echograms, observed in March 2000, may suggest a possible change in the tendency.

3. In the southern area, the percentage of negative echograms in the 5 to 25 m depth layer remains high. However, the median of echoes increased significantly in the last cruise, March 2000. A change in the tendency?

4. Before El Niño 1997, echo-counting was, either high in the 5 to 25 m layer or similar as the observed in the lower stratum in both areas. The behavior is reverted during El Niño. In the last cruises, abundance of echoes in the northern area is similar in both strata. In the southern area only until March 2000 the behavior was similar as the observed before El Niño 1997.

5. In both areas, the 25 to 50 m depth layer shows no evident temporal changes in the behavior.

6. In the northern area, El Niño 1997 reduced significantly the abundance of echoes in the oceanic region. However in the south, the behavior was similar in the Neritic and in the Oceanic region.

Literature Cited

Brandt, S.B. (1996). Acoustic assessment of fish abundance and distribution. *In*: Murphy, B.R. and Willis, D.W. (Eds). Fisheries Techniques. 385-432 pp.

Craig, R. E. and Forbes, S. T. (1969). A sonar for fish counting. *Fiskkeridir Skr. Ser. Havenders* 15, 210-219.

Freon, P. and Misund, O.A. (1999). Dynamics of pelagic fish distribution and behaviour: effects on fisheries and stock assessment. Fishing News Book. 348 pp.

Lindem , T., and Houari, H. A. (1988). Hydro Acoustic Data Acquisition System. HADAS. Oslo; Department of Physics, University of Oslo.

Love, R. H. (1971). Dorsal-aspect target strength of an individual fish. *Journal of Acoustic Society American* 49, 816-823.

MacLennan, D.N. (1990). Acoustical measurement of fish abundance. *Journal of Acoustic Society American* 87, 1-15.

MacLennan, D. and Simmonds, J. (1992). Fisheries Acoustics. Chapman Hall, London 325 p.

Table 1. Date of cruises to the west coast of Baja California and number of echograms analyzed for each area. Results are for both strata and regions.

	Northern Area	**Southern Area**
Date	Echograms Analyzed	
December 1993	114	82
October 1994	77	154
March 1995	130	134
July 1995	148	138
October 1995	88	83
March 1996	40	82
July 1996	86	60
September 1997	106	80
December 1997	69	122
March 1998	53	140
July 1998	120	108
December 1998	138	130
March 1999	108	126
December 1999	244	112
March 2000	104	114

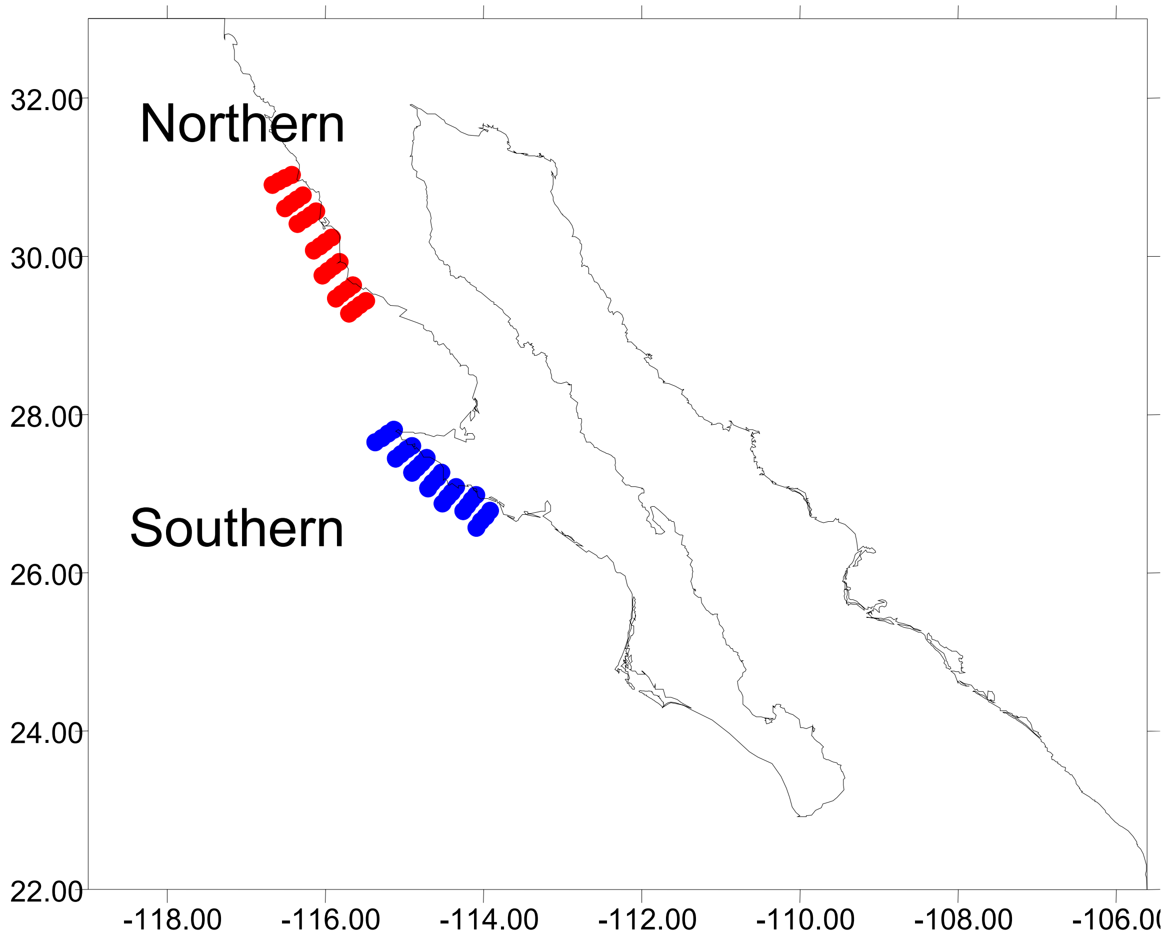

Figure 1. Map of the study area showing the transects in both areas.

