# *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***

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# Proceedings of the Sardine Symposium 2000

**Stephen H. Phillips, Editor**

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| **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.

## *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 ($\square_r$) 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., $\square_r=1.0$). Based on this method, the CalCOFI index was down weighted to $\square_r=0.7$ and the spotter index was down weighted to $\square_r=0.15$.

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:

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

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).

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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:

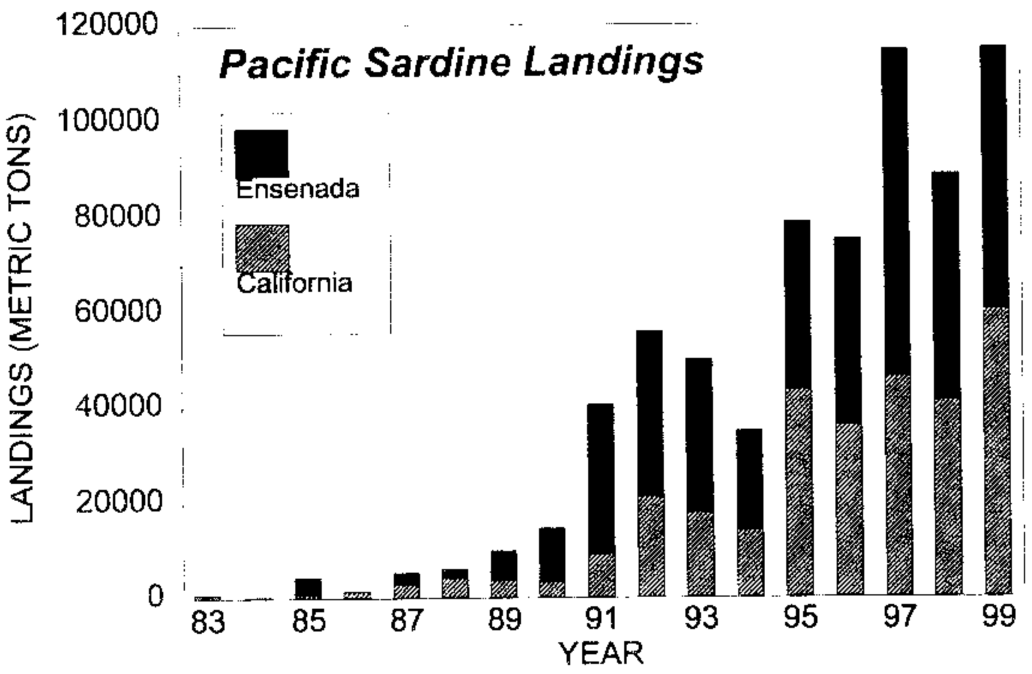


Figure 1. Annual Pacific sardine landings in California and Ensenada.

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:

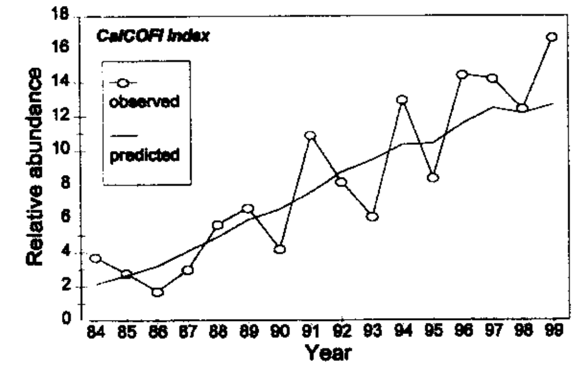


Figure 3. Relative abundance (proportion positive stations) of Pacific sardine eggs and larvae off southern California based on CalCOFI bongo tows, 1984-1999. Model was fit with an exponent of 0.3547. Survey was weighted to lambda = 0.70 based on relative proportion of total area sampled.

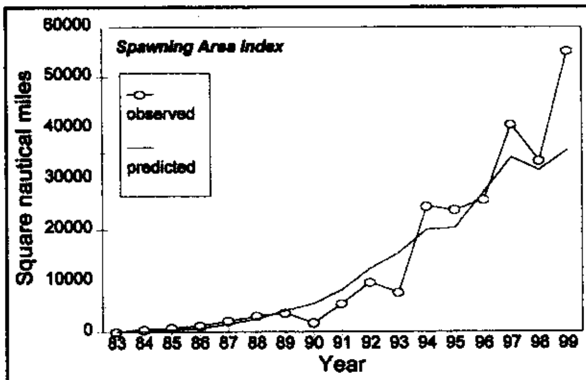


Figure 4. Relative abundance Pacific sardine spawners off California based estimates of spawning area (Nm²), 1983-1999. Model was fit with an exponent of 1.0. Survey was weighted to lambda = 1.0.

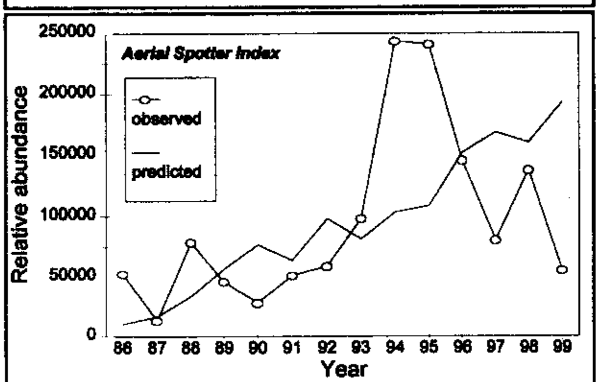


Figure 5. Relative abundance of Pacific sardine off California based on aerial spotter pilot sightings, 1986-1999. Model was fit with an exponent of 0.4586. Survey was weighted to lambda = 0.15 based on relative proportion of total area sampled.

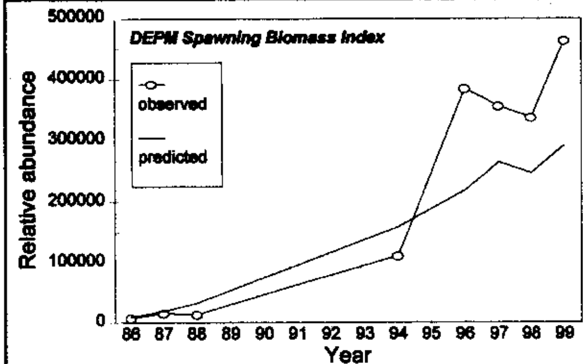


Figure 6. Relative abundance of Pacific sardine spawning biomass off California based on daily egg production method estimates, 1986-1999. Model was fit with an exponent of 1.0. Survey was weighted to lambda = 1.0 based on relative proportion of total area sampled.

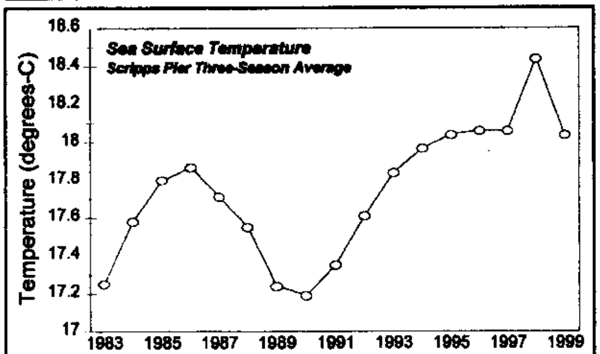


Figure 7. Sea surface temperature (SST) at Scripps Pier. Three-season running average was calculated as described in Jacobson and MacCall (1995). SST is used by CANSAR-TAM to model the spawner-recruit relationship. SST is also used to scale FRACTION in the harvest formula.

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:

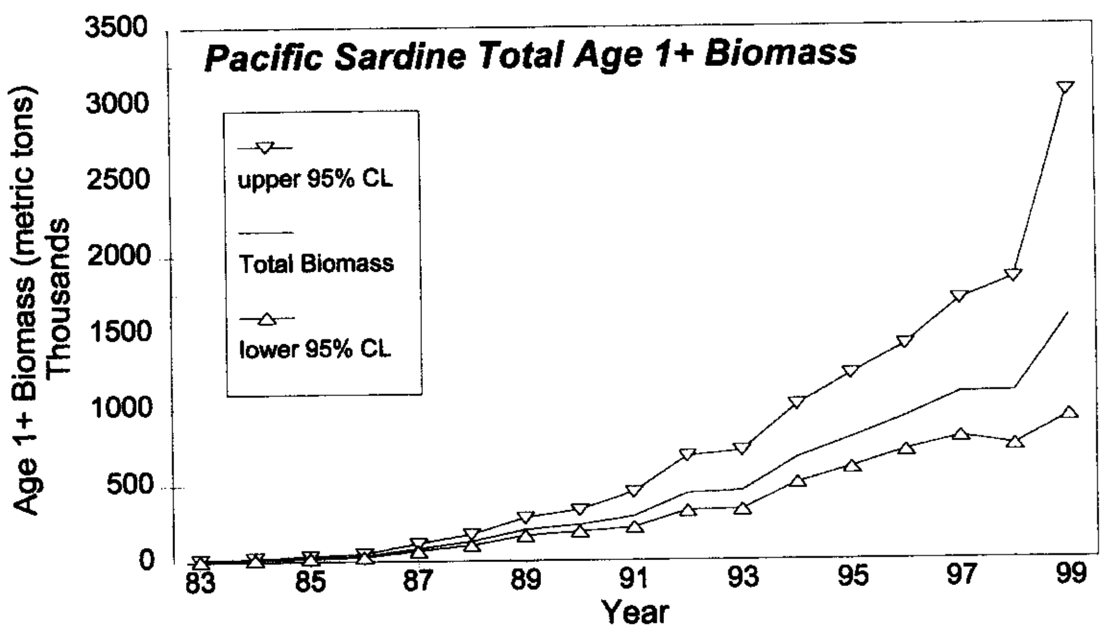


Figure 8. Pacific sardine age 1+ biomass for July 1 of each year, based on CANSAR-TAM.

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*

**Walterio García Franco, Centro Regional de Inv. Pesquera de Ensenada, Instituto Nacional de la Pesca de la SEMARNAP, Ensenada, Mexico**

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).**

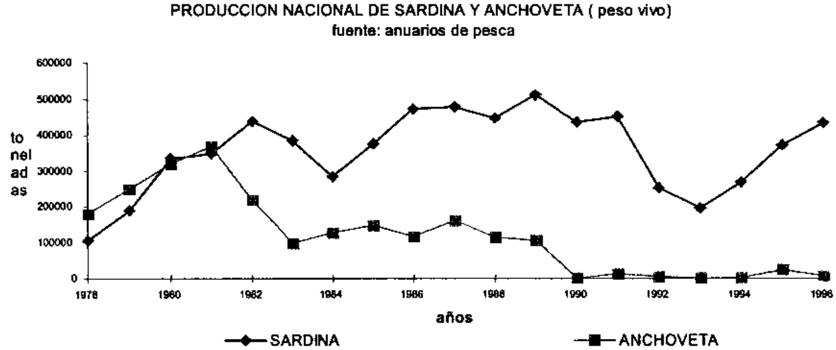


**Figure 2**

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).

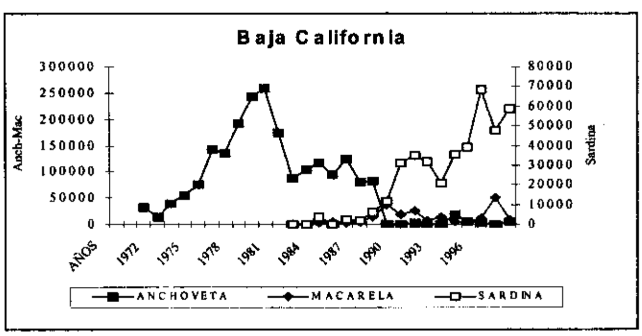


**Figure 3**

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).

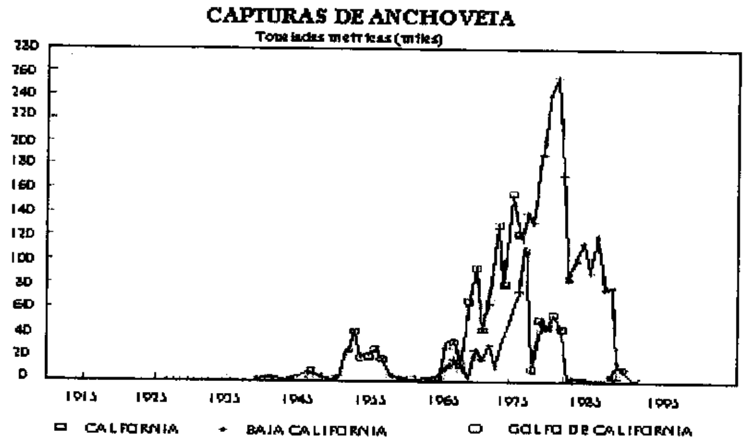


**Figure 4**

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,

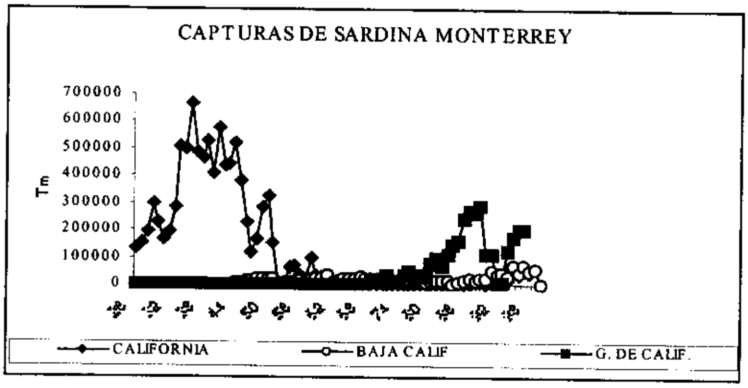


**Figure 5**

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 (<u>Sardinops</u> <u>caeruleus</u>) and the northern anchovy (exclusively <u>Engraulis</u> <u>mordax</u>). 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.

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# *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.

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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 |

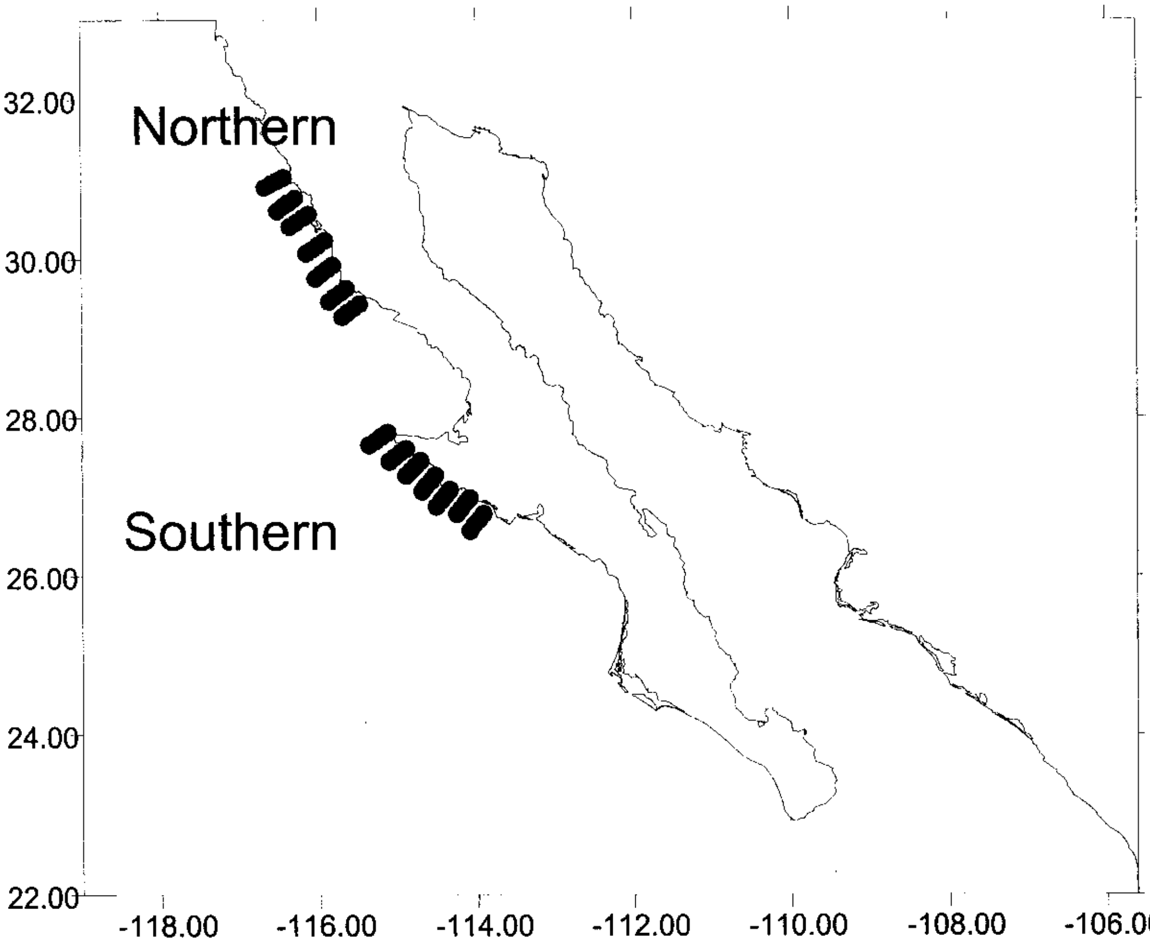


Figure 1. Map of the study area showing the transects in both areas.

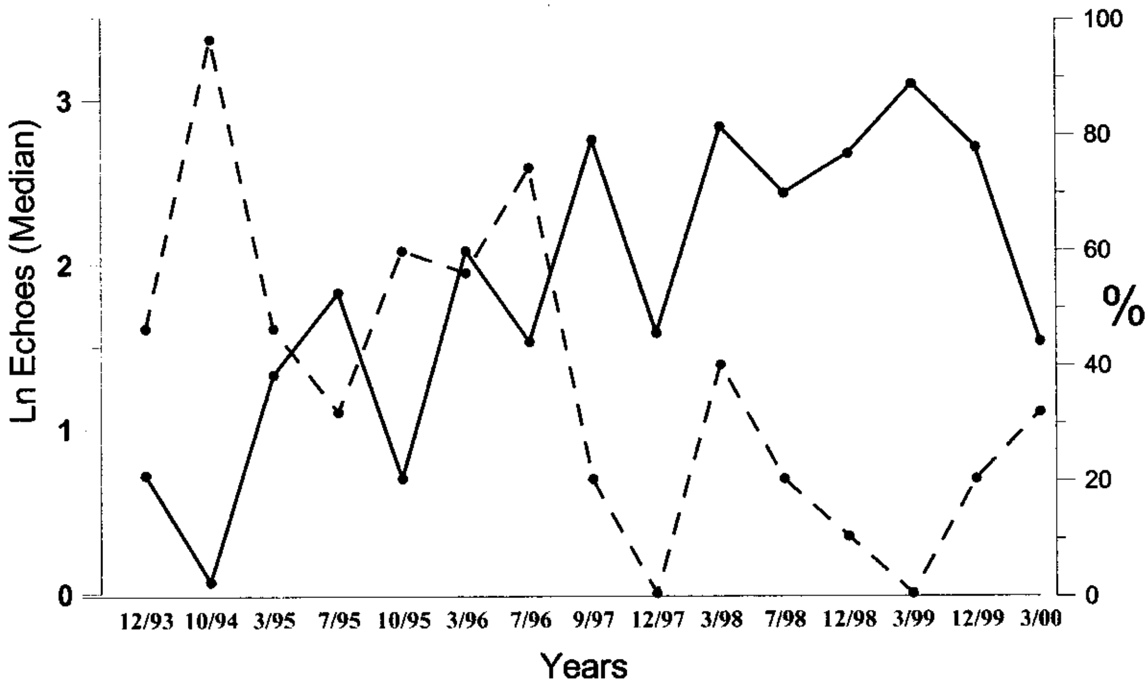


Figure 2. Median number of echoes (dotted line, left axis) and percentage of negative echograms (continuos line, right axis) in the 5-25 m depth stratum. Northern area.

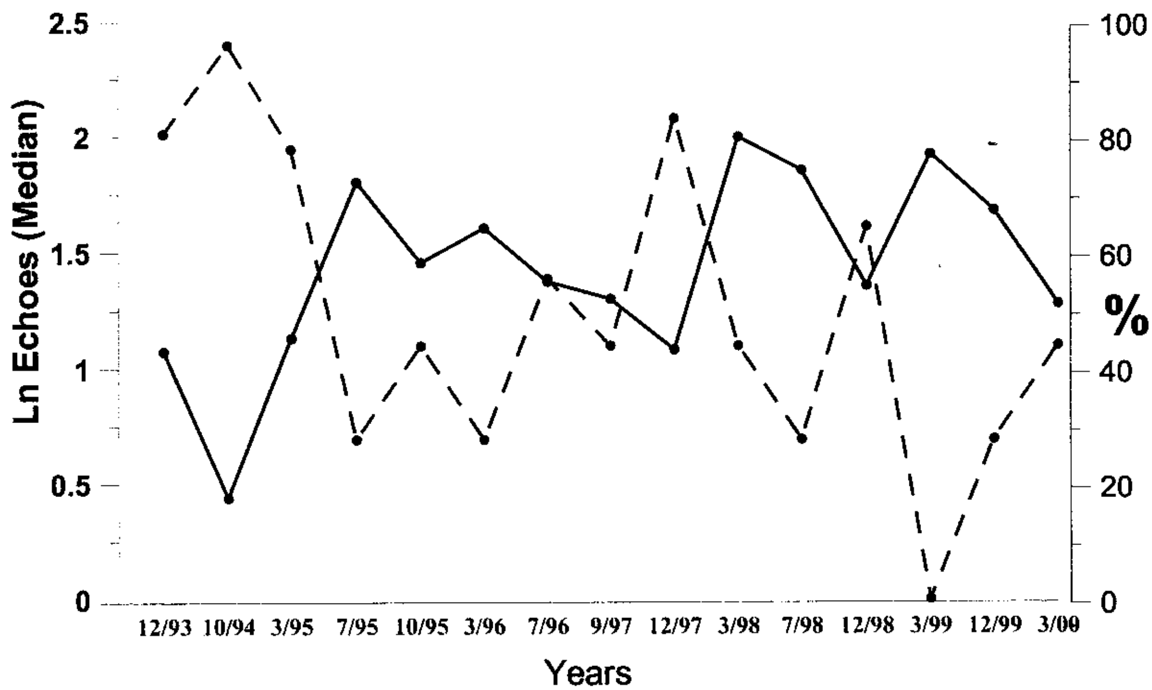


Figure 3. Median number of echoes (dotted line, left axis) and percentage of negative echograms (continuos line, right axis) in the 25-50 m depth stratum. Northern area.

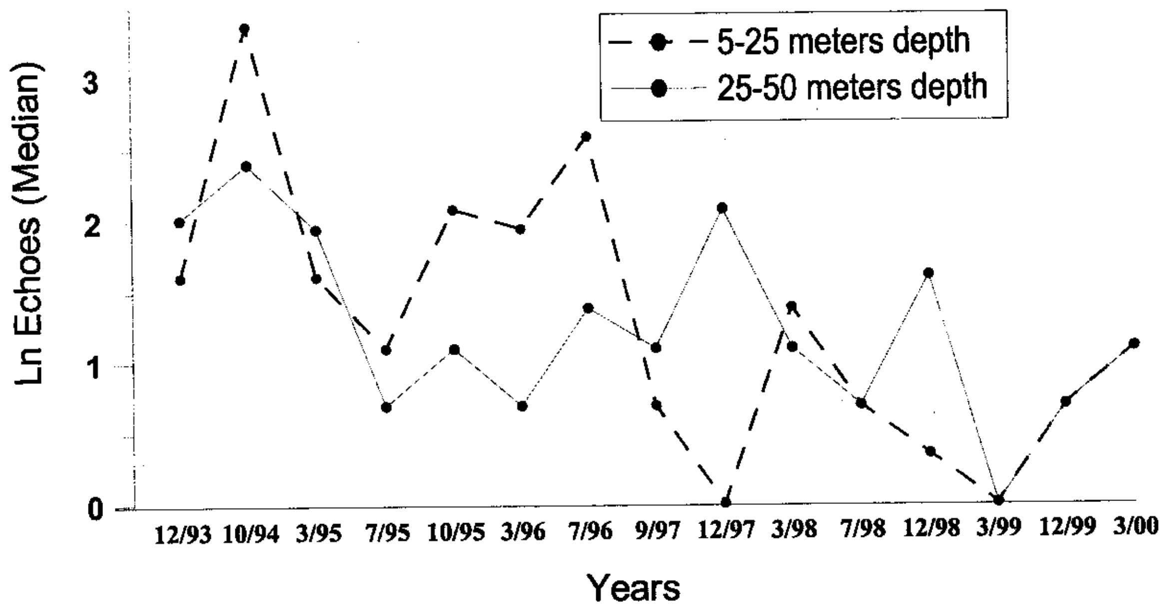


Figure 4. Median number of echoes in both strata. Northern area.

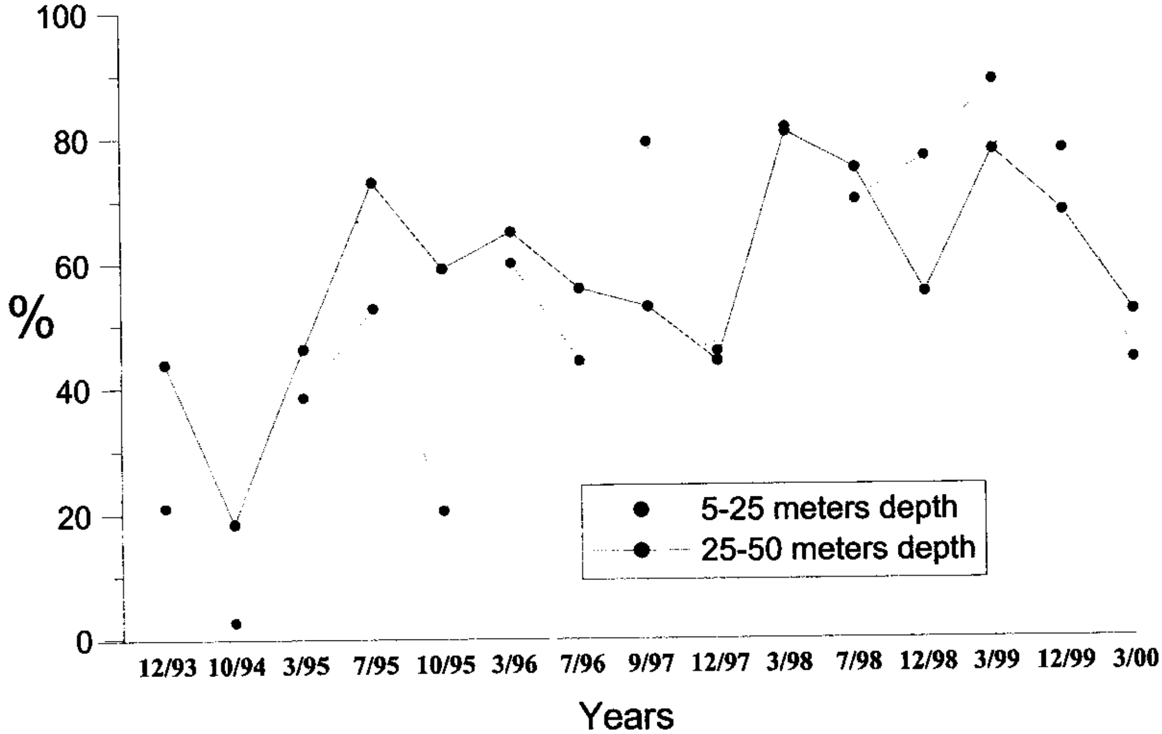


Figure. 5. Percentage of negative echograms in both strata. Northern area.

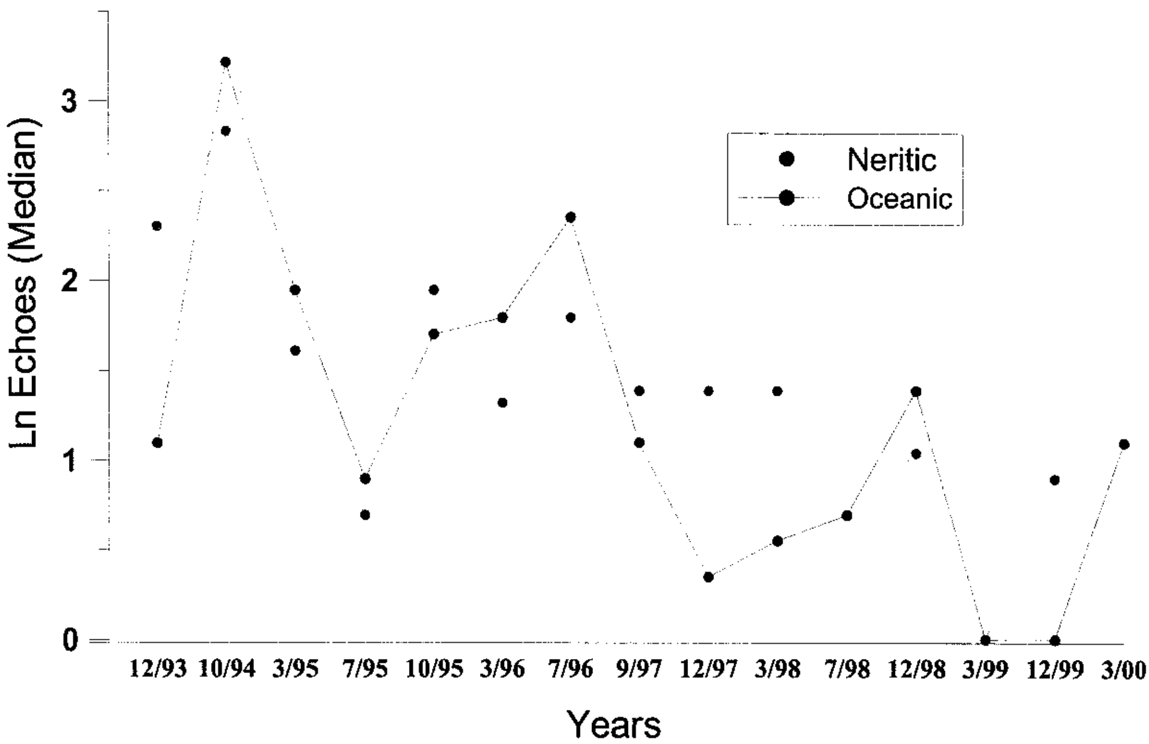


Figure 6. Median number of echoes in the nertic and the oceanic zones. Northern area.

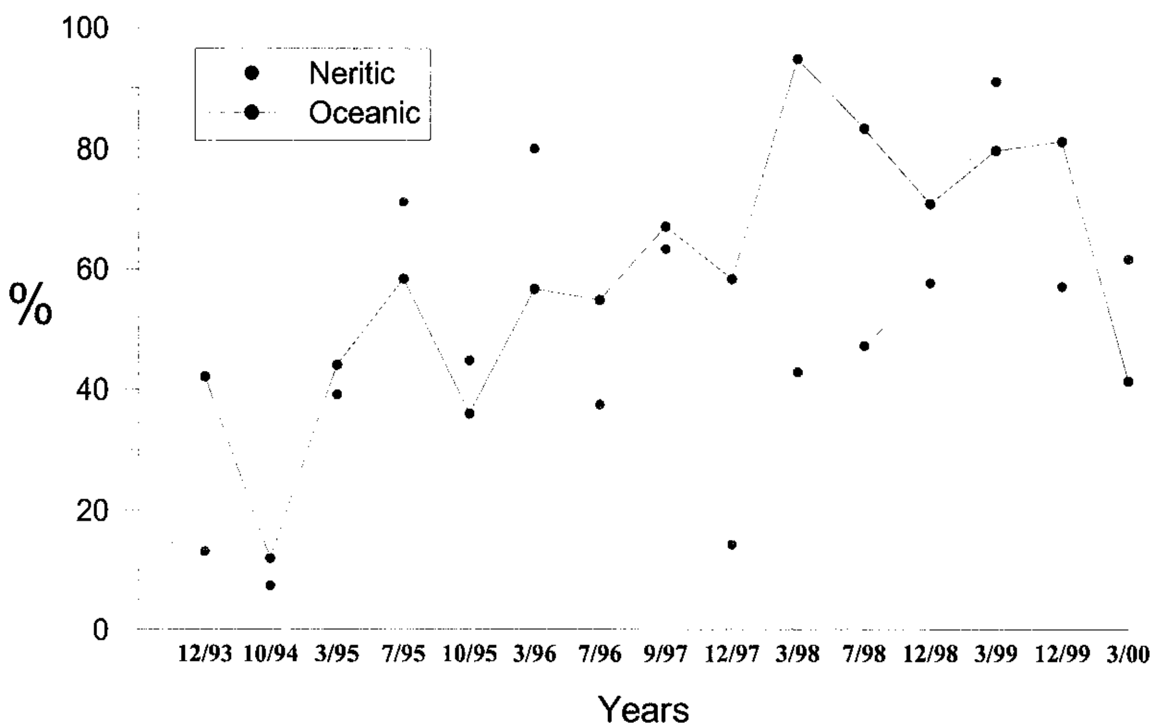


Figure 7. Percentage of negative echograms in the nertic and the oceanic zones. Northern area.

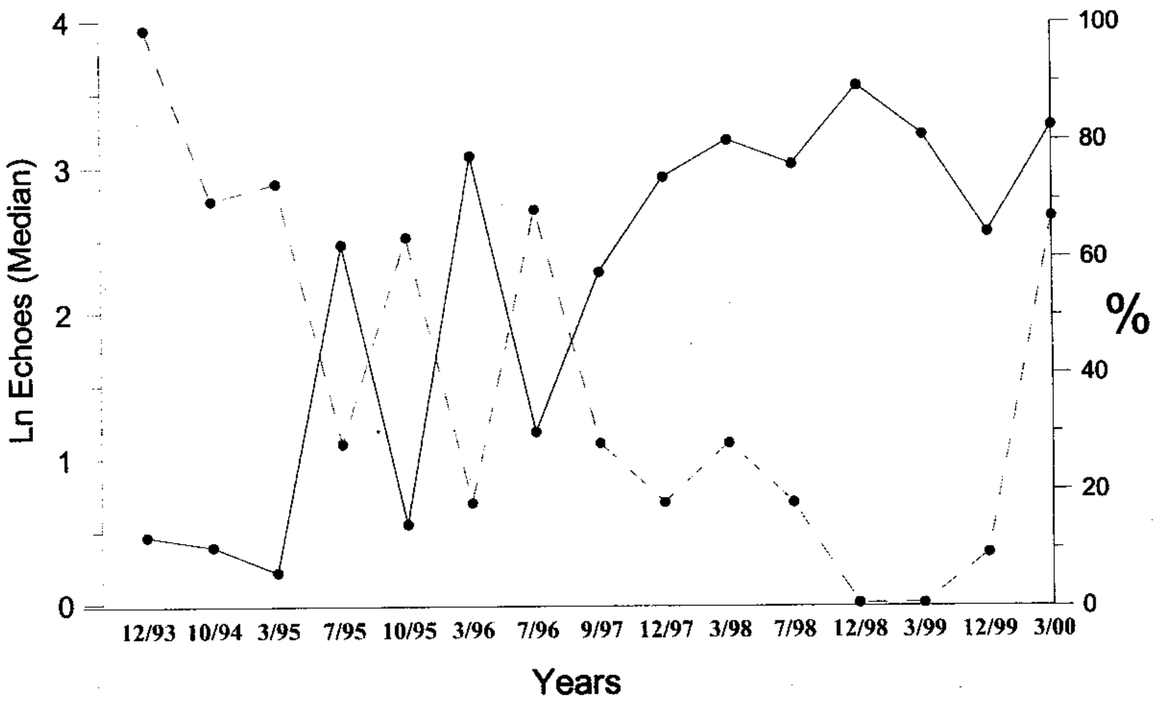


Figure 8. Median number of echoes (dotted line, left axis) and percentage of negative echograms (continuos line, right axis) in the 5-25 m depth stratum. Southern area.

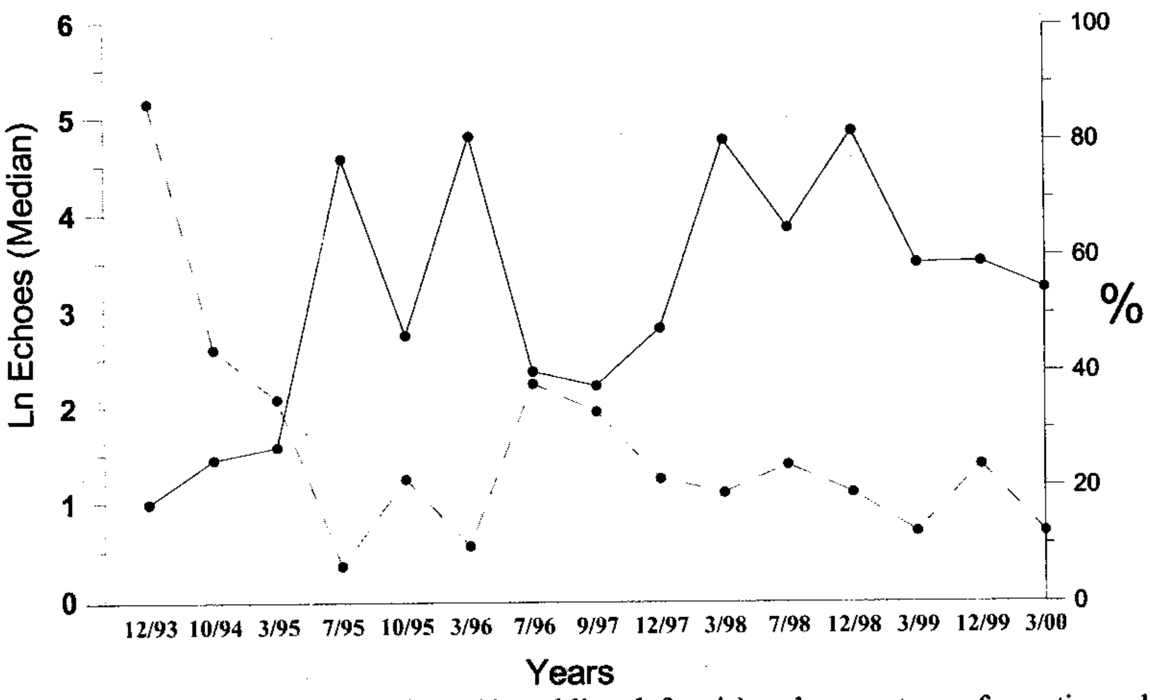


Figure 9. Median number of echoes (dotted line, left axis) and percentage of negative echograms (continuos line, right axis) in the 25-50 m depth stratum. Southern area.