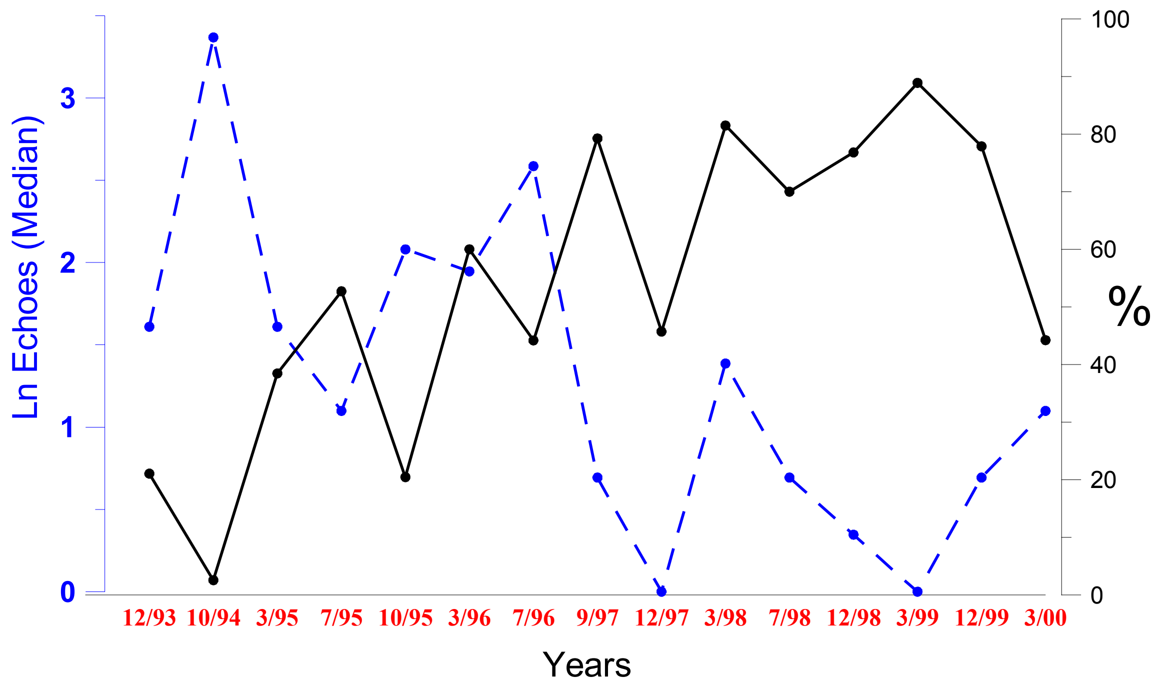

Figure 2. Median number of echoes (dotted line, left axis) and percentage of negative echograms (continuos line, right axis) in the 5-25 m depth stratum. Northern area.

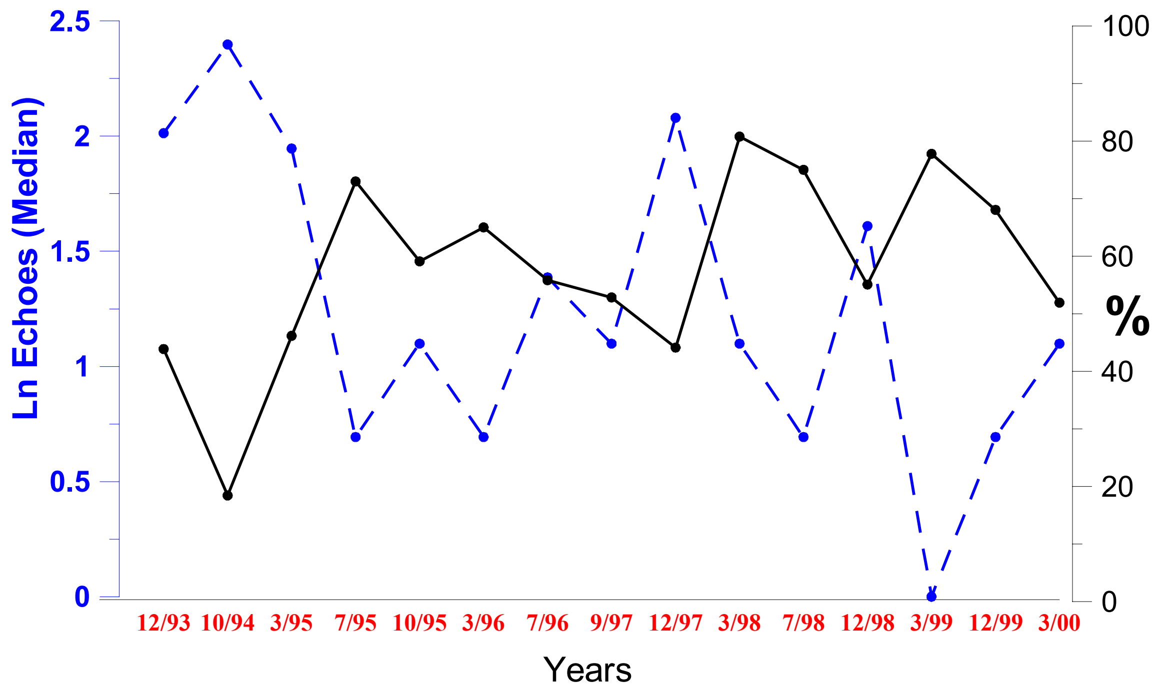

Figure 3. Median number of echoes (dotted line, left axis) and percentage of negative echograms (continuos line, right axis) in the 25-50 m depth stratum. Northern area.