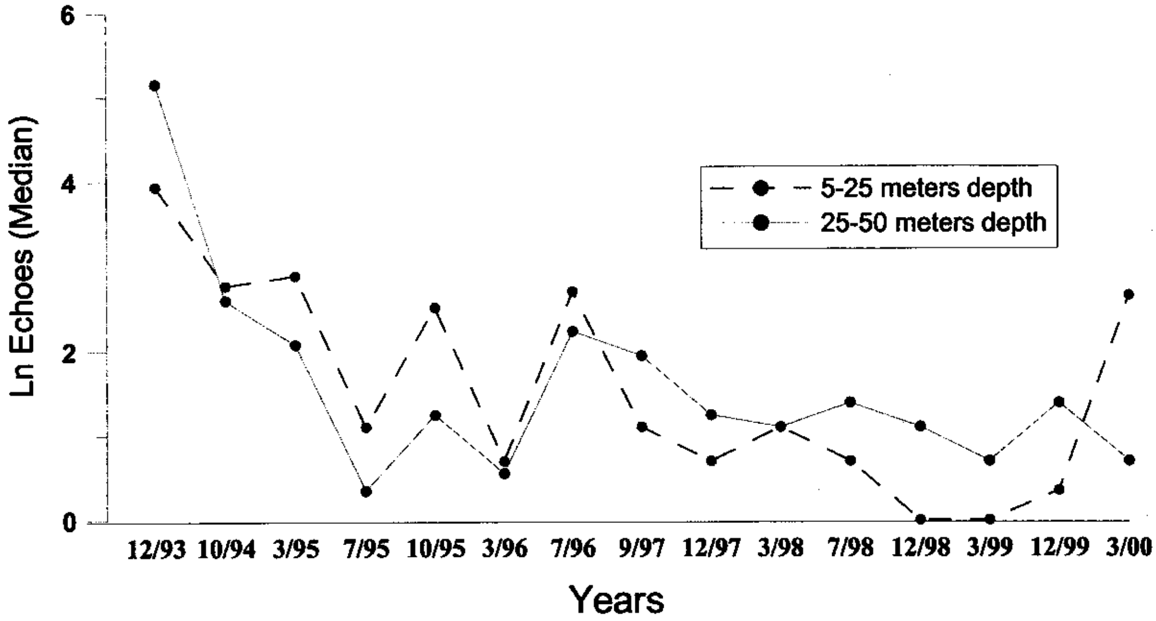


Figure 10. Median number of echoes in both strata. Southern area.

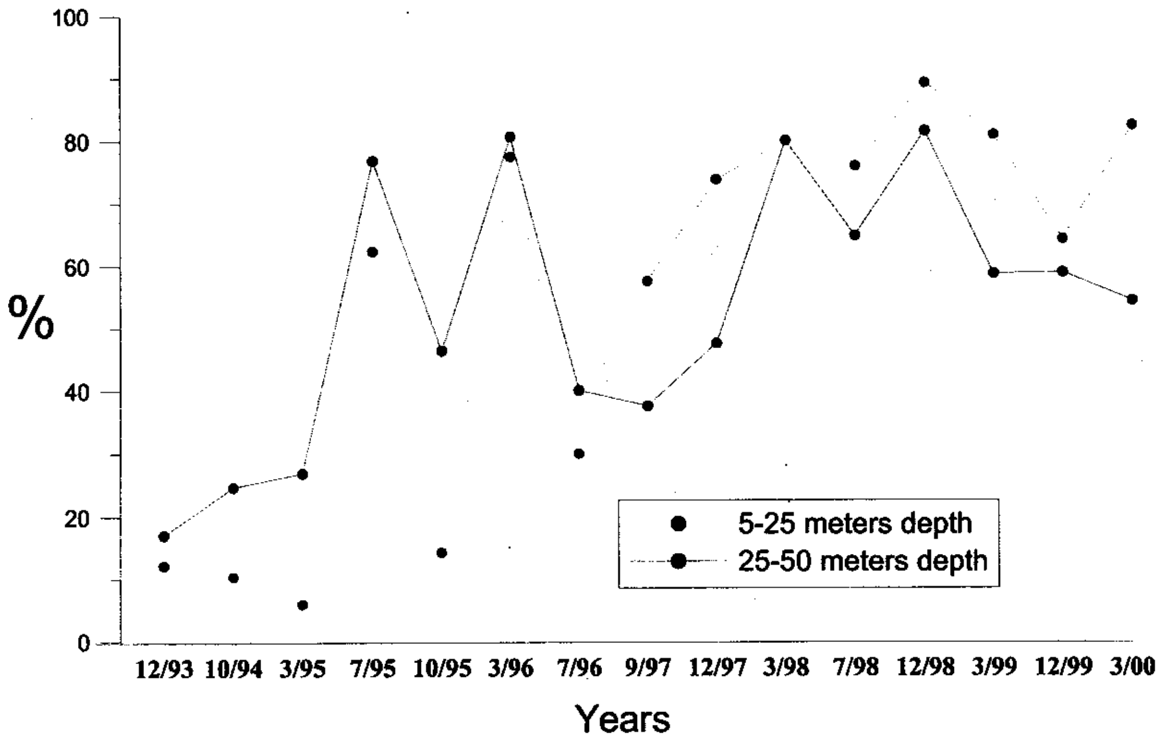


Figure. 11. Percentage of negative echograms in both strata. Southern area.

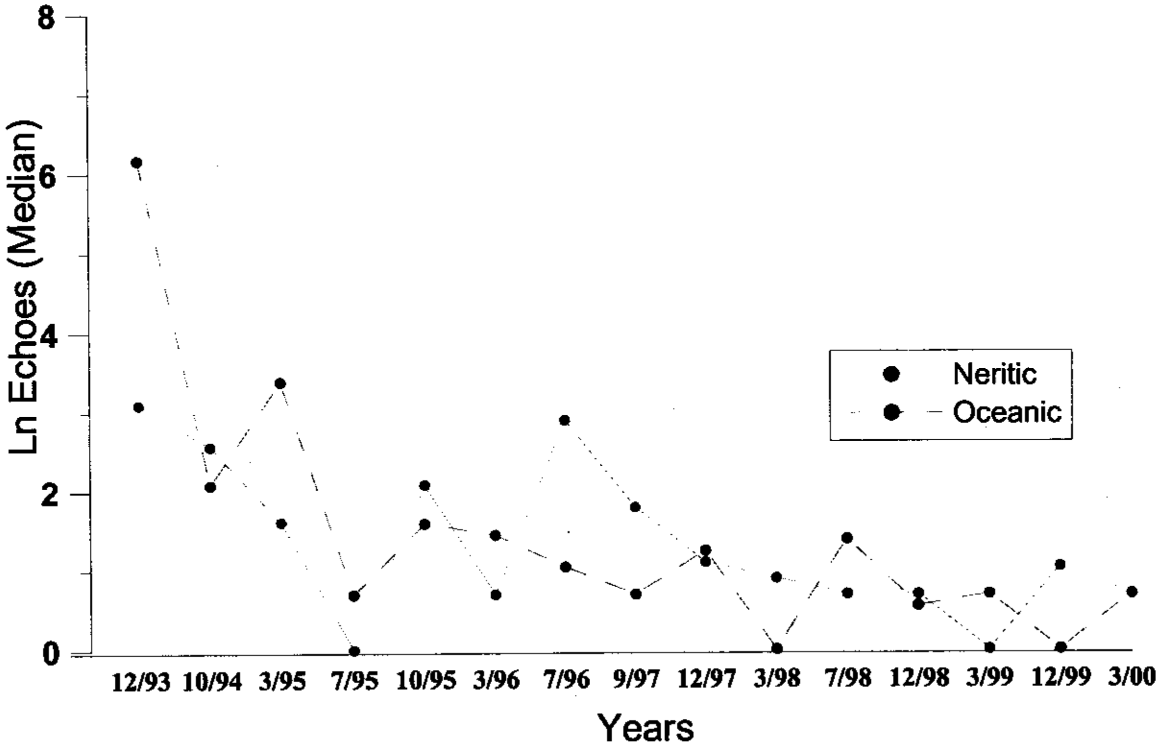


Figure 12. Median number of echoes in the nertic and the oceanic zones. Southern area.

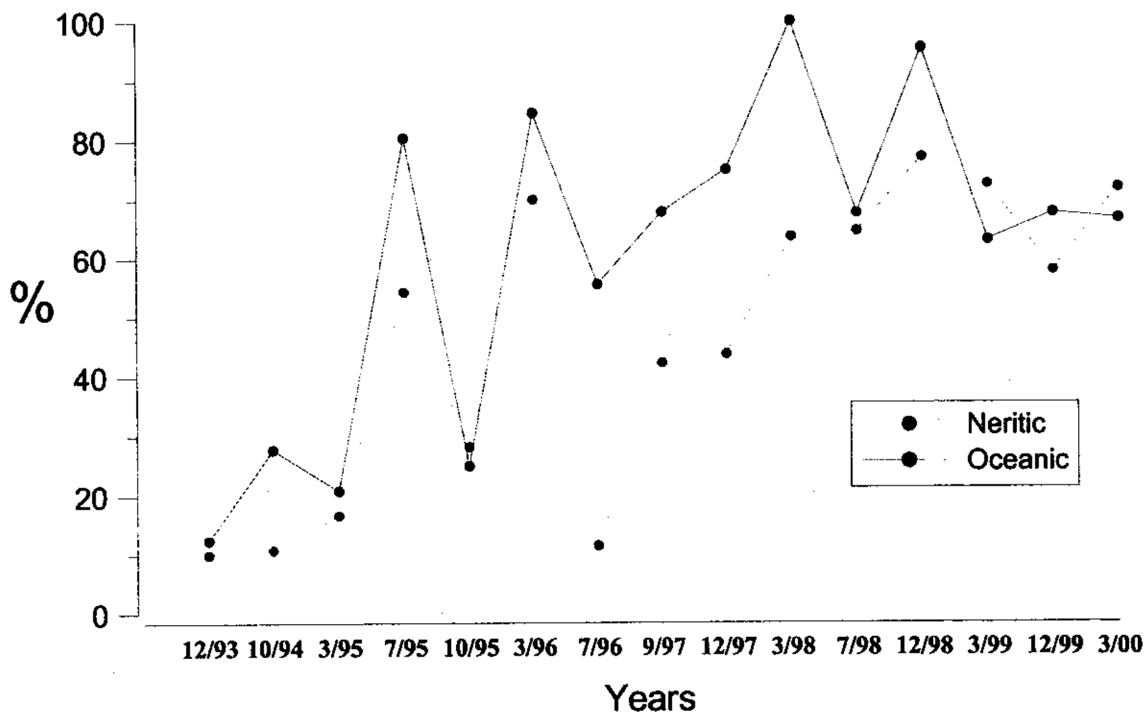


Figure 13. Percentage of negative echograms in the nertic and the oceanic zones. Southern area.

## *Age Composition and Growth Rates from Coast-Wide Sampling Programs*

**Kevin T. Hill, California Department of Fish and Game; John L. Butler, National Marine Fisheries Service, La Jolla, California; Matthew D. Levey, Moss Landing Marine Laboratories, Monterey, California**

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.

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## *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.

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## *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 °C) or earlier (warmed, 13-16 °C). 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?

Acknowledgements: The data discussed here were collected by individuals in the Southwest Fisheries Science Center, La Jolla Laboratory, NOAA. Particular thanks go to John Hunter, Ron Dotson, Dave Griffith, Amy Hays, Geoff Moser, Richard Charter, Nancy Lo, and Ron Lynn. Thanks also CaCOFI participants of the Marine Life Research Group and to Kevin Hill of the California Department of Fish and Game.

## *Cores from Effingham Inlet (West Coast Vancouver Island)*

**Diego Holmgren, School of Fisheries, University of Washington, Seattle, Washington**

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).

# *Regime Shifts, Ecosystem Change and Sardines off the West Coast of Canada*

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**(summarized from McFarlane and Beamish, 2000)**

The Pacific sardine (*Sardinops sagax*) fishery was the largest in British Columbia from the mid – 1920s to the mid – 1940s. From 1925 to 1946 catches of sardines ranged from approximately 5 to 80,000t and averaged approximately 40,000t annually. The collapse of this fishery in 1947 was historically described as an example of over-fishing (Hillbourn & Walters, 1992). However, more recent information has led to the recognition that fishing may have affected the rates of population change, but the collapse in 1947 and subsequent reappearance in 1992 of sardines is a function of climate and ocean change. The change in sardine dynamics in 1947 is now seen as synchronous with the 1947 regime shift (Minobe, 1997; Francis & Hare, 1994; Beamish et al., 1999). The reappearance in 1992 is proposed to be related to the now accepted 1989 regime shift (Beamish et al., 1999; McFarlane et al., 2000; Hare & Mantua 2000). The observation that the 1977 regime shift did not reverse the conditions (for sardines) that occurred after 1947 is possibly evidence of the multidimensional nature of the impact of regime changes on the organization of ecosystems.

It was also believed that a genetically distinct northern migratory stock had been over-fished to a biomass too small to rebuild, leaving little prospect for the recovery of the fishery off the British Columbia coast (Murphy, 1966; MacCall, 1979). In this study we describe the reappearance of sardines off British Columbia in relation to climate and ocean conditions and compare current biology with descriptions published during the 1940s.

## Biological Data

Midwater trawl research cruises have been conducted annually off the west coast of Vancouver Island since the early 1970s. Biological data were collected from sardine during all research trawling operations since they reappeared in catches in 1992. Fork length, sex and maturity were recorded for all sardine sampled. Paired otoliths were collected for age determinations from fish from selected sets, according to the procedures described in Beamish and McFarlane (2000).

No sardines were captured in nearly 1500 reasearch trawl sets conducted off the west coast of Vancouver island between 1977 and 1992 (DFO Groundfish database). From 1992 to 1995 small numbers of sardines were captured in both commercial and research catches of Pacific hake (*Merluccius productus*) (Fig. 1). The catches in the hake fishery have continued through 1999, but are not an indication of sardine abundance as hake are fished at depths below the concentrations of sardines (McFarlane & Beamish, 1999). Since 1995 catches in an experimental fishery have increased from 200t to over 1200t in 1999 (Fig. 1). The sex ratio of

50% male and 50% female sardines in the catch in the 1990s was similar to that determined during the 1930s (45% male) (Table 1). The average length of fish captured during the summer in 1992 (244mm) and 1993 (262mm) was similar to the average length from 1936 to 1940 (258mm) (Fig. 2). From 1997 to 1999 the average length (230mm) was smaller than previously reported (Fig. 3). Similarly, the average age of sardine in 1997, 1998 and 1999 (4.1 years) was younger than that in the 1930s (6.2 years) and 1940s (4.6 years) (Table 2; Fig. 4), and the range of ages was smaller (Fig. 4).

Sardine in spawning condition were sampled off southern Vancouver Island in July 1997, and large numbers of young of the year (x = 10mm) were captured in the same area in February, 1998, juvenile sardines were a common component of the fish community in Vancouver Island surface waters, outnumbering catches of 1997 year class herring (*Clupea harengus*) 2 to 1. These young sardines have remained off the coast and have been captured throughout British Columbia waters including the Strait of Georgia, northern Hecate Strait and Alaska. Sardines remained abundant and spawned off the west coast of Vancouver Island in 1998.

Stomach contents for sardine from selected sets during cruises in 1997, 1998 and 1999 were identified to lowest taxonomic group possible and volume (cc) estimated for each prey item.

During 1997 and 1998 sardines fed mainly on phytoplankton (diatoms, *Coscinodiscus* spp.) and zooplankton (copepods and euphausiids), similar to the diet in the late 1920s (Fig. 5). During 1999, a major portion of the diet was composed of surface water tunicates (*Oikopleura* spp.) as well as diatoms, copepods and euphausiids.

Abundance of sardines off the west coast of Vancouver Island was estimated using the volume fished in each of 6 regions from the northern part of Vancouver Island (region 1) to the southern part (region 6) (Fig. 6). Tracklines were predetermined to ensure maximum coverage within the limited cruise time available. Only sets which fished the top 30m of the water column were used as 99% of sardines were captured in the top 30m (McFarlane & Beamish, 1999). Swept volume for each set was determined according to the procedures described by Beamish et al. (2000).

The minimum estimated abundance of sardines in coastal waters off the west coast of Vancouver Island was 85, 993t in 1997 and 72, 080t in 1999 (Table 3). These assume a catchability of 1, and do not include sardines occupying large inlets along the west coast of Vancouver Island, or large concentrations just outside of the survey area on the northern tip of Vancouver Island. From 1992 until 1996 most sardine were captured off the west coast of Vancouver Island. Sardines were captured in Queen Charlotte Sound and Dixon Entrance in 1997 and 1998, and some were captured in waters off south – east Alaska in 1998 (Fig. 7). During 1999, no research fishing for sardines was conducted in waters north of Queen Charlotte Sound

**Climate data**

The Aleutian Low Pressure Index (ALPI), Pacific Circulation Index (PCI), and Atmospheric Forcing Index (AFI) were obtained from the Pacific Biological Station website (http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/english/ clm_indx1.htm). For a detailed description of these indices see McFarlane et al., 2000. The Pacific Interdecadal Oscillation Index (PDO) (Martua et al., 1997) was obtained via the website (http://ipbc.washington.edu/staff/home/html/decadal/ post1977). The Southern Oscillation index (SOI), commonly associated with El Niño events was obtained via the website (http://www.ios.bc.ca/ios/osap/projects/ elnino/s_osc.txt) (Fig. 8). In general, the intensity and position of the Aleutian Low determines atmospheric circulation patterns. Atmospheric circulation patterns drive oceanic circulation, which determines amount of ekman pumping and spatial distribution of sea surface temperatures. The three climate – ocean indices (ALPI, PCI, PDO) were combined to form the Atmospheric Forcing Index (AFI) using principal component analysis based on their concentration matrix (McFarlane et al., 2000) (Fig. 9). The first principal component scores positive for an intense Aleutian Low, above average frequency of south-westerly and westerly atmospheric circulation, and a general cooling in the central north Pacific and warming in the coastal areas. The composite index scores negative for a weak Aleutian Low, a decrease in south-westerly and westerly circulation, and a warming trend in the central north Pacific and cooling along the coast. Decadal scale patterns in sea surface temperatures along the south west coast of Vancouver Island since 1935 have not been synchronous with larger scale climate/ocean index patterns, nor with ecosystem changes seen in fish and plankton, such as periods of sardine population fluctuation (Fig. 10).

**Other recent changes in the ecosystem occupied by sardines**

A number of other indications of ecosystem change have been reported (McFarlane et al., 2000; Hare & Mantua, 2000). Like sardines, salmon population abundance patterns have reflected ecosystem change (Fig. 11). Decadal scale trends have also been evident in other fish species, such as Pacific Hake, Pacific Mackerel, Sablefish, Pacific Cod and English Sole (Francis, 1983; Saunders & McFarlane, 1998; McFarlane et al., 2000; King et al., 2000; Fargo, 1998) (Fig. 12, 13 & 14).

Zooplankton sampling off southern Vancouver Island has been conducted frequently since 1979, and exists as a reasonably consistent time series since 1985. Zooplankton populations have undergone chages in distribution and composition since 1989, such as a shift to a more southerly copepod fauna, and increases in the biomass of the two major euphausiid species (Mackas et al., 2000) (Fig. 15).

The reappearance of sardines off the west coast of Canada in 1992, and their spawning patterns in 1997 and 1998 represent a change in their behaviour. Although we do not understand fully the mechanisms that are responsible for the fluctuations in sardine abundance, it is clear that ocean conditions affect distribution and survival. Neither overfishing nor sea – surface temperature fluctuations alone can account for the large increases and decreases in sardine abundance recorded during the last century. It does seem evident, however, that the appearance and disappearance of sardines off of Canada's west coast corresponded with periods of regime shifts. Recent changes we have seen in sardine distribution, abundance and spawning (and the same changes in other fish) appear consistent with a major shift in the dynamics of the ecosystem in waters off British Columbia at the time of the 1989 regime shift. Kawasaki and Omori (1986) recognised that there was a synchrony in the trends of abundance of sardine populations off Japan, California and Chile, supported the theory that large fluctuations in sardine populations are a consequence of changes in ocean habitat around the north Pacific ocean. A key to understanding why large fluctuations in sardine abundance occur may be by understanding why they have shifted their range northward. We also hypothesize that during the 1989 regime shift phytoplankton (particularly diatom) abundance and composition was affected by an altered nutrient supply, as was observed in the Black Sea after the damming of the Danube River (Humborg et al., 1997). However, it is difficult to observe these changes in waters off the west coast of Vancouver Island as the recycling of nutrients and phytoplankton masks variations in this system (Parsons et al., 1977).

In the past, changes in fish population abundance have usually been linked to fishing effects; however, in order to understand how to manage sardine stocks we must understand how they are regulated naturally. The history of sardine behavior is an example of the effects that climate/ocean changes can have on abundance, and a reminder that ecosystem changes need to be regarded as distinct organizations, rather than cycles or oscillations. In addition, population dynamics of other species, such as coho (*Oncorhynchus kisutch*) and chinook (*O. tshawytscha*) salmon may also respond to changes in a manner specific to the new organization. Climate related fluctuations need to be recognized in any legislation requiring expenditures and management actions.

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**Figure Captions**

Figure 1. Catches of Pacific sardine in Canadian waters. (A) catches from 1920 – 1999. (B) combined research and fishery catches, 1992 – 1999.

Figure 2. Length frequency of Pacific sardine (A) Summer 1997; (B) February – April 1998; (C) Summer 1998. Note the abundance of 7 and 8 month old sardines in the winter.

Figure 3. Length frequency of Pacific sardine captured in Canadian waters, 1929 – 1933, 1992, 1993, and 1997 – 1999.

Figure 4. Age frequency of Pacific sardine captured in Canadian waters, 1940 –1942 and 1997 – 1999.

Figure 5. Stomach contents of Pacific sardine captured in Canadian waters from 1927 – 1930 and 1997 – 1999.

Figure 6. The west coast of Vancouver Island, divided into the six regions used to estimate abundance. Tracklines were occupied during July and August, 1997 and 1999.

Figure 7. Distribution of Pacific sardine in Canadian waters from 1992 to 1999.

Figure 8. Index of Southern Oscillation, 1950 – 1999.

Figure 9. Indices of climate change (A) Aleutian Low Pressure Index (ALPI); (B) Pacific Circulation Index (PCI); (C) Pacific Interdecadal Oscillation Index (PDO); (D) Atmospheric Forcing Index (AFI), a composite of A, B and C.

Figure 10. Sea surface temperature anomalies off south west Vancouver Island, 1935 – 1999. Black bar indicates presence of sardine in Canadian waters.

Figure 11. Total catch of Pacific salmon (pink, sockeye, chum, coho and chinook) 1970 – 1999.

Figure 12. Changes in distribution and spawning area of Pacific hake during the 1990s, illustrating (A) increased northward movement in Canadian waters; (B) a change in spawning area during the 1990s.

Figure 13. Distribution of Pacific mackerel from 1992 to 1999.

Figure 14. Indices of relative year class strength of (A) sablefish (1960 – 1996); (B) Pacific cod (1960 – 1998); and (C) English sole (1960 – 1996).

Figure 15. Annual average log scale anomalies of biomass of major southern Vancouver Island zooplankton taxa.

Table 1. Sex ratio of Pacific sardine captured from 1936 to 1940[a] and from 1992 to 1999.

| year | % male | n | year | % male | n |
|---|---|---|---|---|---|
| 1936 | 48.0 | | 1992 | 51.8 | 2023 |
| 1937 | 45.0 | | 1993 | 53.9 | 193 |
| 1938 | 45.0 | | 1997 | 47.0 | 4067 |
| 1939 | 50.0 | | 1998 | 48.9 | 1005 |
| 1940 | 51.0 | | 1999 | 46.9 | 3942 |

a) Data from 1936 – 1939 from Clemens (e.g. Clemens 1936).
Data from 1940 from Foerster (1940)

Table 2. Average age of Pacific sardine captured in Canadian waters from 1935 to 1939[a], from 1940 to 1945[a] and from 1992 to 1999.

| year | average age (years) | n | year | average age (years) | n | year | average age (years) | n |
|---|---|---|---|---|---|---|---|---|
| 1935 | 7.5 | | 1940 | 5.15 | | 1997 | 4.02 | 96 |
| 1936 | 4.6 | | 1941 | 3.96 | | 1998 | 3.93 | 142 |
| 1937 | 6.7 | | 1942 | 3.66 | | 1999 | 4.23 | 136 |
| 1938 | 6.5 | | 1943 | 4.65 | | | | |
| 1939 | 5.69 | | 1944. | 4.77 | | | | |
| | | | 1945 | 5.16 | | | | |

a) Ages from 1935 to 1945 from Marr (1960).

Table 3. Biomass of Pacific sardine (t) off the west coast of Vancouver Island, 1997 and 1999.

| Year | Area[a] | Total Vol ($km^3$) | Mean Swept Vol ($km^3$) | Swept Vol (±) 95% CI | Average # fish/set | Average weight (kg)/fish | Total numbers | Biomass (t): 95% C.I. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Min. | Avg. | Max. |
| 1997 | 1 | 91.02 | 0.00468 | 0.0013838 | 36 | 0.165 | 707580 | 90 | 117 | 166 |
| | 2 | 66.6 | 0.00341 | 0.0007695 | 4386 | 0.165 | 57153884 | 11080 | 14144 | 19549 |
| | 3 | 119.7 | 0.00292 | 0.0011891 | 537 | 0.165 | 41930677 | 2459 | 3637 | 6976 |
| | 4 | 83.85 | 0.00320 | 0.0010563 | 10585 | 0.165 | 185113128 | 31837 | 45730 | 81132 |
| | 5 | 71.76 | 0.00256 | 0.0005061 | 1537 | 0.165 | 42896895 | 5934 | 7106 | 8856 |
| | 6 | 127.65 | 0.00200 | 0.0002673 | 1450 | 0.165 | 270325085 | 12764 | 15260 | 18969 |
| | | | | | | | | 64165 | 85993 | 135648 |
| 1999 | 2 | 66.6 | 0.00271 | 0.000496 | 1161 | 0.165 | 28575758 | 3985 | 4715 | 5772 |
| | 3 | 119.7 | 0.00215 | 0.00005 | 828 | 0.165 | 46187276 | 7274 | 7621 | 7828 |
| | 4 | 83.85 | 0.00223 | 0.0008278 | 228 | 0.165 | 8591544 | 1048 | 1418 | 2326 |
| | 5 | 71.76 | 0.00192 | 0.0006377 | 375 | 0.165 | 14030575 | 1738 | 2315 | 3466 |
| | 6 | 127.65 | 0.00192 | 0.0004952 | 5115 | 0.165 | 339467563 | 44587 | 56012 | 75311 |
| | | | | | | | | 58787 | 72080 | 94704 |

a) See Figure 6.

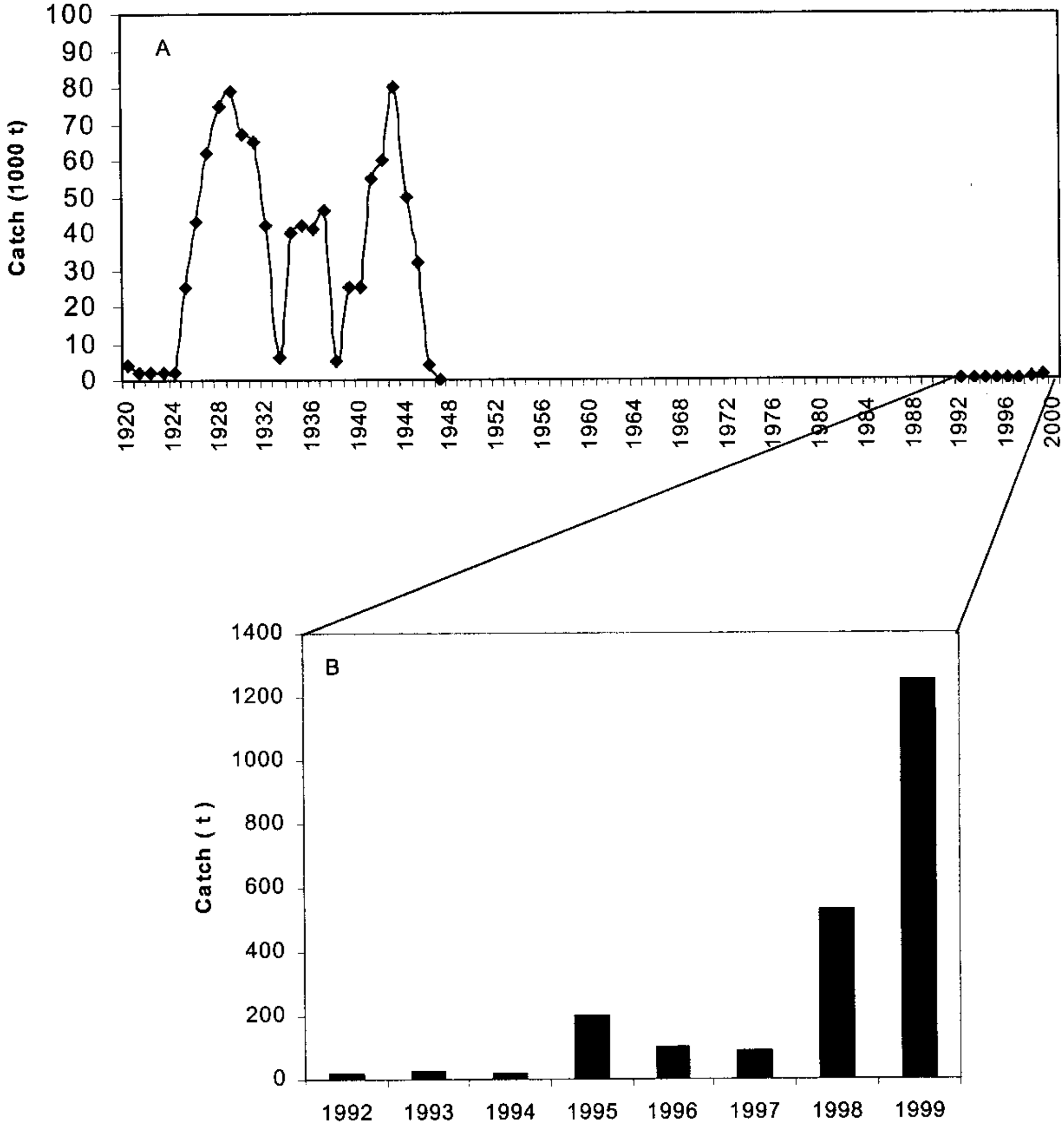

A
Catch (1000 t)
100
90
80
70
60
50
40
30
20
10
0
1920
1924
1928
1932
1936
1940
1944
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
B
Catch ( t )
1400
1200
1000
800
600
400
200
0
1992
1993
1994
1995
1996
1997
1998
1999

Figure 1

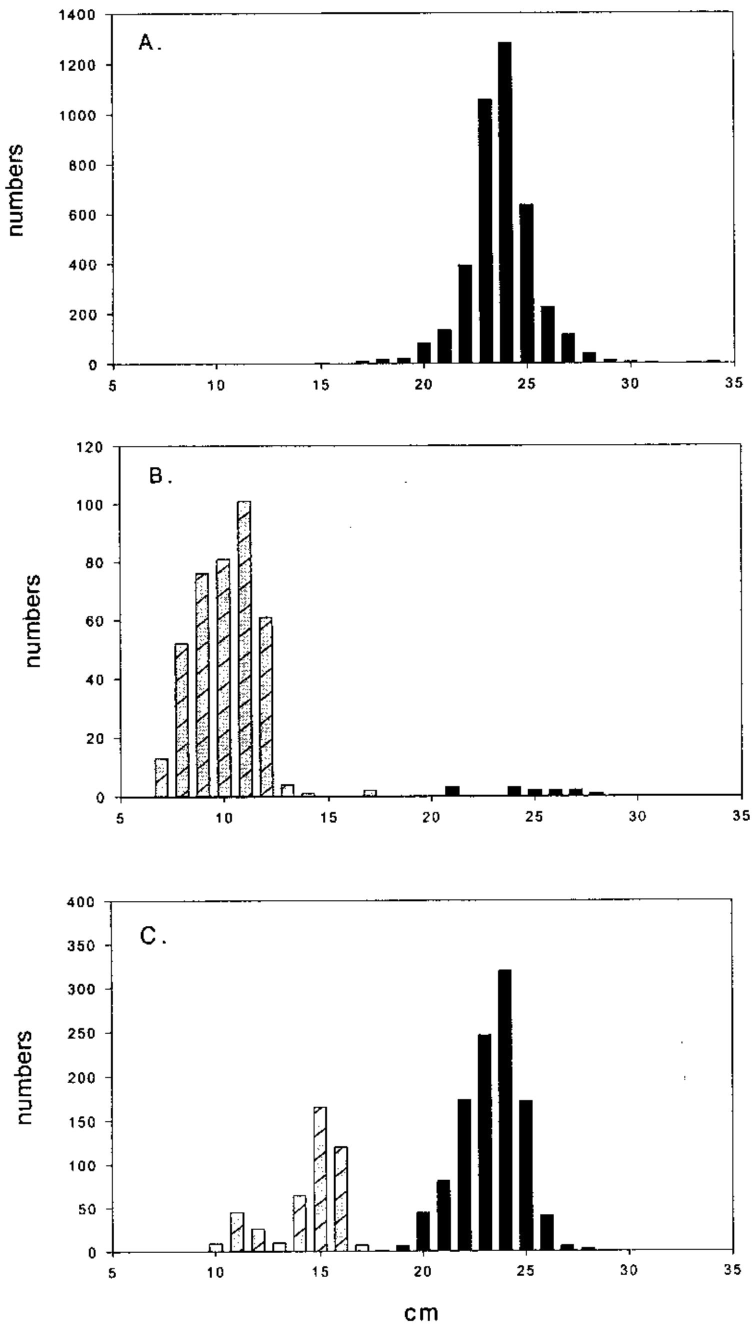



Figure 2

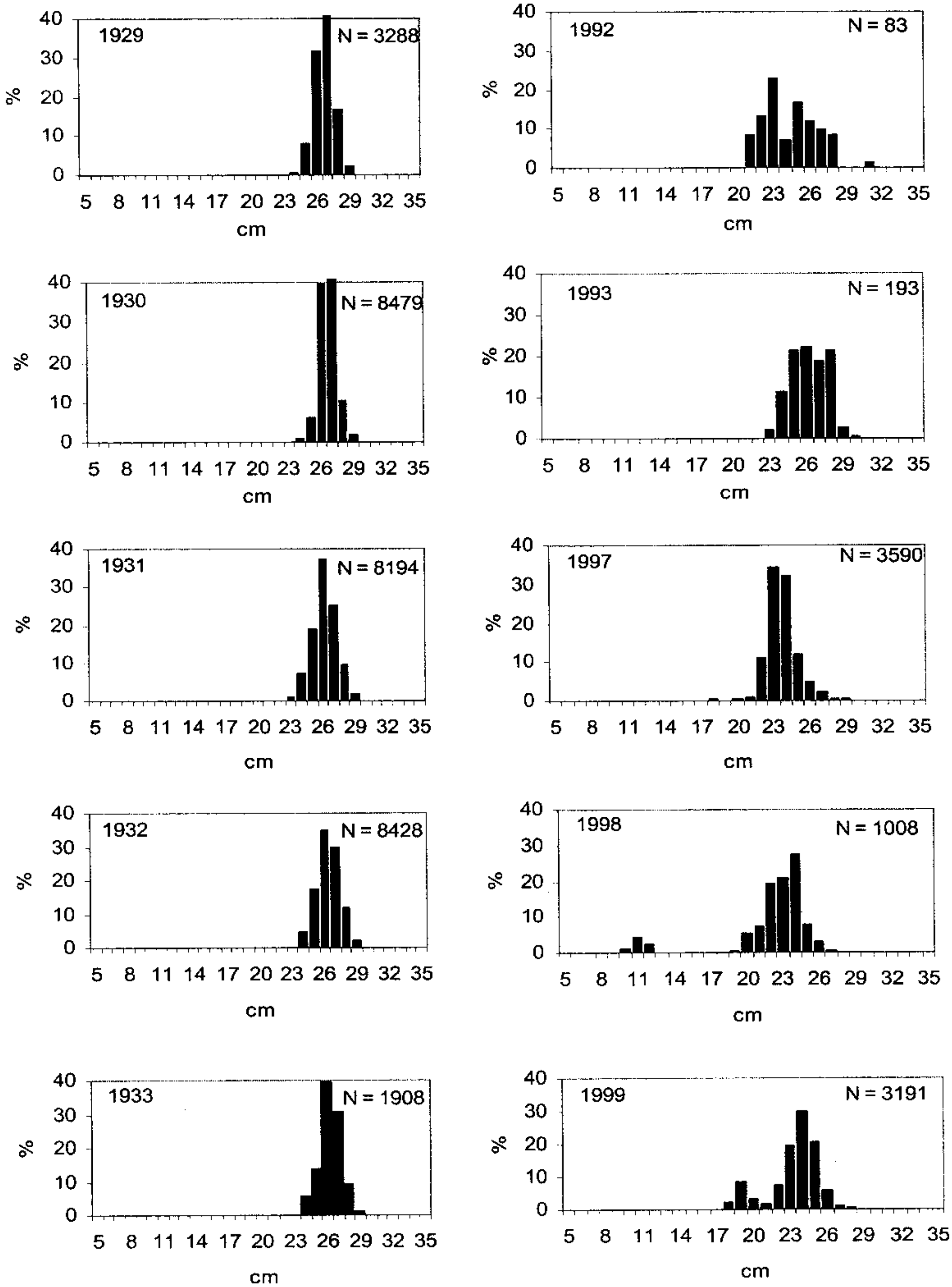

1929
N = 3288
1930
N = 8479
1931
N = 8194
1932
N = 8428
1933
N = 1908
1992
N = 83
1993
N = 193
1997
N = 3590
1998
N = 1008
1999
N = 3191
%
cm
5 8 11 14 17 20 23 26 29 32 35
0 10 20 30 40