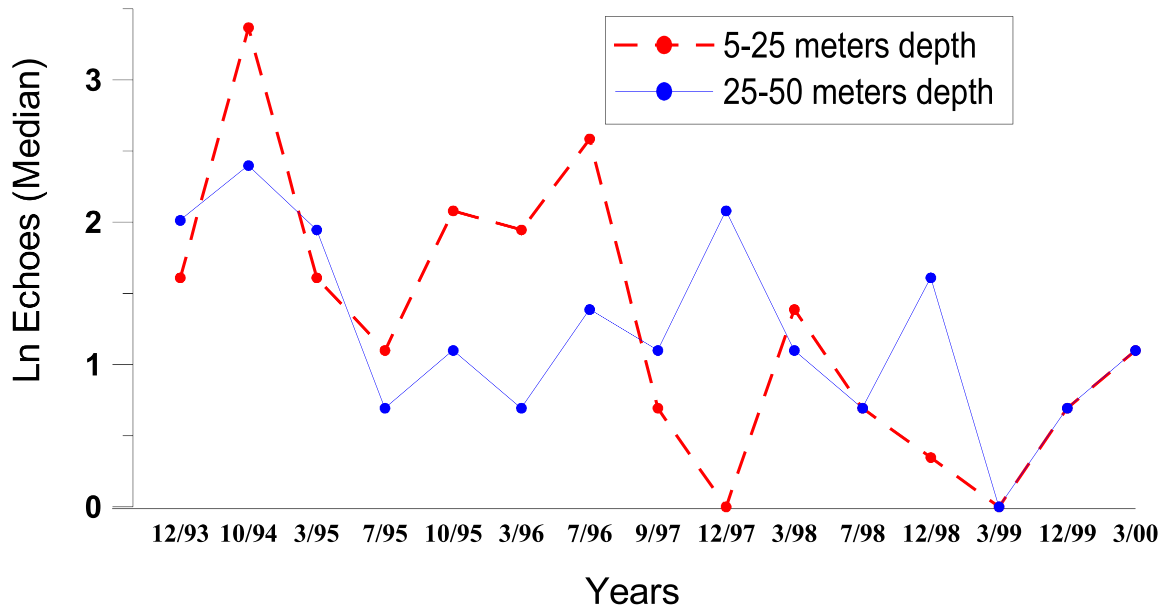

Figure 4. Median number of echoes in both strata. Northern area.

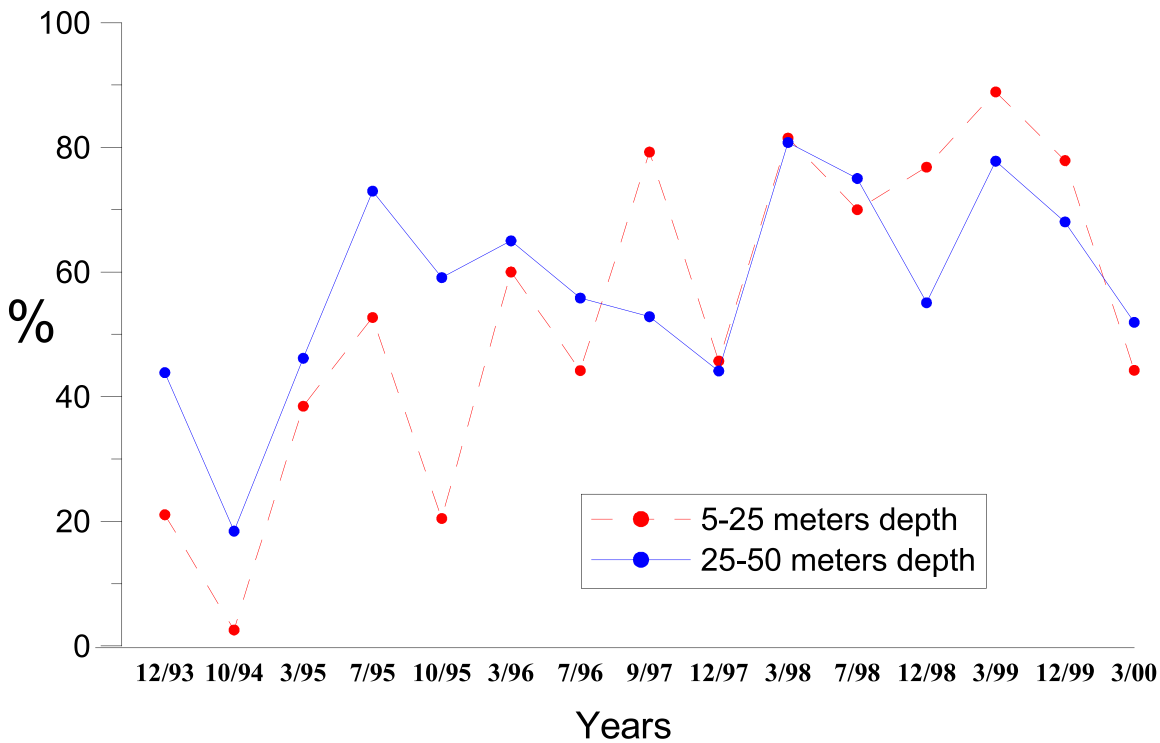

Figure. 5. Percentage of negative echograms in both strata. Northern area.

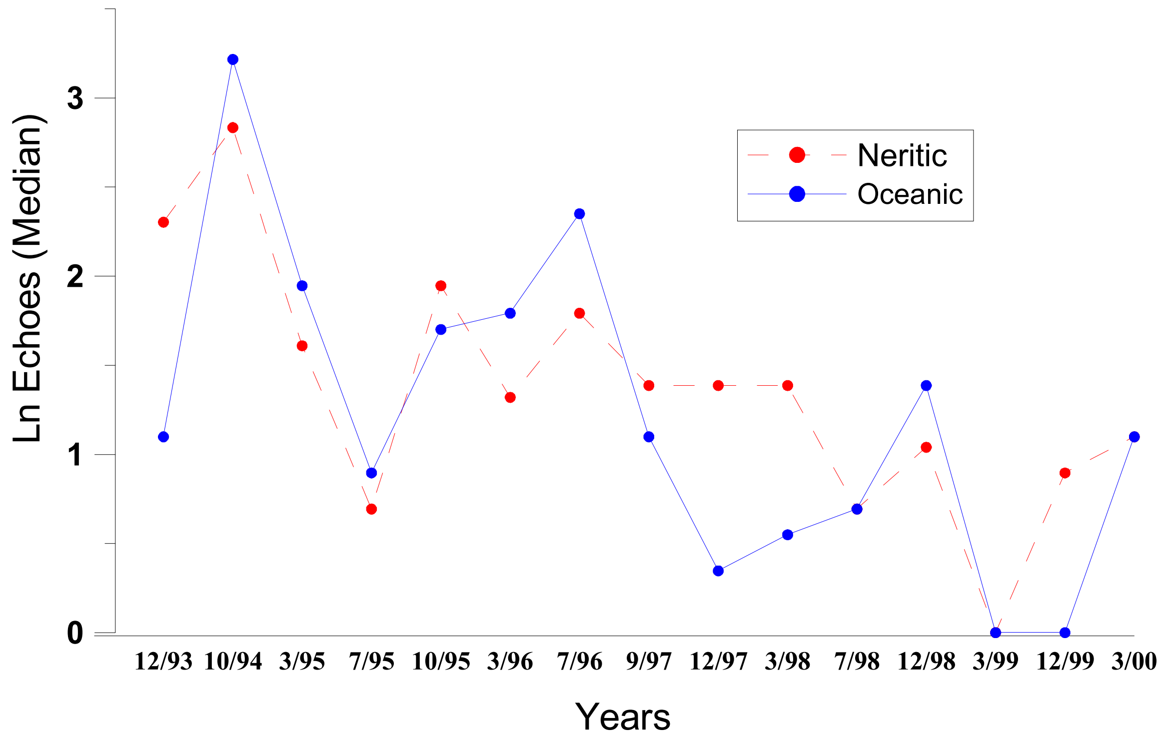

Figure 6. Median number of echoes in the nertic and the oceanic zones. Northern area.

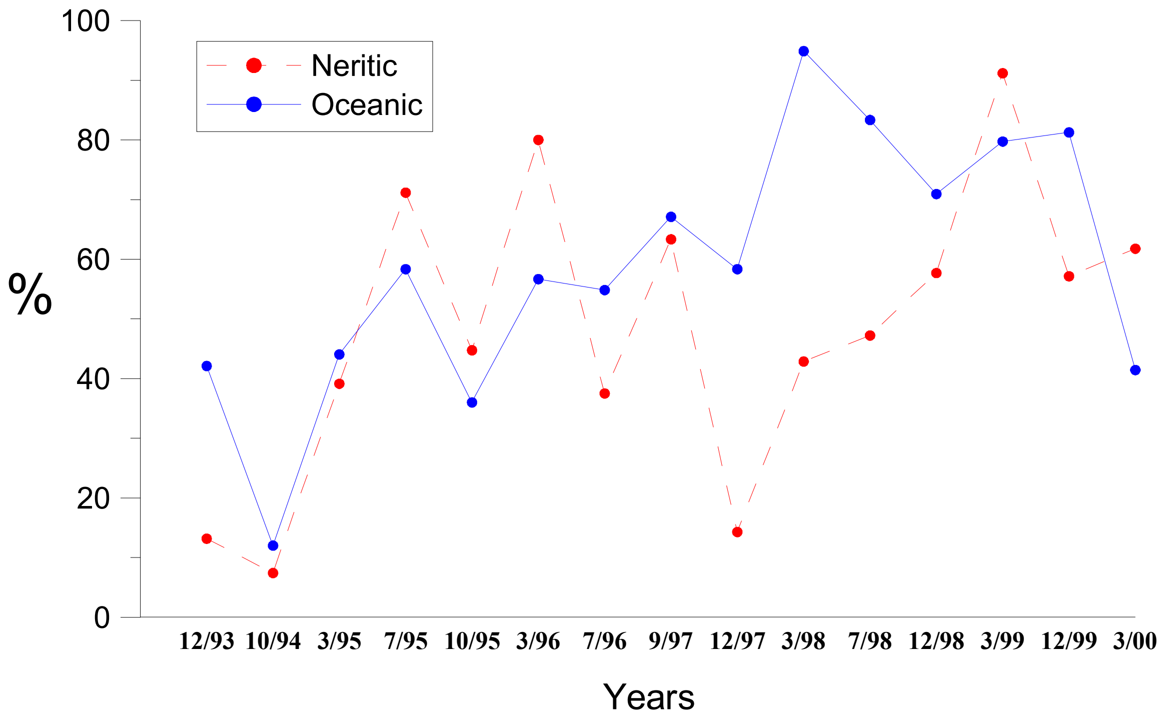

Figure 7. Percentage of negative echograms in the nertic and the oceanic zones. Northern area.

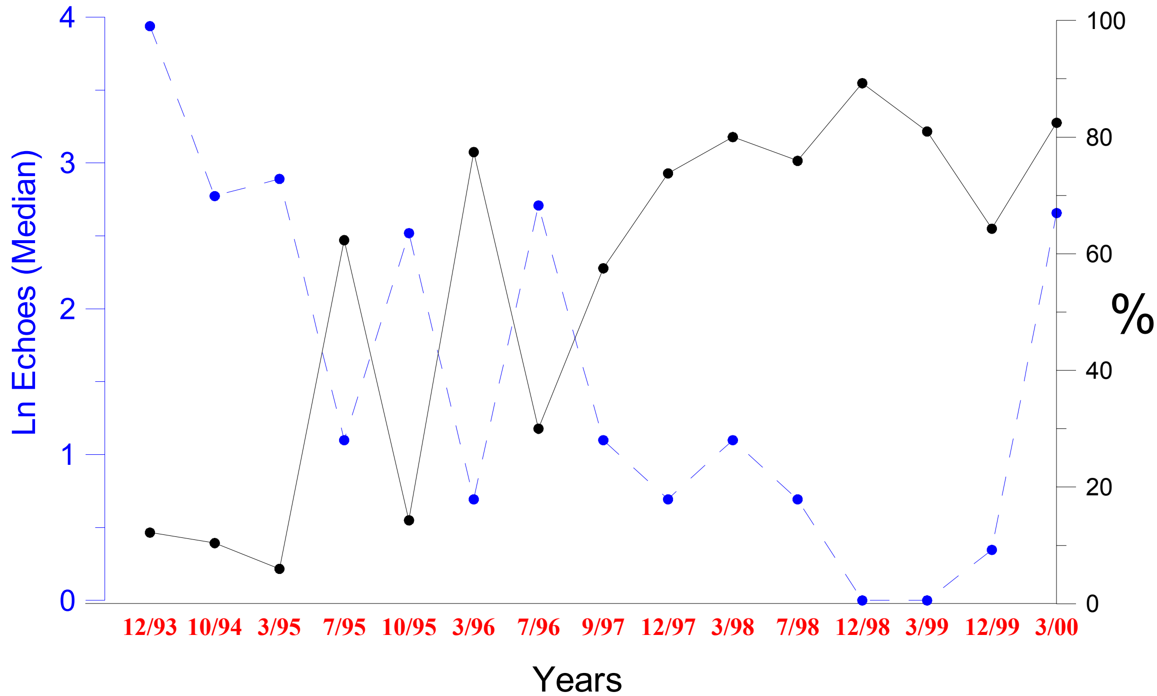

Figure 8. Median number of echoes (dotted line, left axis) and percentage of negative echograms (continuos line, right axis) in the 5-25 m depth stratum. Southern area.