Figure 3

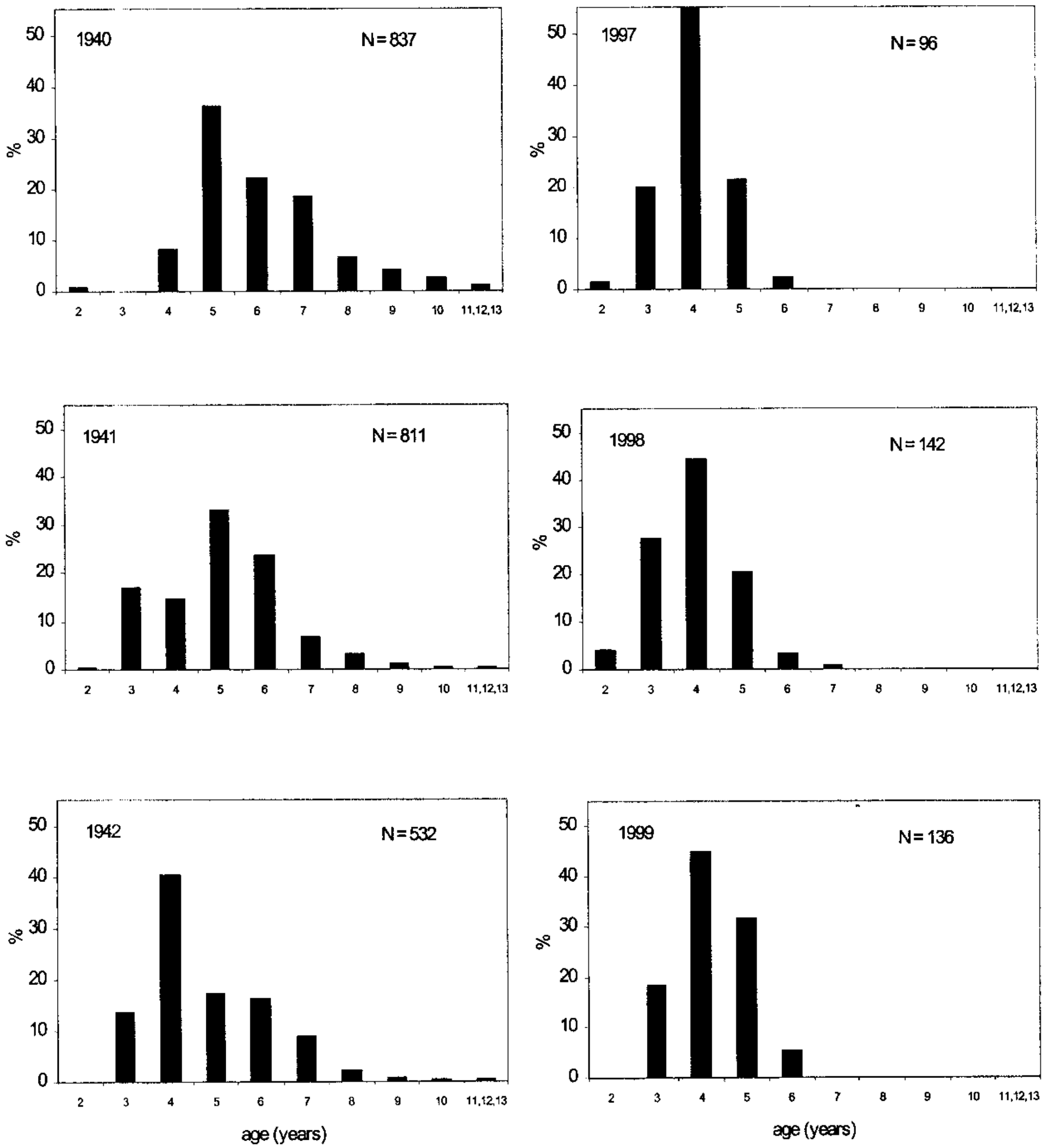

1940
N=837
1997
N=96
1941
N=811
1998
N=142
1942
N=532
1999
N=136
%
50
40
30
20
10
0
2
3
4
5
6
7
8
9
10
11,12,13
age (years)

Figure 4

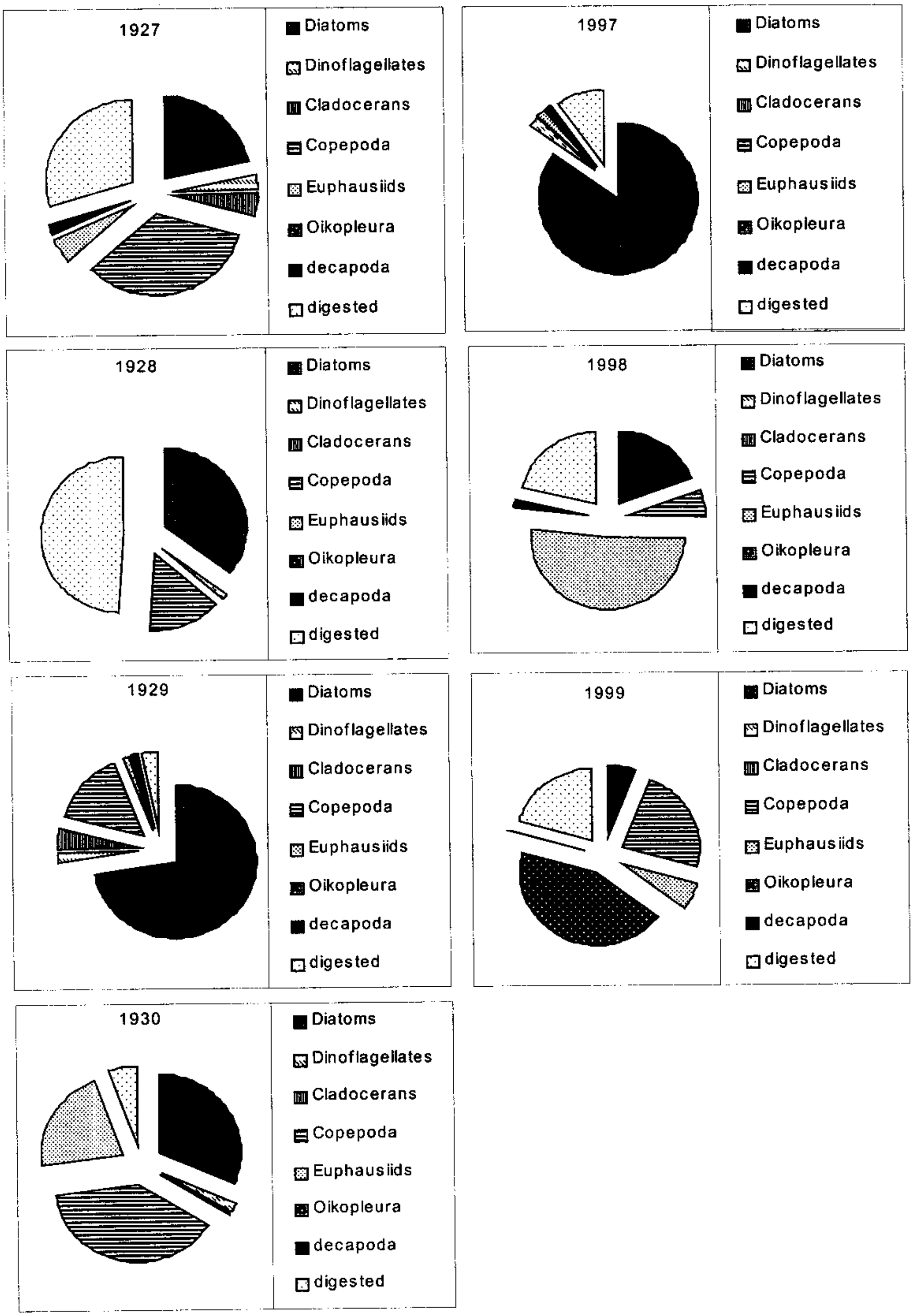

1927
Diatoms
Dinoflagellates
Cladocerans
Copepoda
Euphausiids
Oikopleura
decapoda
digested
1997
Diatoms
Dinoflagellates
Cladocerans
Copepoda
Euphausiids
Oikopleura
decapoda
digested
1928
Diatoms
Dinoflagellates
Cladocerans
Copepoda
Euphausiids
Oikopleura
decapoda
digested
1998
Diatoms
Dinoflagellates
Cladocerans
Copepoda
Euphausiids
Oikopleura
decapoda
digested
1929
Diatoms
Dinoflagellates
Cladocerans
Copepoda
Euphausiids
Oikopleura
decapoda
digested
1999
Diatoms
Dinoflagellates
Cladocerans
Copepoda
Euphausiids
Oikopleura
decapoda
digested
1930
Diatoms
Dinoflagellates
Cladocerans
Copepoda
Euphausiids
Oikopleura
decapoda
digested