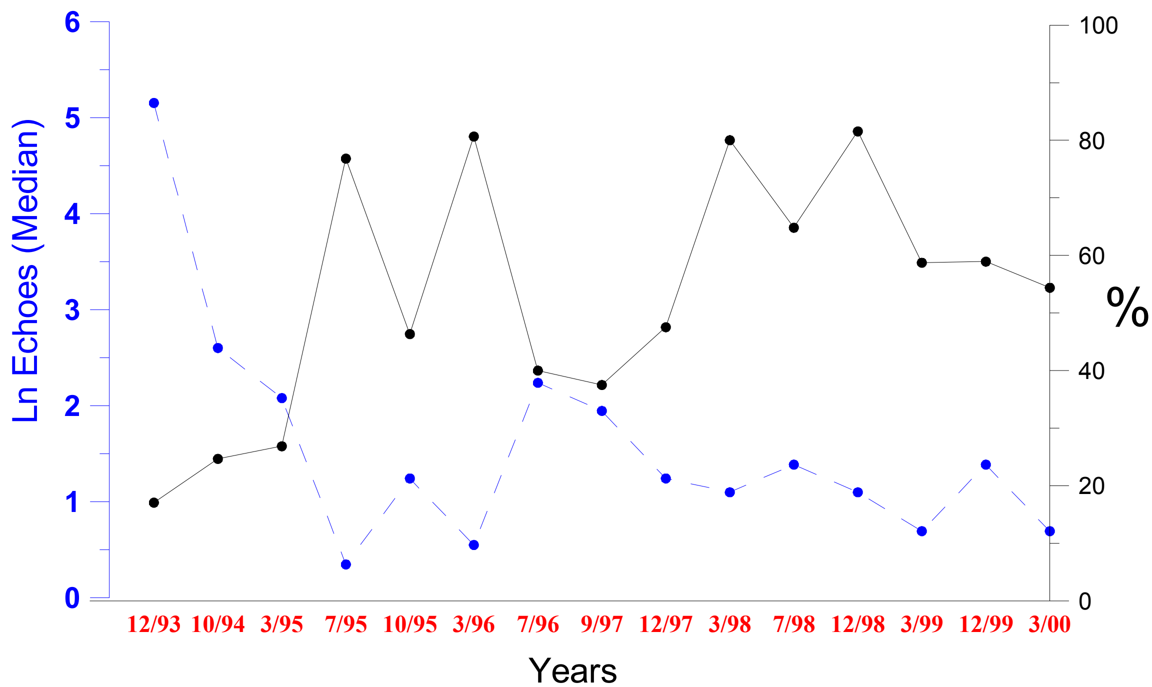

Figure 9. Median number of echoes (dotted line, left axis) and percentage of negative echograms (continuos line, right axis) in the 25-50 m depth stratum. Southern area.

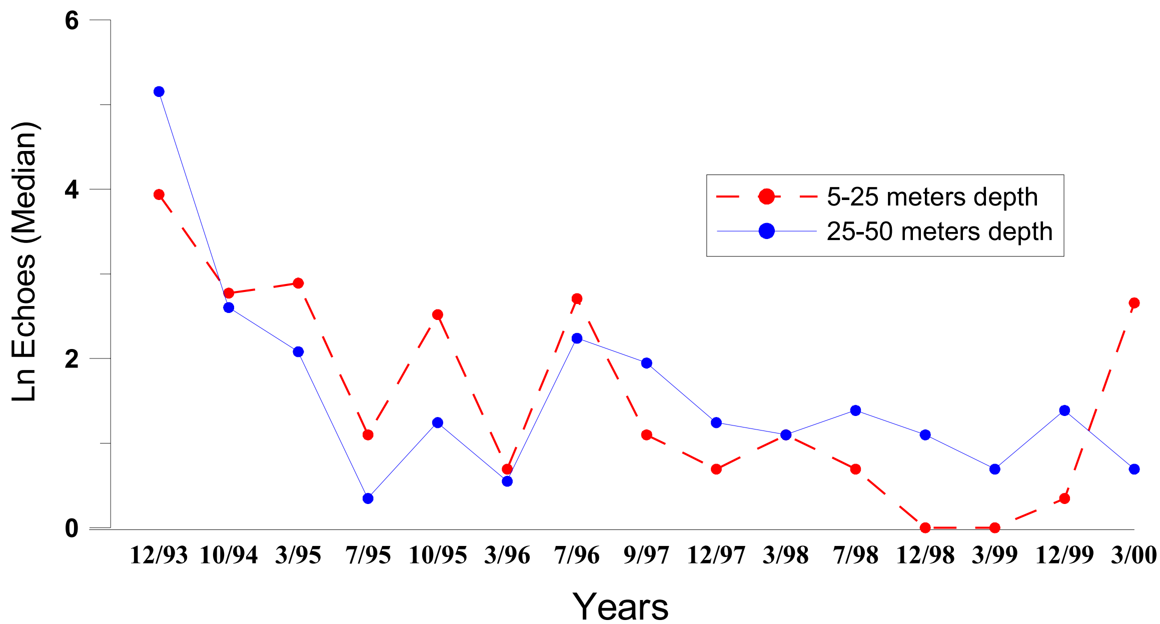

Figure 10. Median number of echoes in both strata. Southern area.

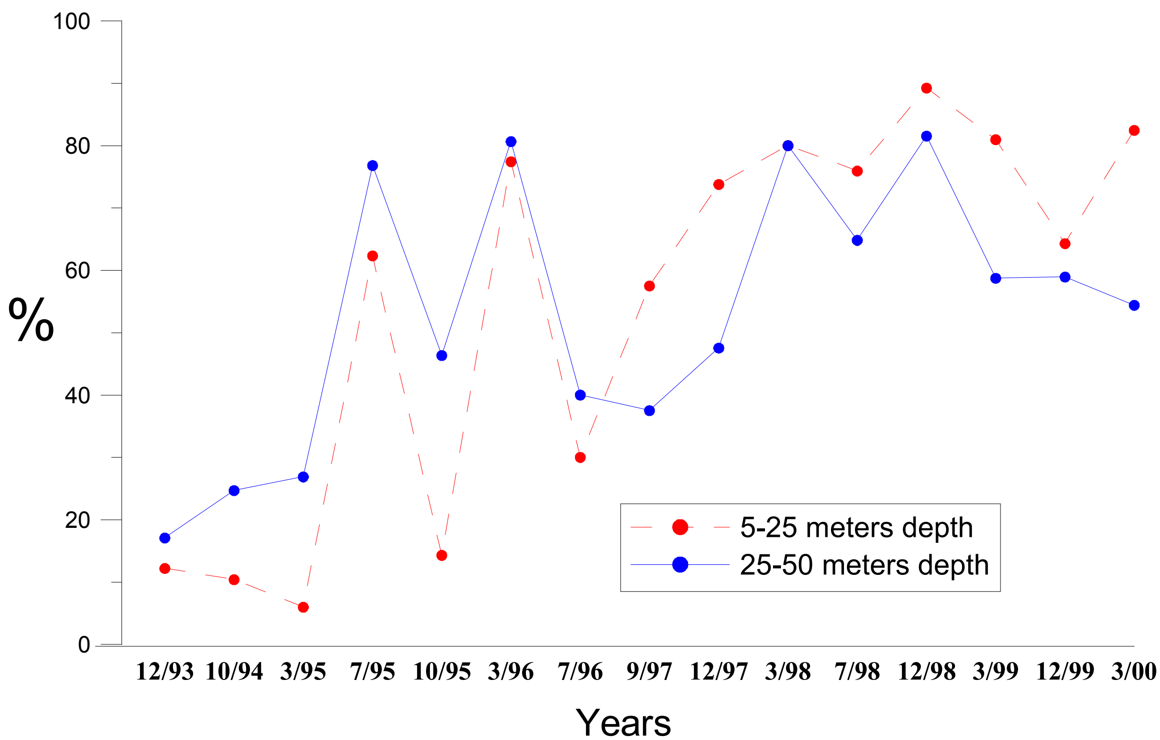

Figure. 11. Percentage of negative echograms in both strata. Southern area.

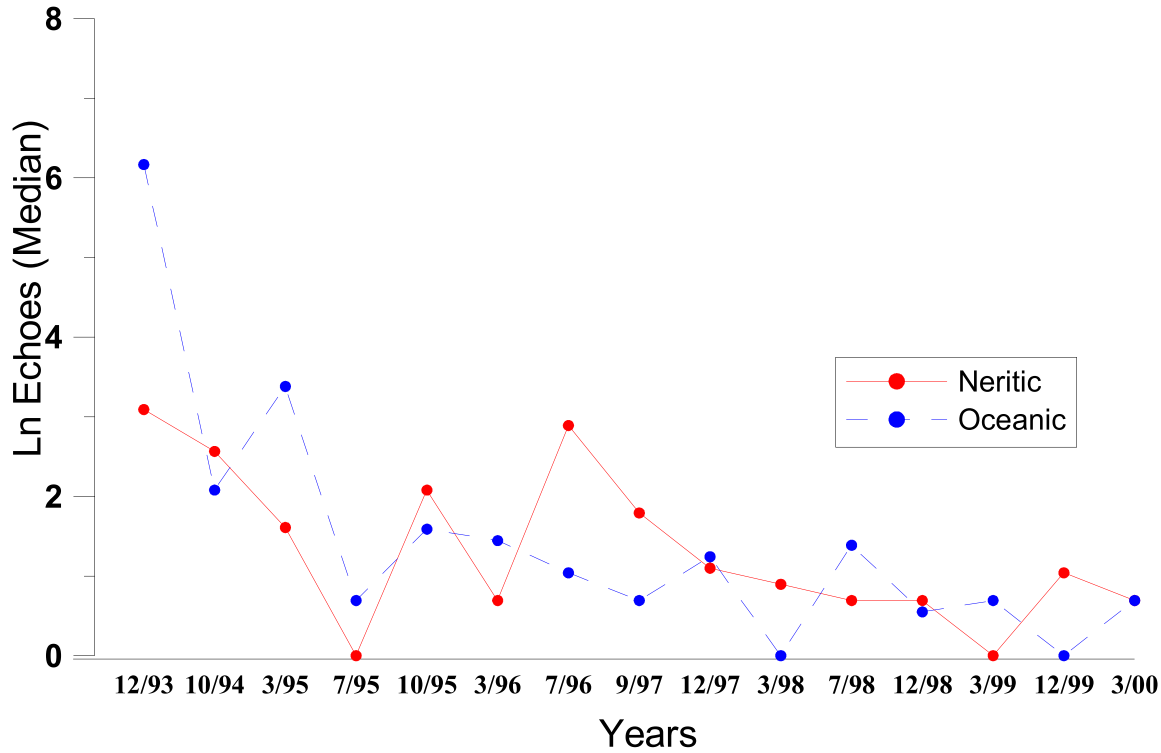

Figure 12. Median number of echoes in the nertic and the oceanic zones. Southern area.