Figure 5

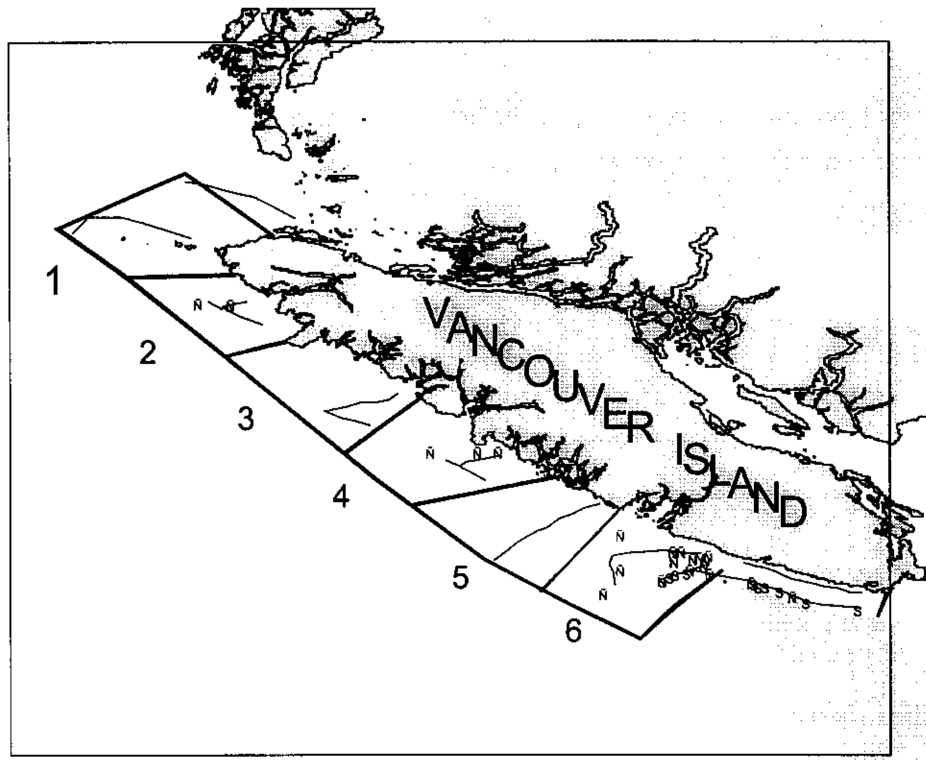



Figure 6

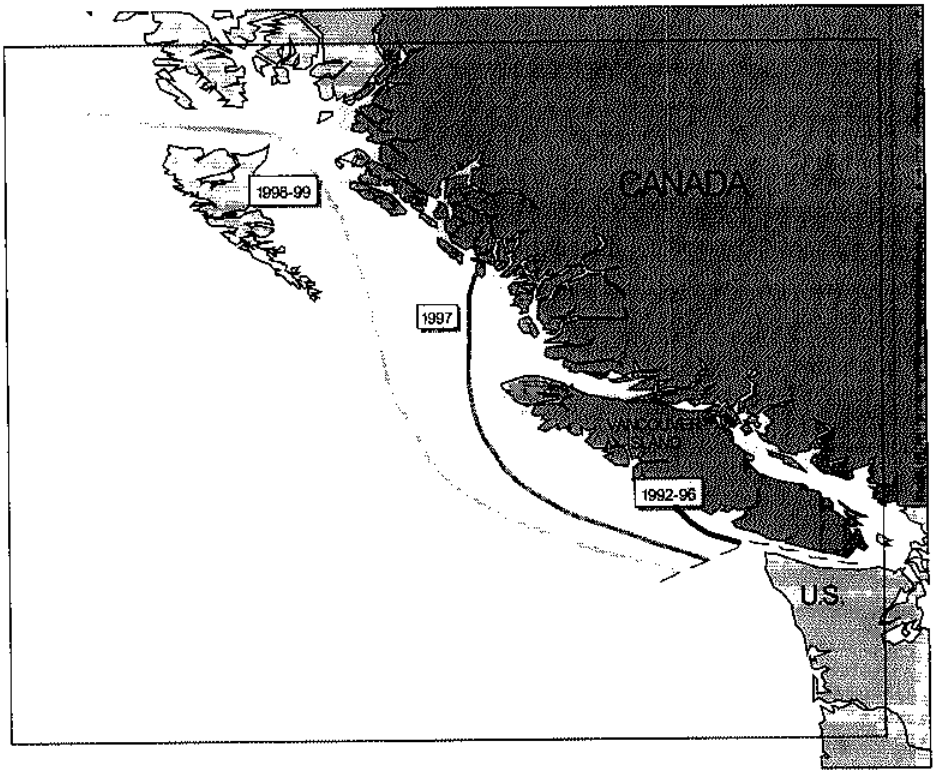



Figure 7

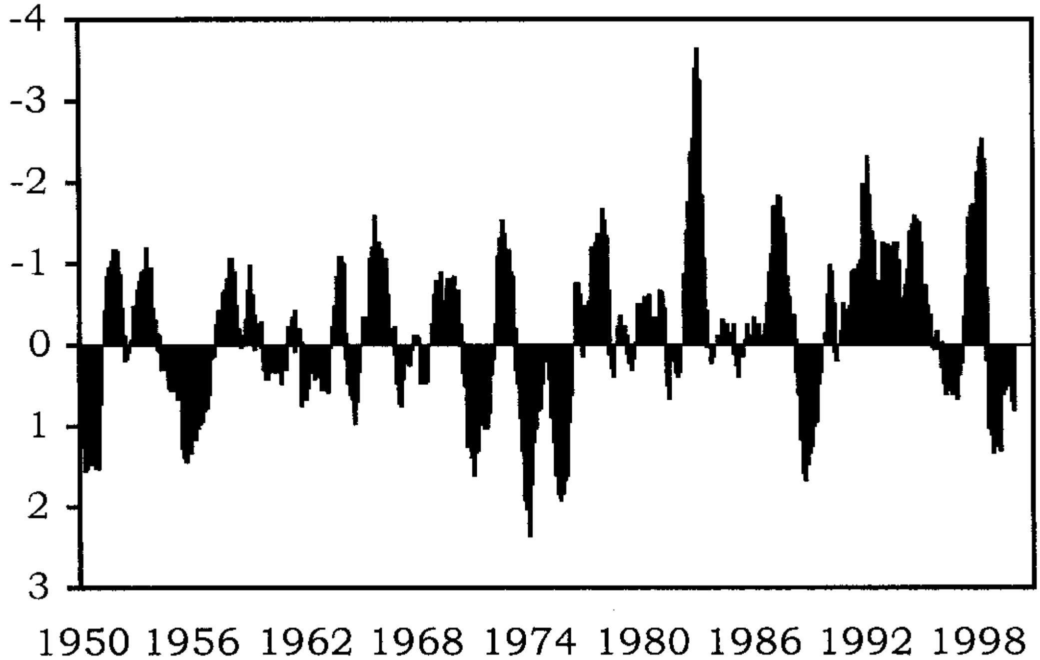



Figure 8

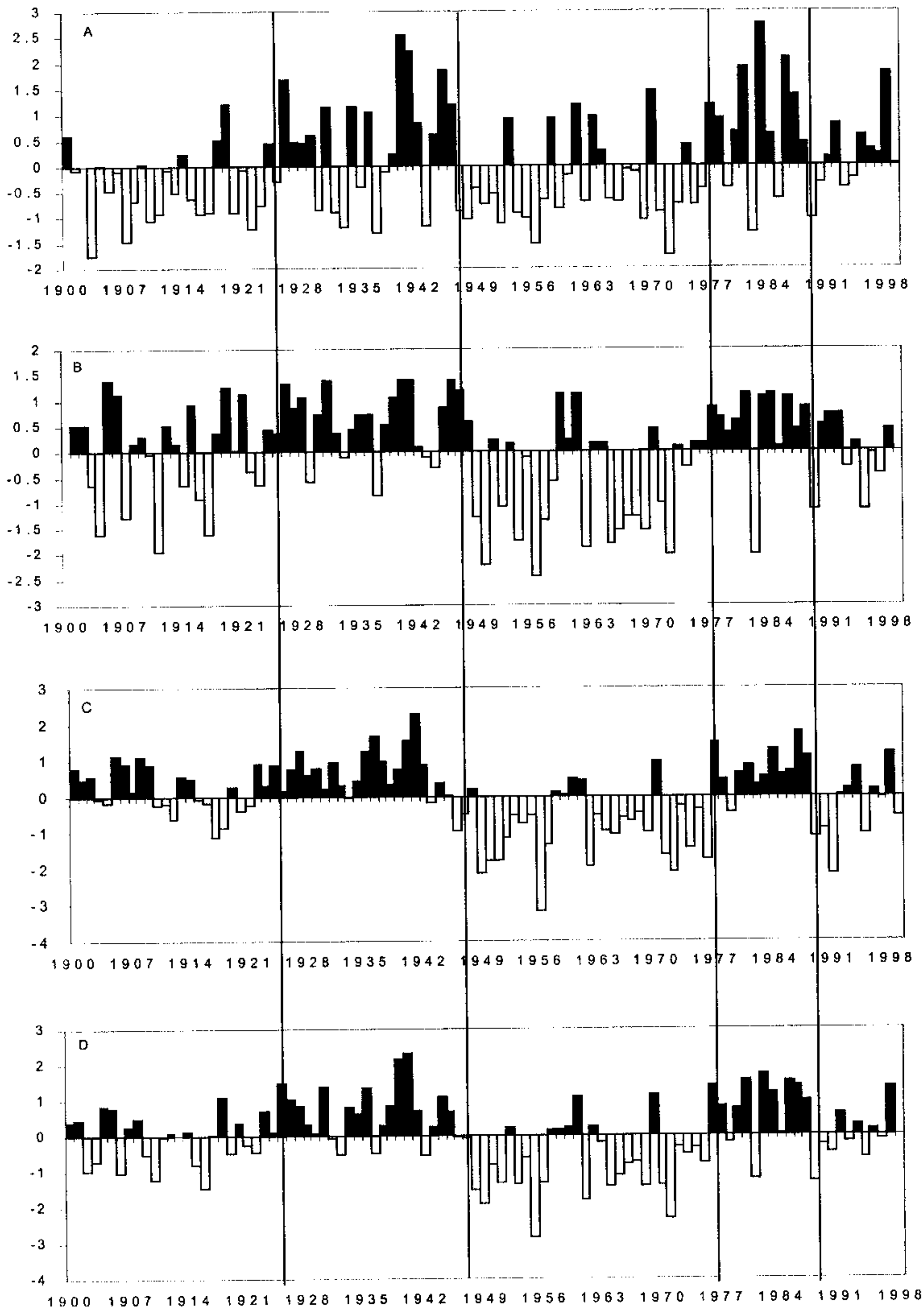

A
B
C
D
1900 1907 1914 1921 1928 1935 1942 1949 1956 1963 1970 1977 1984 1991 1998

Figure 9

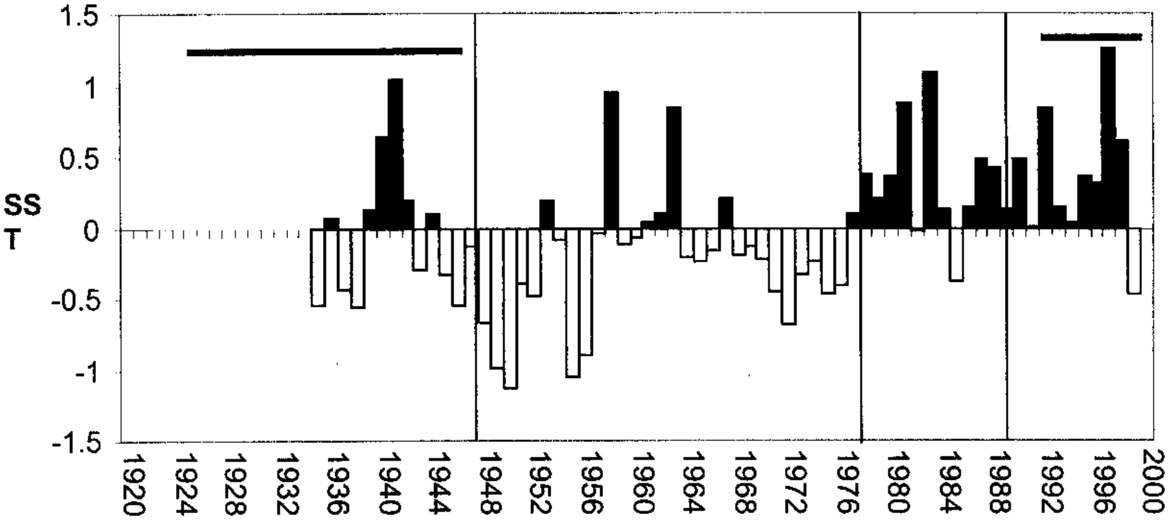



Figure 10

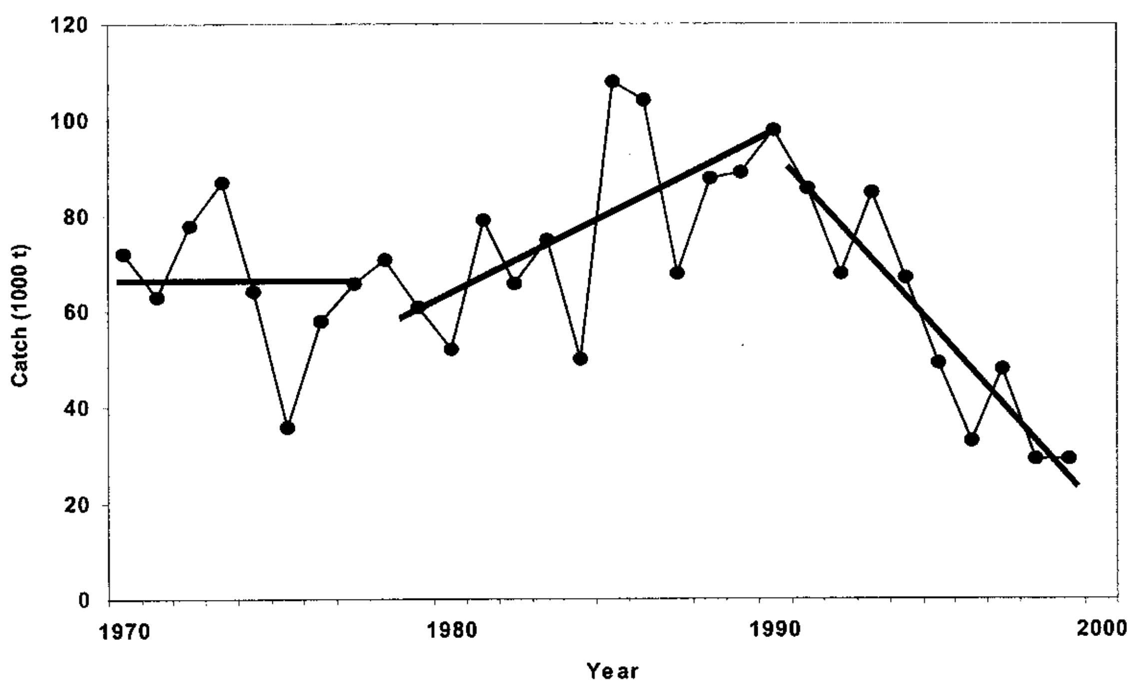



Figure 11

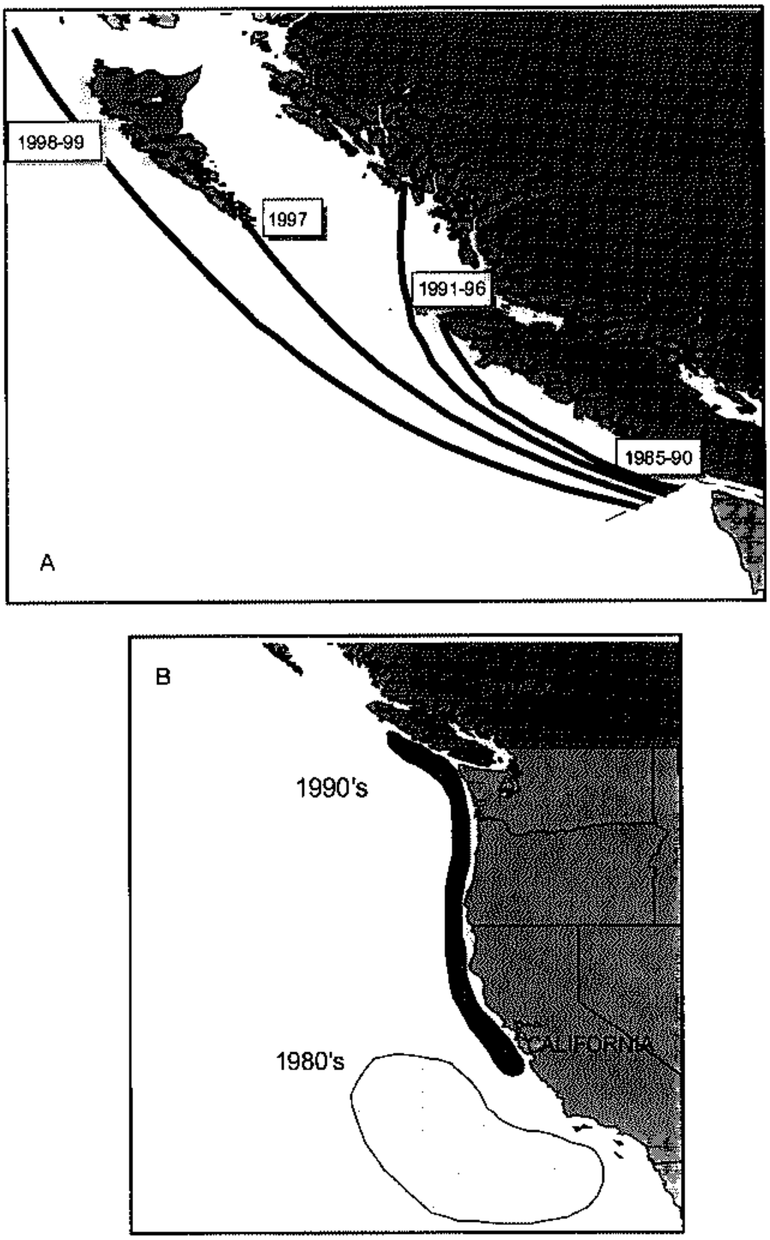



Fig. 12

Figure 12

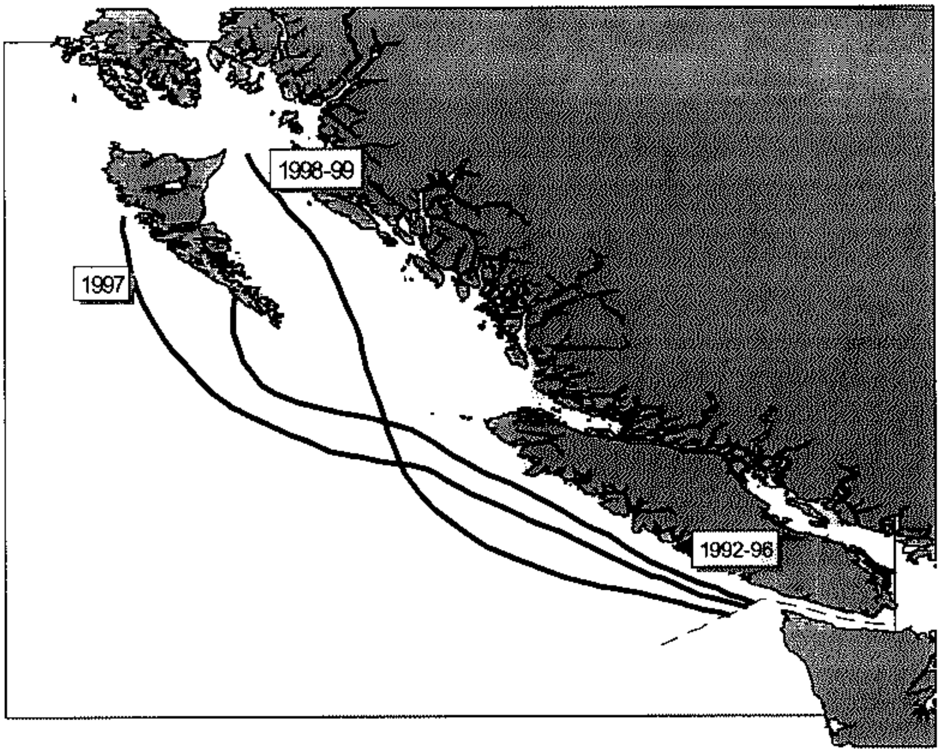



Figure 13

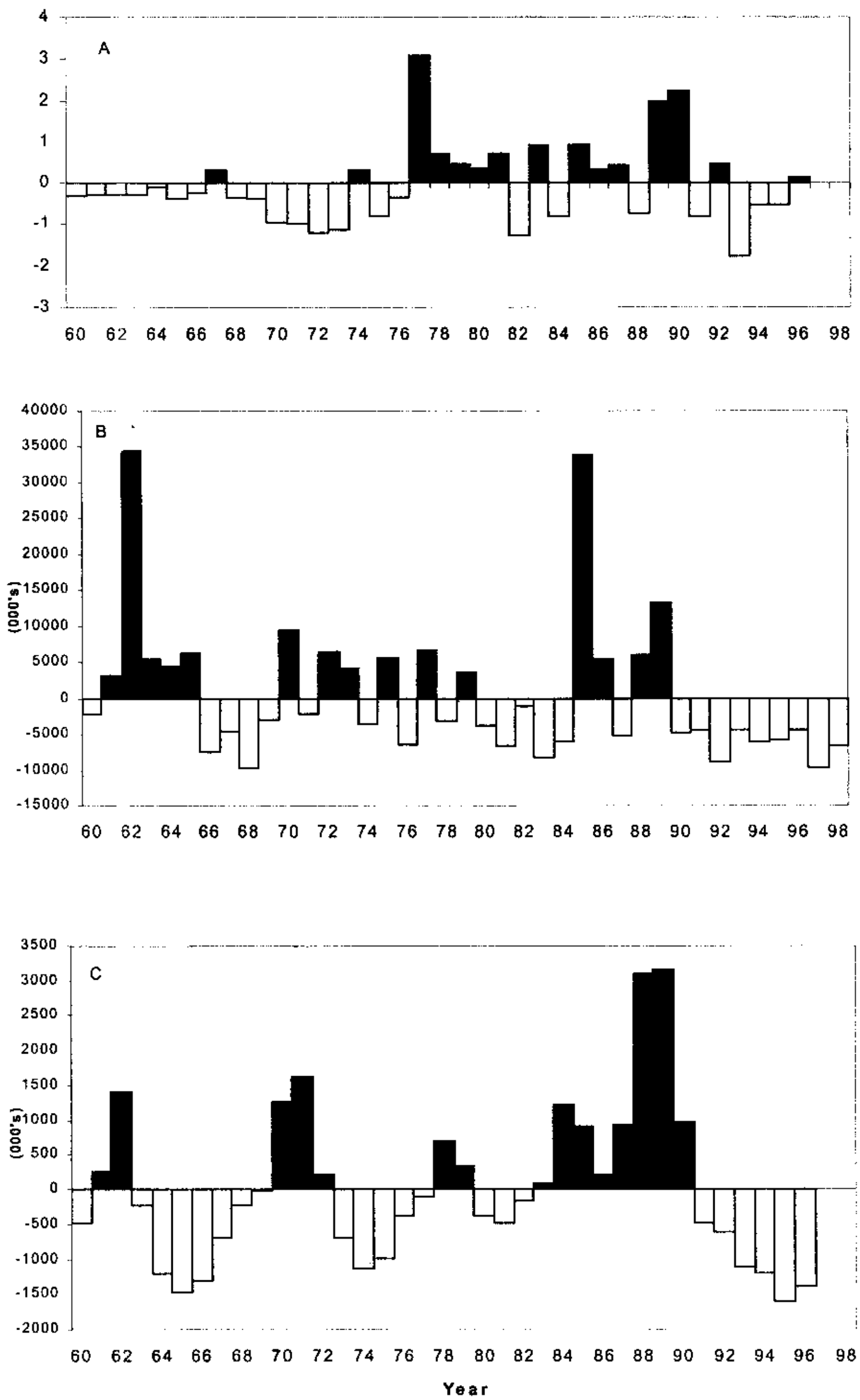



Figure 14

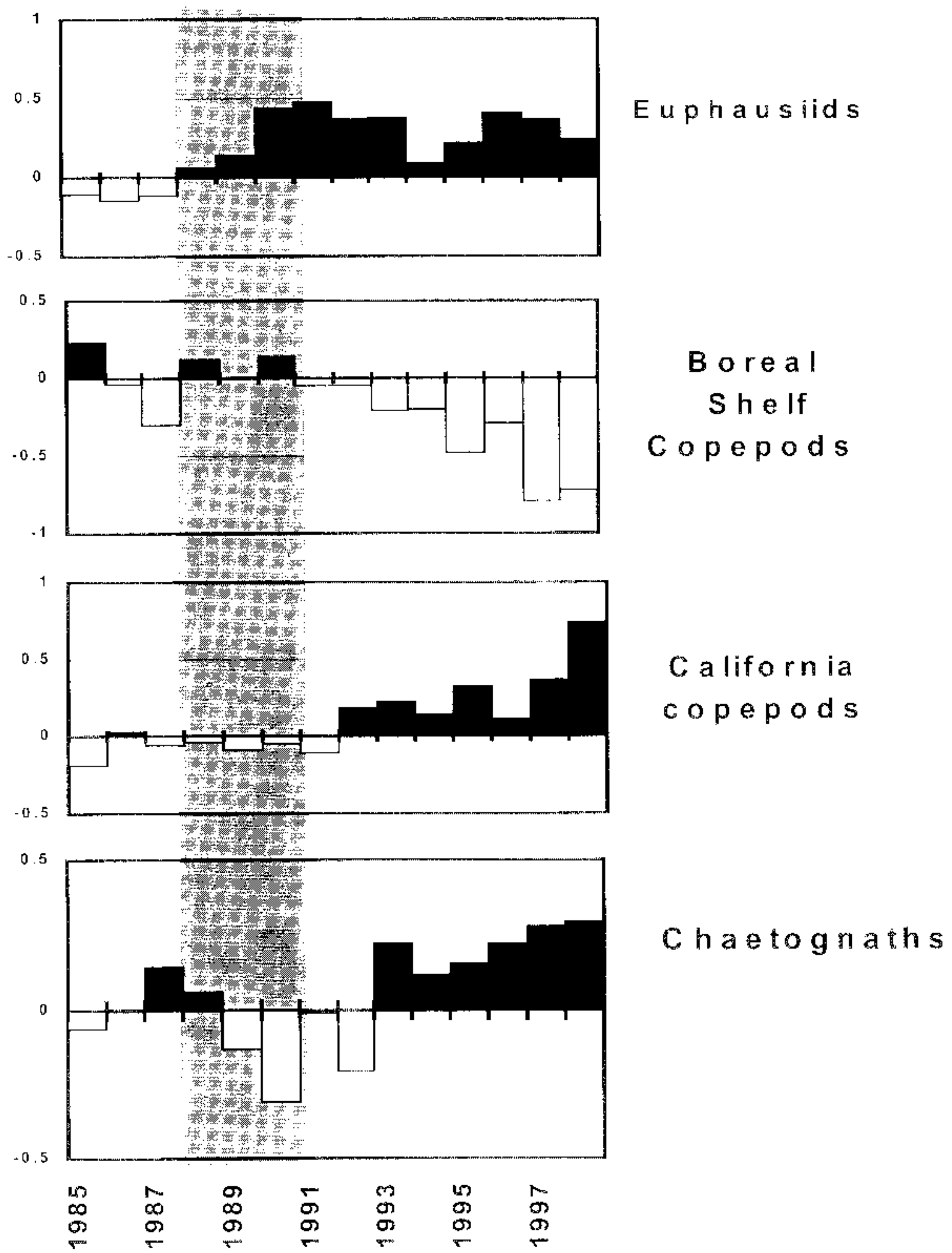

Euphausiids
Boreal Shelf Copepods
California copepods
Chaetognaths
1
0.5
0
-0.5
-1
1985
1987
1989
1991
1993
1995
1997

Figure 15

## *Ecosystem Consequences and Sardine Population - Zooplankton Effects*

**Michael Mullin, Scripps Institution of Oceanography, University of California -- San Diego, La Jolla, California**

On the interannual time scale (1950-1984), changes in biomass of macrozooplankton are correlated from San Francisco to mid-Baja California; hence, data from the Southern California Bight (SCB) sector can be taken as representative. On the interdecadal time scale (1950-1998), biomass of macrozooplankton in the SCB has decreased, and the water is warmer; unlike the effects of El Niño, however, these trends were not accompanied by a reduction in the California Current's geostrophic transport, nor by an increase in salinity. Hence, what provided food for the expansion of the sardine? Biomass of macrozooplankton in the Alaska Gyre has increased during these decades, but too far north to "cause" the sardine expansion. In the SCB sector, euphausiids (an important food source for sardines) have not decreased in proportion to the total macrozooplankton, nor have the smaller types of zooplankton. Hence, better definition of what constitutes sardine "food" for various life stages and in various environmental regimes is needed, as are more general use of measured of physiological health and growth.

# *Of Sardines and Seabirds*

**Julia K. Parrish[1,2], Elizabeth Logerwell[1], William Sydeman[3], David Hyrenbach[4]**

**(1) School of Fisheries and (2) Zoology Department, University of Washington, Seattle, Washington (3) Point Reyes Bird Observatory, Stinson Beach, California, (4) Scripps Institution of Oceanography, University of California – San Diego, La Jolla California**

Although seabirds are often overlooked by scientists, fishers, and fishery managers as significant marine predators, in fact, many species feed exclusively on finfish, including the juveniles of many important commercial species (e.g., rockfish, salmon), as well as on the adults of commercially important baitfish (e.g., anchovy, herring). The degree to which seabirds impact fishery stocks thus depends on the abundance of each piscivorous seabird species and their diet (also expressible more generally as daily energetic demand). Because many piscivorous seabirds take forage fish, the re-emergence of sardines (*Sardinops sagax*) over anchovies within the California Current System (CCS) may create both trickle down and trickle up change in nearshore systems.