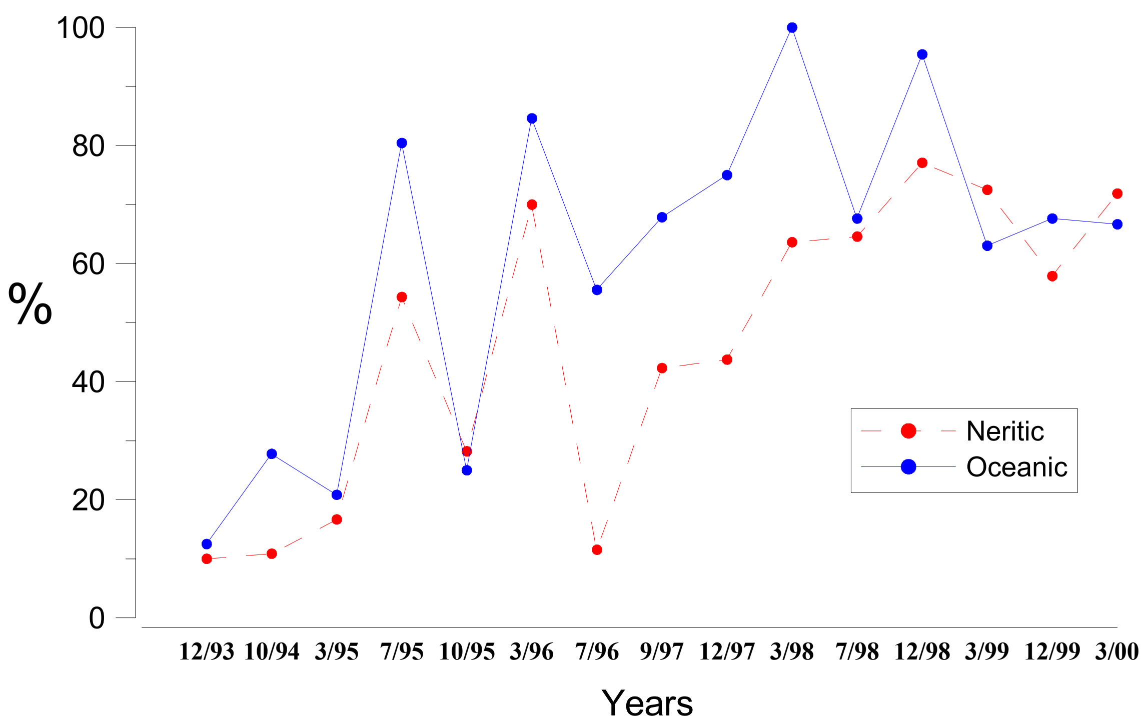

Figure 13. Percentage of negative echograms in the nertic and the oceanic zones. Southern area.

Age Composition and Growth Rates from Coast-Wide Sampling Programs

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The California Current ecosystem has shown a large-scale change in physical structure resulting in warmer than average ocean temperatures since 1977. This shift has coincided with the return of the Pacific sardine to its historical northern range off British Columbia (B.C.). In southern California, growth of the sardine population allowed resumption of a limited fishery for the species in 1984. By 1993, Pacific sardine had appeared in significant numbers off B.C., while in 1994, sardine eggs were collected in abundance off Oregon (Bentley et. al. 1996). By the mid-1990's the presence of sardine off Oregon (OR) and Washington (WA) prompted those States to propose pilot fisheries. In California (CA), sardine had become one of the largest volume fisheries in the state.

Under the auspices of the Pacific States Marine Fisheries Commission, the California Department of Fish & Game (CDFG), Oregon Dept. of Fish & Wildlife (ODFW), and Washington Dept. of Fish & Wildlife (WDFW) coordinated a plan to collect biological data on sardine off of their respective coasts. The Canadian Department of Fisheries and Oceans (DFO) and Mexico's Instituto Nacional de la Pesca (INP) supplied additional samples. In California, sardine were obtained by sampling from the directed sardine fishery. Sardine were sampled by WDFW and ODFW from mid-water trawl or purse seine vessels. Due to the relative rarity of sardine as bycatch, most samples were obtained by directed fishing. In addition, the National Marine Fisheries Service, in conjunction with State and foreign government agencies, conducted coordinated sampling of sardine from Mexico to British Columbia in July 1998. Ages were determined from otoliths using the methods described by Yaremko (1996). Whole body condition factor (K) was calculated as $K = (W/L^3)*100$, where W = weight in grams, and L = length in centimeters. Age composition and mean size-at-age were compared to data from the historical fishery when biomass was in a state of steady decline (Phillips 1948).

There was an apparent latitudinal cline in sardine age composition for recent years. California sardine were generally younger than those taken to the north, with a mode of two years and range of zero to six. Southern California (San Pedro) sardine were even younger, dominated by one year old fish. To the north (OR, WA, B.C.), fish ranged in age from one to eight years, with age zero fish being virtually absent. Washington and B.C. sardine had an age mode of three years, with relatively more four, five, and six year old fish in the samples. Latitudinal differences were also apparent in the historical fishery, but sardine were generally older to the south and the north. The historical fishery off southern California was dominated by 3 year old fish, with a range of two to nine years. Sardine off the Pacific northwest had a mode of five years, and ranged two to twelve years of age. The absolute differences in age composition between the present day (younger) and historical (older) fisheries may be explained in part by the expected shift in relative age distributions in growing and declining populations. The current population is in a state of rapid growth, with more younger fish recruiting to the population, whereas the population of the 1940s was undergoing a series of recruitment failures, resulting in a shift in relative abundance of older fish.

Size composition data suggest a gradient of increasing length-at-age from the south to north. For example, two, three, and four year-old fish are an average of 15 mm longer off of B.C. compared to southern California. The same trend was apparent in the historical fishery. Latitudinal differences in sardine size-at-age have been attributed to size-dependent migration rates, with longer fish swimming faster and traveling greater distances in their annual migrations. There was also an apparent cline of increasing condition factor (K) from south to north, with Mexico sardine having the lowest mean K value (1.27), and sardine off OR, WA, and B.C. ranging from K=1.4 to 1.52.

Literature Cited

Bentley, P. J., R. L. Emmett, N. C. H. Lo and G. Moser. 1996. Egg production of Pacific sardine (*Sardinops sagax*) off Oregon in 1994. Calif. Coop. Oceanic Fish. Invest. Rep. 37:193-200.

Phillips, J. B. 1948. Growth of the sardine, Sardinops caerulea, 1941-42 through 1946-47. Calif. Dep. Fish Game Fish Bulletin No. 71.

Yaremko, M. Age determination in Pacific sardine, Sardinops sagax. NOAA-TM-NMFS-SWFSC-223. 34 p. (1996).