Seabirds are marine birds foraging primarily to exclusively in the marine environment. Many species spend the majority of their lives on the ocean, returning to land only to breed. Seabirds are generally long-lived (20-70 years, depending on the species), and display many life history traits common to mammals: sexual maturity is delayed several years, annual reproductive output is low (from a maximum of 3 chicks in the gulls and terns, to a minimum of one chick every other year in some albatross), juvenile survivorship is low, and adult survivorship is usually high (90+ percent annually). Because of the tradeoff between long life and low fecundity, seabird populations are vulnerable to decline if adult survivorship decreases by as little as 3-5%. Many seabirds are natally philopatric – returning to their place of birth to breed. This latter trait has the potential to create somewhat closed populations, if environmental conditions remain favorable at the colony site.

Within the CCS, seabirds are found both breeding and as non-breeders. This latter category includes young individuals (prebreeders), individuals which have elected to skip breeding in any given year, and species which breed elsewhere, but spend time foraging in the CCS (Table 1). In total, 16 primarily piscivorous seabird species (excluding minor gull species) are found within the nearshore CCS (defined herein as from the shoreline out to 2000 meters of depth). For this analysis, we divide the CCS into political regions (British Columbia, Washington, Oregon, and California), and further subdivide California into north and south (subdividing the State at Pt. Conception). Although oceanographic regions may be more biologically appropriate, data are most often reported by state.

There are several patterns of note. First, several species occur during the summer, but are not found in substantial numbers in the winter (e.g., pelicans, shearwaters, albatross), and vice versa. The latter two species breed outside of the CCS (southern hemisphere and Hawaii, respectively). Kittiwakes and fulmars (the Alaska breeders) are only found in the CCS during the winter.

Second, some species exhibit a cline in distribution (e.g., pelicans are found in the south, but not in the north; murres are found predominantly in the middle of the CCS). Third, some species appear to have an erratic distribution and abundance pattern (e.g., rhinoceros auklets). This latter pattern may be more indicative of data quality, than biological reality, and reflects the fact that the smaller, burrow nesters are harder to adequately sample both during the breeding season and on the water in the winter.

Abundance, although useful, does not adequately represent seabird pressure on forage fish resources, because piscivorous seabirds range widely in mass from black-legged kittiwakres (.04 kg) to black-footed albatross and brown pelicans (3.0 kg). Figure 1A shows annualized biomass (metric tons) for all species combined. Using standard field and laboratory-derived measurements, as well as occasional allometric standardization equations, it is possible to calculate a second parameter – energy demand (billions of Kcal; Figure 1B). In total in the CCS, we estimate 3606 metric tons of seabirds annually demand 431 billion kilocalories of fish. Note that these estimates only include adult birds, and do not include the chicks produced within the breeding season. Thus, these values are conservative. Because the nearshore environment differs greatly in size among the political regions of the CCS, we have also divided seabird biomass and energy demand by region size, to produce annual estimates per kilometer squared (Figure 2A & B).

Energy demand can be translated into biomass of forage fish using literature-derived values for forage fish energy content (in kcal/g). Thus, if seabird diet is known, total biomass for each fish species consumed can be calculated. Results of such a calculation are shown for common murres (*Uria aalge*), by region, based on gut contents from birds collected at sea and observation of fish brought back to chicks (Figure 3). Of course, during the breeding season, murres and other CCS breeders do not range evenly over the nearshore, but are found clustered adjacent to the colony. Assuming murres have a foraging range of 30 km, prey consumption for the largest colonies may be 5-15 times higher than the estimates given in Figure 3.

Will sardines be affected by seabird energy demands? We conservatively estimate total seabird biomass in the nearshore CCS at 3,600 metric tons. Excluding chicks, these birds require 431 billion kilocalories each year. Thus, depending on which prey species are consumed, seabirds eat 220-300 thousand metric tons of fish annually. Because sardines are a high energy content fish (2.08 kcal/g), second only to eulachon (*Thaleichthys pacificus*) and well above anchovy (*Engraulis mordax*; .094 kcal/g), they should be a preferred food resource for any predator. If all seabird demand was satisfied by sardines, seabirds would consume 0.21MMT, or approximately 13% of the 1999 total age1+ population estimate (1.58MMT). This is approximately twice as much as the fishery landed in 1999.

However, there are several reality caveats. First, sardines should be highly desirable as food, especially as food for chicks because adults must transfer fish back to the colony. Thus, low value fish such as Pacific cod (Gadus macrocephalus, 0.94 kcal/g) would require many more trips to satisfy the energy demands of the chick(s). Second, because sardines have a higher energy value than anchovies, there may be additional predation pressure on sardines. At the same time, the ecosystem may produce a lower biomass of sardines, if trophic energy is conserved. In other words, a kilogram of anchovies is worth only 0.76 kg of sardines, if the currency is energy rather than biomass. Third, adult sardines are large enough to escape seabird predation, potentially falling prey to only the largest species of gulls, cormorants, pelicans, and albatross. However, these seabird species make up a minor proportion of the total seabird biomass (15 %). Thus, seabird predation on sardines may actually be less than that on anchovies (per fish biomass) during the previous half of the cycle. In this case, the replacement of sardines by anchovies may negatively affect seabirds by effectively removing a food source. Finally, because all seabirds can take juvenile sardines, seabird predation may have the greatest effect on the early life history stages. Since the last cycle of sardine dominance, seabird populations throughout the CCS, particularly breeding seabirds which must target smaller fishes to feed their chicks, have grown substantially. Whether this route of trophic interaction significantly affects sardines, for instance by depressing the re-initiation of sardine predominance, is not known.

**Table 1.** Summer and winter population estimates for seabird taxa in the CCS, by region. Data are taken from a variety of published sources and represent an amalgam of at sea and on colony counts and estimates from the 1970s through the 1990s. Data quality vary greatly across regions.

| | BC | WA | OR | nCA | sCA |
|---|---|---|---|---|---|
| **Summer** | | | | | |
| Murres | 13000 | 15000 | 1068000 | 527000 | 0 |
| Rhinos | 1078500 | 91200 | 1500 | 2600 | 0 |
| Gulls | 86900 | 59900 | 25500 | 50700 | 41900 |
| Cormorants | 19900 | 9800 | 81500 | 81000 | 44000 |
| Puffins | 116900 | 4500 | 7500 | 0 | 0 |
| Terns | 0 | 0 | 24000 | 0 | 0 |
| Pelicans | 0 | 0 | 0 | 0 | 17900 |
| Shearwaters | 114000 | 415000 | 55700 | 2161700 | 107500 |
| Albatross | 14100 | 4400 | 3300 | 20100 | 600 |
| | | | | | |
| **Winter** | | | | | |
| Murres | 33700 | 94500 | 97800 | 296400 | 0 |
| Gulls | 31100 | 35900 | 22400 | 227700 | 838700 |
| Rhinos | 25500 | 1000 | 1400 | 149900 | 0 |
| Kittiwakes | 0 | 28000 | 12500 | 103800 | 42100 |
| Fulmars | 9400 | 68300 | 7600 | 23000 | 85500 |
| Cormorants | 7500 | 5700 | 5000 | 8400 | 0 |

**Figure 1A & B**. Annual total biomass and total energy demand by region for all species listed in Table 1 combined.

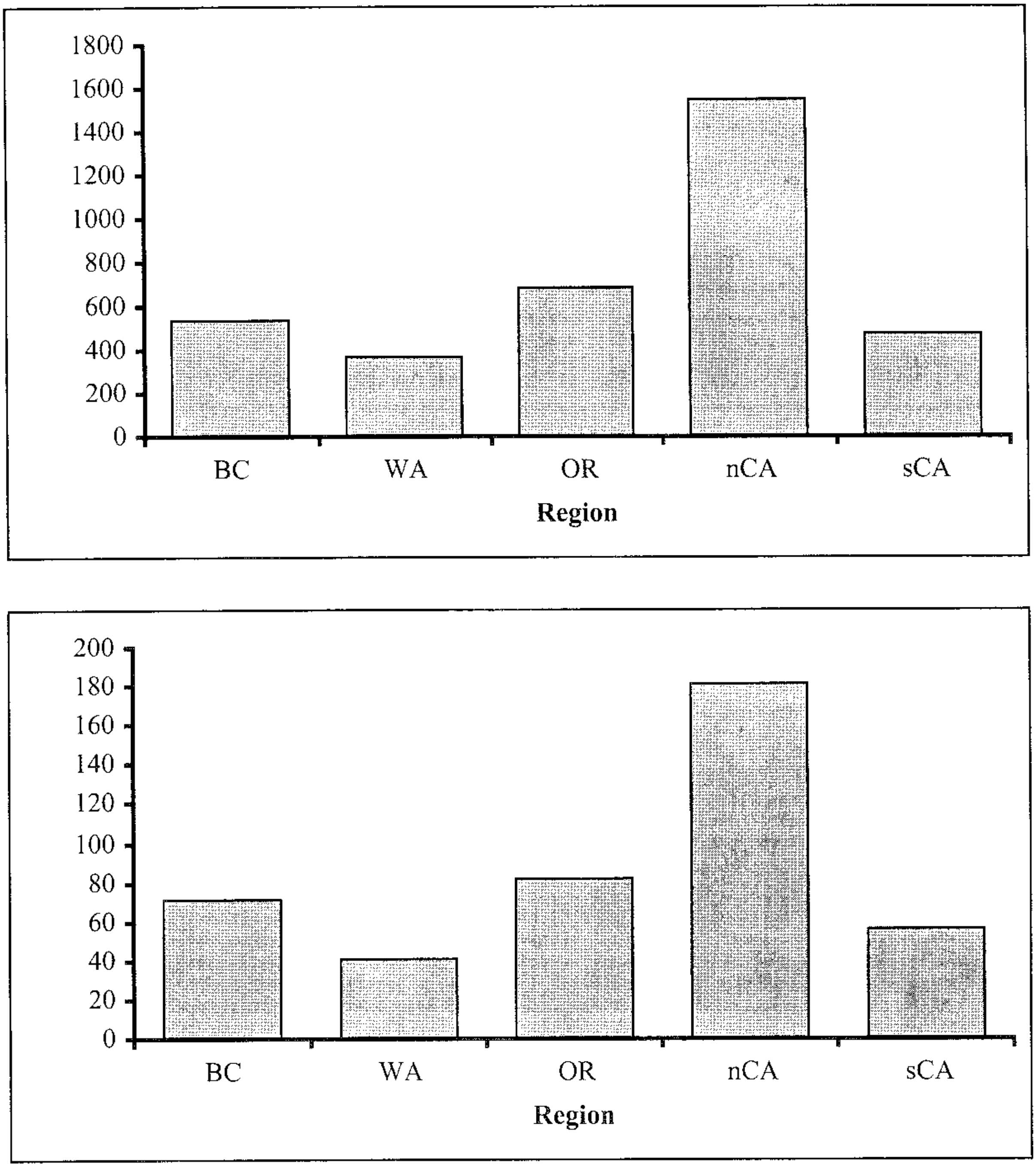
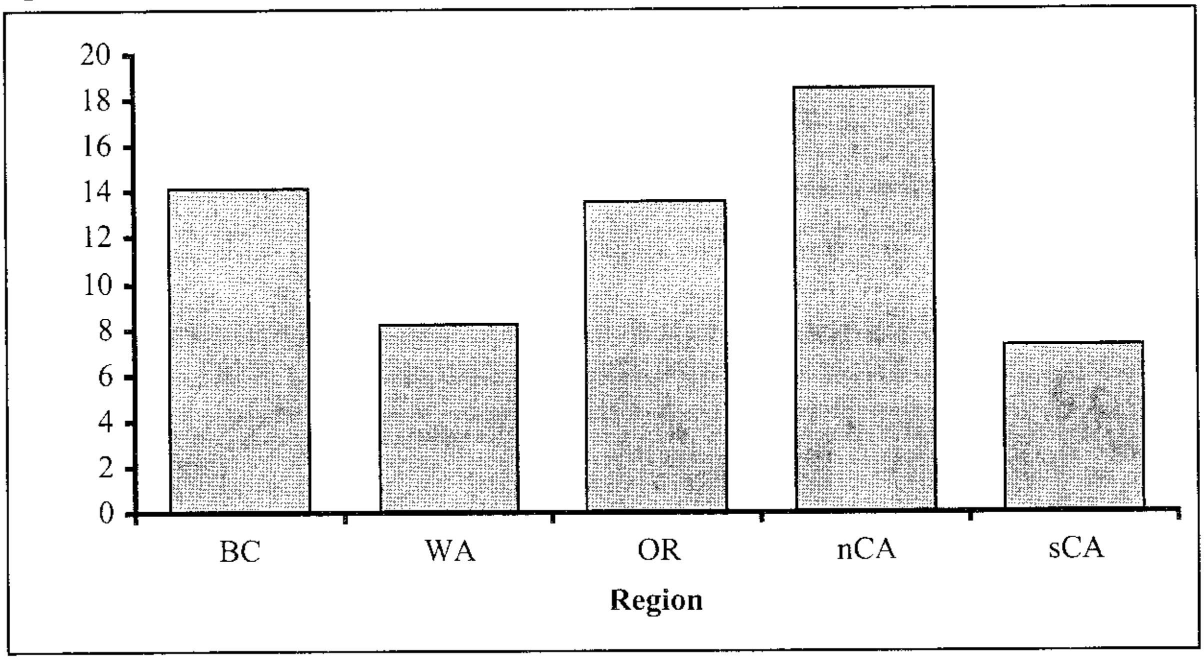


**Figure 2A & B.** Annual biomass and energy demand per km$^2$, by region.



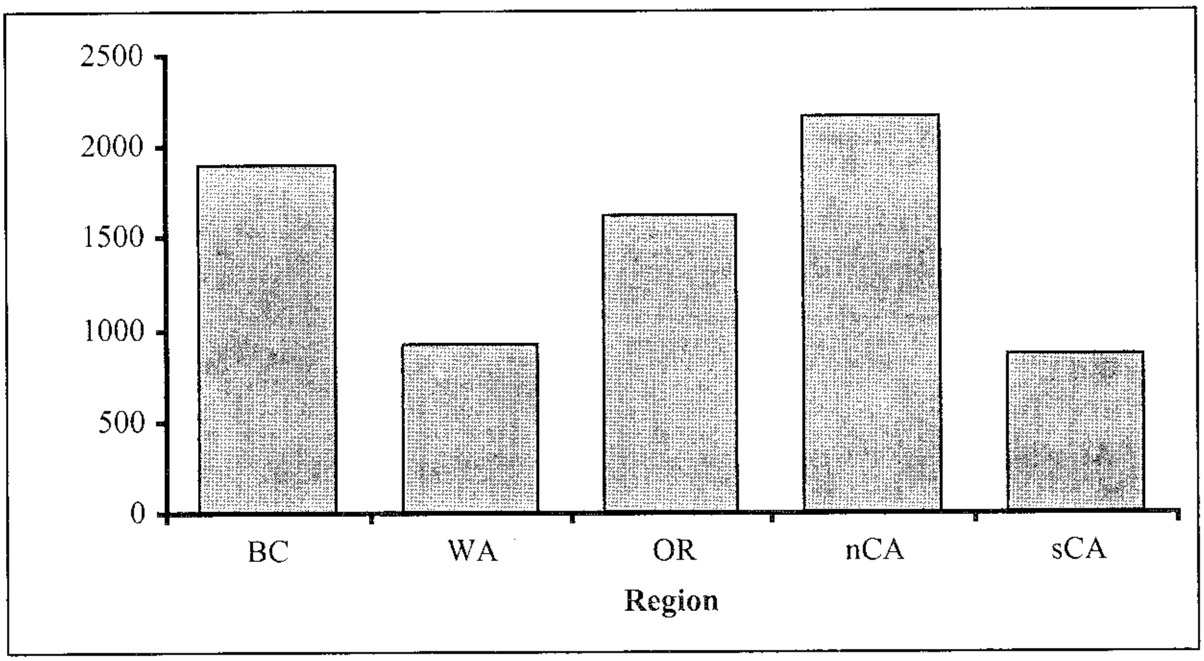
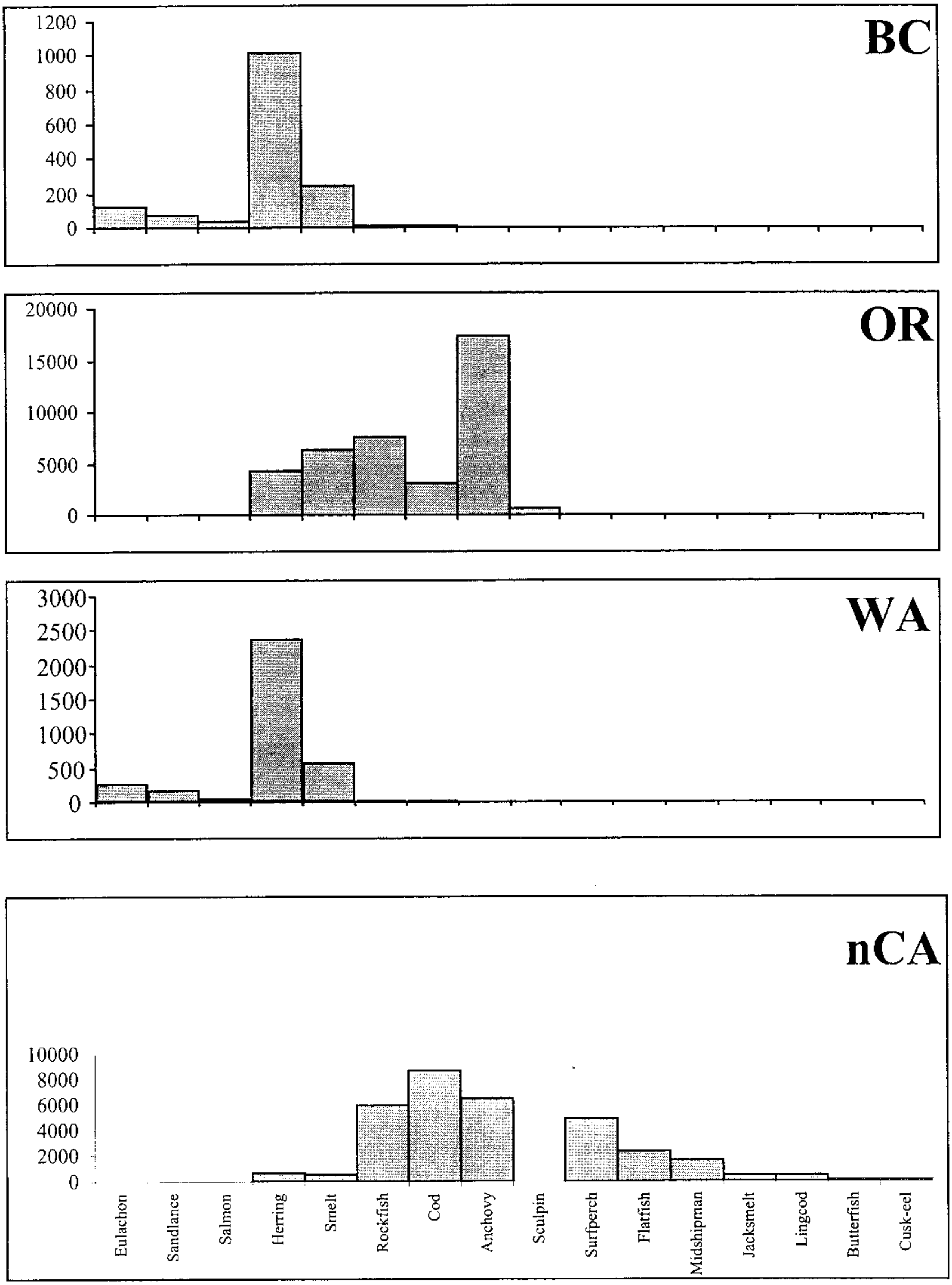



**Figure 3.** Annual prey consumption in MT of common murres, by region.



## *Large-and Long-Term Natural Variability of Small Pelagic Fishes in the California Current*

**Rodríguez-Sánchez, R., D. Lluch-Belda, H. Villalobos and S. Ortega-García**
**Centro Interdisciplinario de Ciencias Marinas (CICIMAR - I.P.N.), La Paz, Mexico**

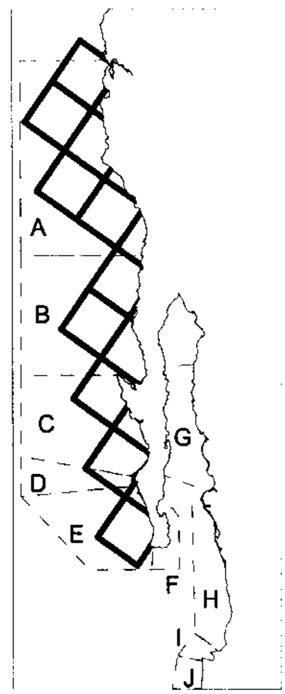
A number of recent studies have suggested that ocean-climate interactions can drastically change the productivity of small pelagic fish populations in different current systems, with seemingly parallel variations in the biomass of phytoplankton, zooplankton, and other fish.