Effects of Basin-Wide Ocean Climate Change on Sardine Productivity

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The Pacific sardine (*Sardinops sagax caerulea*) is one of several small coastal pelagic, schooling, planktivorous species that provide important trophic links within the ecosystem of the California Current. Over the course of the past century, its range of distribution has extended from the Gulf of California northward into the waters off southeastern Alaska. The regional ocean dynamics regulating sardine habitat have been subject to relatively abrupt reorganization in the basin-wide ocean-atmosphere circulation three times during the 20th century (1925-26; 1943-44; 1976-77). These interdecadal changes appear to have occurred as shifts between two predominant physical regime states, each associated with a coherent pattern of basin-wide sea-surface temperature distribution similar (but not identical) to those distinguishing the interannual ENSO mode that oscillates between warm (El Niño) and cool (La Niña) phases.

The goal of this presentation is to explore the mechanisms by which overall productivity of the sardine population is mediated by the large-scale climate variability over the North Pacific. I approach this problem from the perspective of a variable habitat model adapted from MacCall's (1990) "basin model" that is based on density-dependent habitat selection. I use a SQFP (Second Quadrant Fixed Point) model designed to fit the data of the sardine stock harvested off California during the period 1932-65. The model allows us to reconstruct the natural variability of the stock separate from the effects of fishing. The model simulation thus provides an estimate of density-independent variability in biomass production that would have occurred under the varying quality of the natural extrinsic habitat had there been no harvesting.

The simulated density-independent growth rates of the population indicate a significant association with the effective size of the area of favorable habitat within the region of the California Current System. The collapse of the population in the first half of the 20th century was due to progressively diminishing rates of population growth associated with the contraction in size of both the spawning and feeding habitats off southern and central California and their extensions into waters off British Columbia. The overall size of the area of favorable habitat appears to have been linked to the large-scale climate regime through its influence on the distribution of near-surface temperature that was, in turn, an expression of the underlying ocean dynamics. This suggests that mesoscale dynamics alone are not as important as the overall size of the regional habitat in which the more localized mesoscale processes are embedded.

Literature Cited

MacCall, A.D., 1990. *Dynamic Geography of Marine Fish Populations*. Univ. Washington Press, Seattle, WA, 153 pages.

Spawning Habitat of Pacific Sardine Inferred from CUFES Surveys 1996-2000

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Population size of the Pacific sardine (*Sardinops sagax*) may depend on the habitat available for spawning. Hence, it is desirable to know the characteristics of the spawning habitat of the Pacific sardine. Since 1996, the Southwest Fisheries Science Center, NOAA, has used the Continuous, Underway Fish Egg Sampler (CUFES) to assess the distribution and abundance of eggs of the Pacific sardine at 3-m depth off Southern California. Concurrent measurements are made of temperature and salinity, and sea surface temperature (SST) is measured from satellites. These data are used with net collections to estimate the spawning biomass by means of the Daily Egg Production Method. They may also be used, as done here, to assess spawning habitat.

In general, eggs of the Pacific sardine were found in water of a type intermediate between the California Current (salinity □ 33.2 ‰) and coastal upwelling (salinity □ 33.3 – 33.6 ‰). This water was also characterized by dynamic height anomalies characteristic of the eastern edge of the California Current. The size of the spawning area as inferred from CUFES samples positive for Pacific sardine eggs appears to have increased from 1996 to 2000, except in 1998, the year of El Niño. Then, sardine eggs were found within 60 nm of shore, but still in waters of similar characteristics as in other years.

Eggs of the northern anchovy (*Engraulis mordax*) showed a complementary distribution to those of the Pacific sardine in all five years, with most eggs found in the Southern California Bight. Water in which anchovy eggs were found was indicative of upwelling (salinity □ 33.3 – 33.6 ‰), either recently (cool, 11-13 ºC) or earlier (warmed, 13-16 ºC). Northern anchovy eggs were also collected occasionally in water of similar characteristics to the north, e.g. in Monterey Bay. During El Niño, in 1998, high salinity water was absent and anchovy eggs appeared in lower salinity water.

Hence, during 1996-2000, sardine and anchovy egg distributions, and presumptive spawning areas, were spatially and hydrographically separate. One may ask, therefore, in regard to the prior decades when anchovy was dominant, whether the change in dominance between sardine and anchovy was associated with a change in the environment, a change in the spawning habitats of the species, or both? To begin to address this question, one might characterize the spawning habitats of anchovy and sardine when anchovy was dominant. Do they differ from those at present?

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Cores from Effingham Inlet (West Coast Vancouver Island)

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The pioneer work of Soutar and Isaacs (1970, 1974) was a landmark in the way we look at natural variability of fish populations, in particular, the decadal-centennial scale. Baumgartner *et al* (1992), by increasing the sampling effort in the same coring site (the Santa Barbara Basin), were able to recalibrate the scale deposition rate to sardine and anchovy paleo-biomass for 1700 years. Their reconstruction showed major recoveries and collapses of the sardine stock over this period, but still was left to answer how sardine has expanded to its northern range during the recovery periods.

Effingham Inlet is a small fjord on the West Coast of Vancouver Island close to the very productive waters of La Perouse bank. The inlet has a silled opening to the ocean (through the Imperial Eagle Channel, Barkley Sound) and reduced freshwater outflow, a combination that restricts the entrance of deeper marine waters into the inlet. This results in a sluggish circulation of the deeper waters within the fjord that, coupled with respiratory consumption and decomposition of organic matter in the water and sediments, leads to anoxic bottom waters. In 1995 we recovered several Kasten and Box cores from the deepest basin (200 m.) of the Inlet. Xrays and radiometric analysis of the sediments (^{210}Pb and ^{14}C) show a record of 800 years of annual varves punctuated by massive beds (probably resulting from earthquake-triggered gravity flows) in 1946, 1700 and about 1420 AD. Fossilized fish scales of several pelagics are abundant, particularly for Northern anchovy, Pacific herring and P. hake. In contrast, P. sardine scales are very scarce, which makes it difficult to resolve trends in abundance. Major changes in the population seem to be recorded in the sediments however. For example, the disappearance of sardine scales from the sediment record in this century matches the collapse of the stock in the mid 1940's. If a more robust time series for sardine were reconstructed it must be based on multiple Kasten cores (probably more than five) and ideally explorations of other sites (like Nootka Sound).