*Sardinops* and *Engraulis* populations, occurring in most of both eastern and western boundary currents seem to be very sensitive to climate-driven interdecadal regime shifts in the systems, and have been associated to long-term changes in distribution. When their population level within a current system is high they dominate its entire neritic zone. Alternatively, when their population level is low their distribution is greatly reduced and they are at times totally absent from certain areas. That spatial processes is known as expansion-contraction.

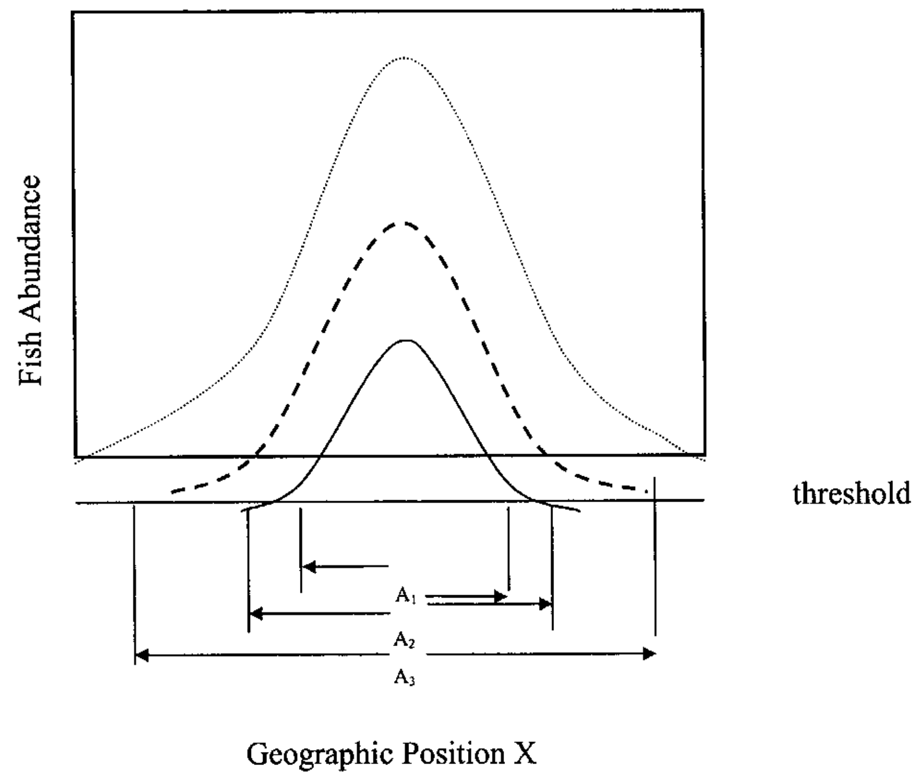
Live-bait boats fishing for tuna in the California Current use as bait available clupeoid fishes caught in the vicinity of tuna fishing grounds. The wide distribution of this fleet during a 50-year period is analyzed on yearly and decadal basis for the area ranging from the California coastline in the north to Cabo Corrientes in the south, including the Gulf of California.

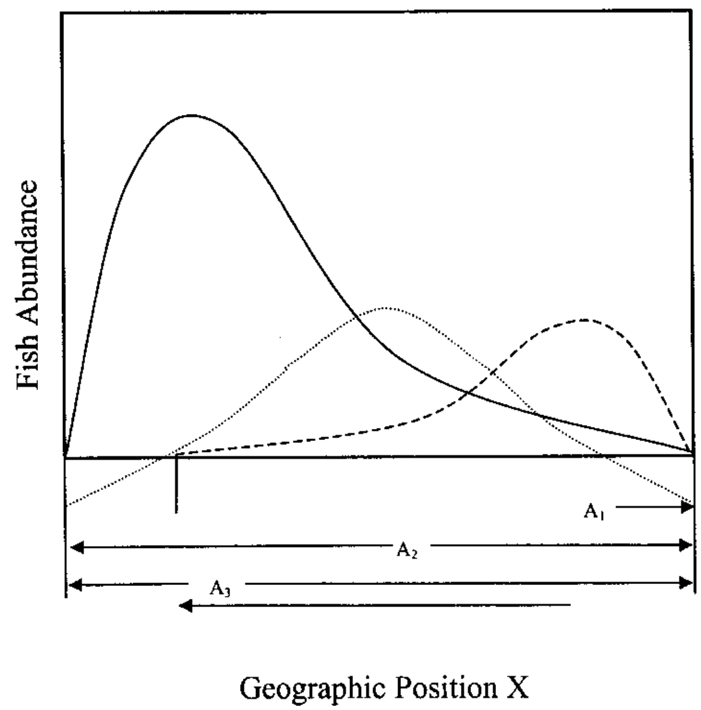
The CPUE pattern for live-bait species, used as a proxy of abundance, suggests that when *Sardinops caeruleus* population increases its geographic range, the bulk of its biomass and the center of distribution is in the north. Prior to the 1960s, when the population was reducing its range, the center of distribution and bulk of abundance shifted from north to south and massively entered the Gulf of California during the cold 1960s.This population movement maybe gave rise to a new fishery inside the Gulf of California.The spatial process described here is different to that of homogeneous spread resulting from simple expansion-contraction.

A spatial pattern of *Engraulis mordax* abundance alongshore is inferred assuming that sardine abundance is deletereous to anchovy populations. Anchovy colonized and increased its abundance where sardine population level was low or absent.

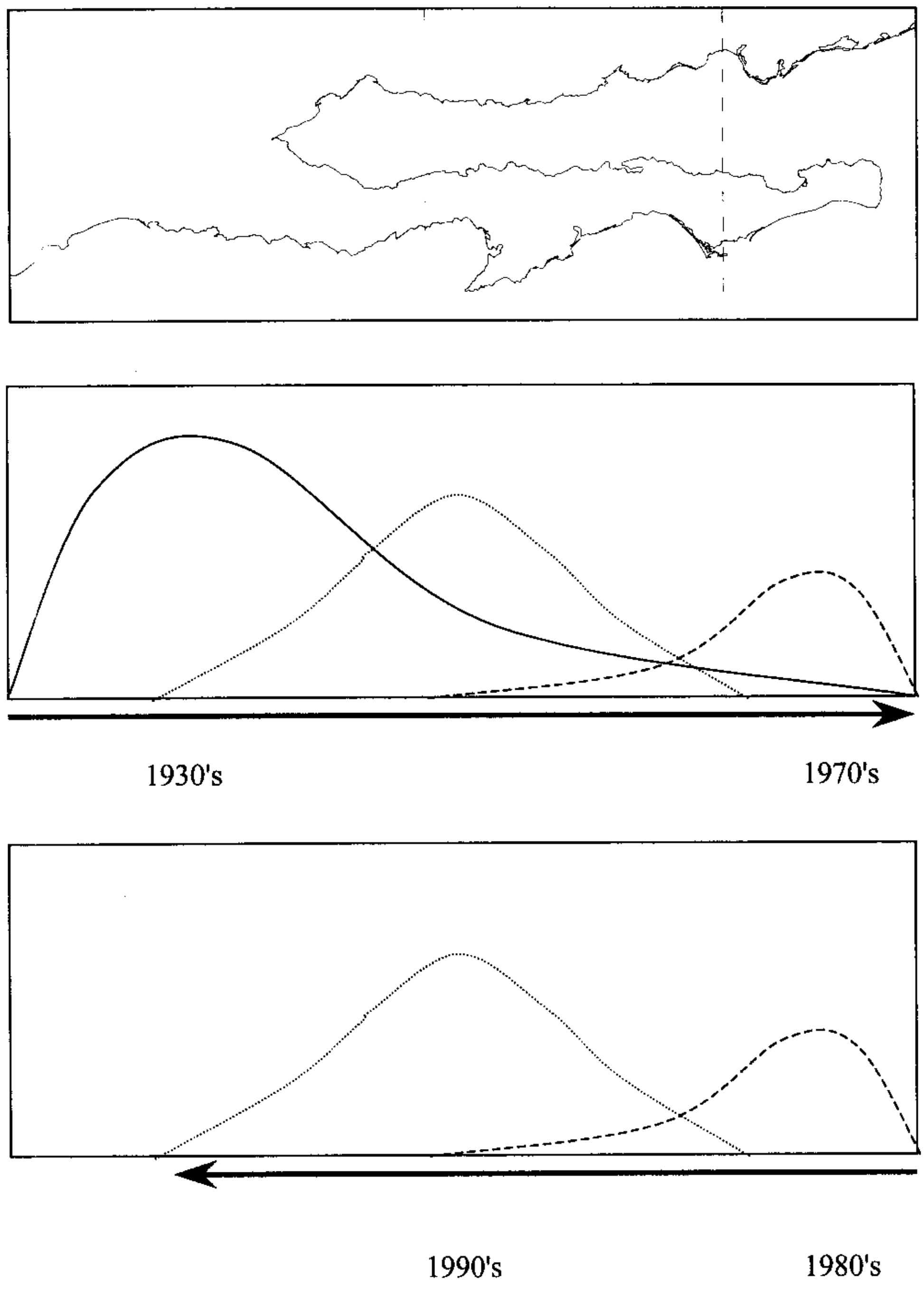



Live-bait fishery areas off California, Baja California and Gulf of California (after Alverson and Shimada 1957), including squares of 2 X 2 degrees from which time-series of SST were obtained from COADS database.




Simplified diagram illustrating the differences between an homogeneous spread resulting from simple expansion-contraction and the spatial process described here for *Sardinops caeruleus*.




Schematic diagram illustrating the large- and long-term sardine population movement. When sardine abundance population increased its geographic range, the bulk of its biomass and the center of distribution was in the north. When the population was reducing its range, the center of distribution and bulk of abundance shifted from north to south. Currently, the abundance of sardine in the California Current System is increasing its range. If the trend of this movement continues our hypothesis predicts an increase in sardine abundance off California and decreasing off Magdalena Bay.

# *Effects of Foraging Strategy on Catches of Northern Bluefin Tuna (Thunnus thynnus) in the Eastern Pacific*

**Rodríguez-Sánchez, R., H. Villalobos-Ortiz, D. Lluch-Belda and S. Ortega-Garcia**
**CICIMAR-IPN, La Paz, Mexico**

Northern bluefin tuna, *Thunnus thynnus*, apparently spawns only in the western Pacific and a portion of the juveniles migrate to the eastern Pacific. During the past decade, catches in the eastern Pacific have declined. One possible cause for this, proposed by Dr Polovina at Honolulu Laboratory SWFSC-NMFS, is a reduction in the proportion of bluefin that migrate out of the western Pacific since 1977. This period of reduced bluefin migration coincides with one during which a prey of bluefin, the Japanese sardine *Sardinops melanosticta*, was abundant off Japan. Polovina's hypothesis points out that during years when sardines are abundant off Japan, a higher proportion of bluefin stay in the western Pacific, as compared to years during which sardines are scarce.

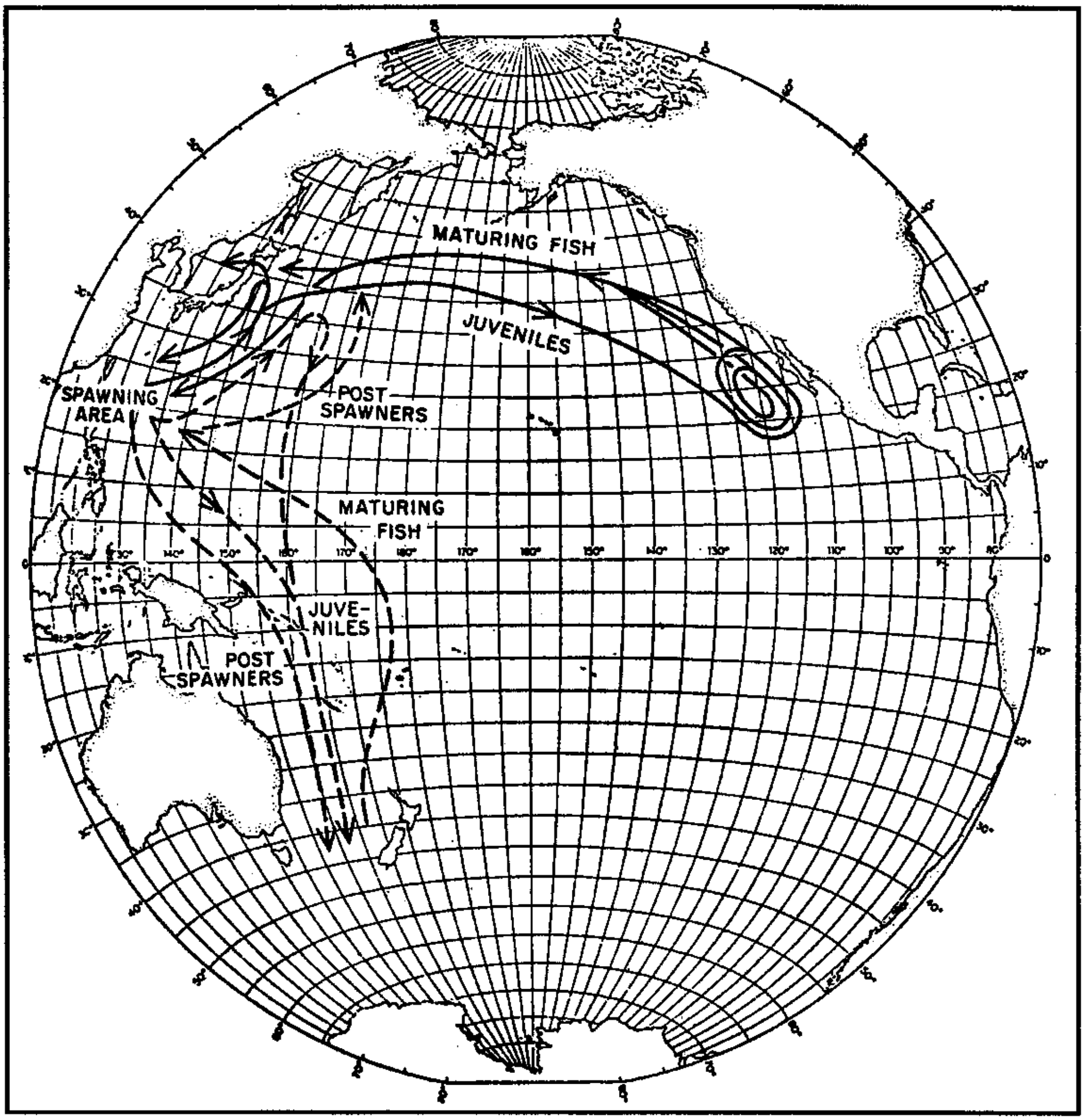
Why does northern bluefin tuna go so far as off the Baja California peninsula, Mexico?

The Pacific or California sardine *Sardinops caeruleus* is distributed along the California Current; it is a similar prey for northern bluefin tuna. We are currently undartaking studies of both spatial and temporal distribution of California sardine using catch records of live-bait by boats fishing for tuna along the California, Baja California, and Gulf of California coasts during a 50-year period (1931-79). The results will shed light on the question of why northern bluefin tuna reaching the eastern Pacific are caught mostly off Baja California.

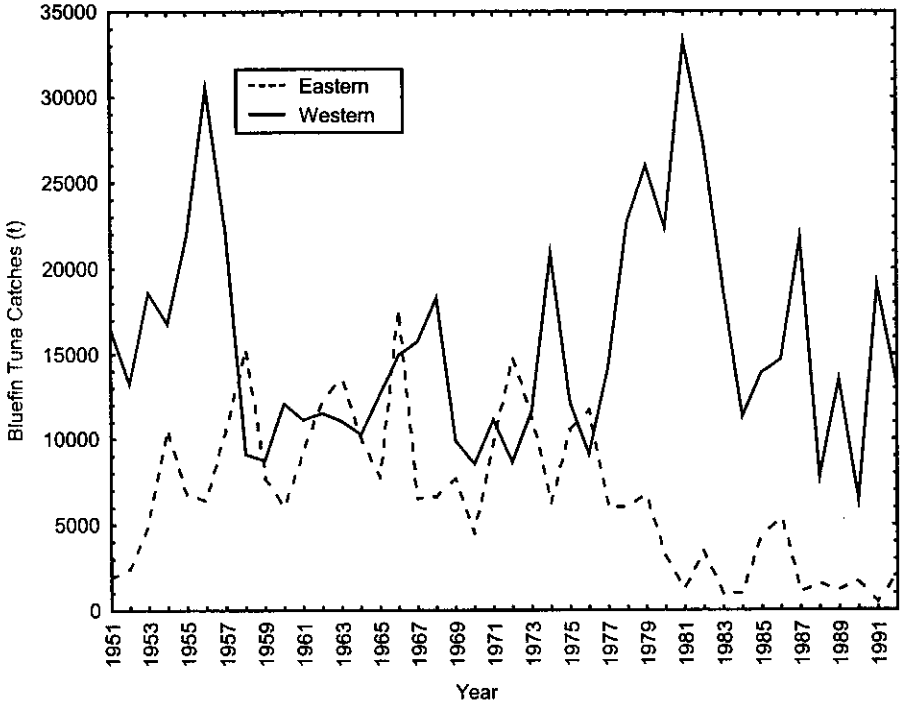
The spatial and temporal results of this sardine studies agrees with already published papers. California sardines were abundant off California during the 1930's, with catches plummeting during the 1940's without recovery until the end of the period. Lagging about a decade, they were abundant south of the Mexico-USA international border to Punta Eugenia during the 1940's, collapsing during the 1950's. In the Punta Eugenia to Cabo San Lázaro subarea, California sardine has always been present during the 50 year series, showing some variations in abundance along with cold-warm periods. These features agree with the formerly published hypothesis of a resident California sardine population in this area.

A permanent population of California sardine off Baja California is an alternative source of food always available to northern bluefin tuna when Japanese sardine abundance diminish. If the Japanese sardine is abundant, a higher proportion of bluefin stay in the western Pacific compared to those years when sardines are scarce, when bluefin migration increases towards the eastern Pacific looking for California sardine.

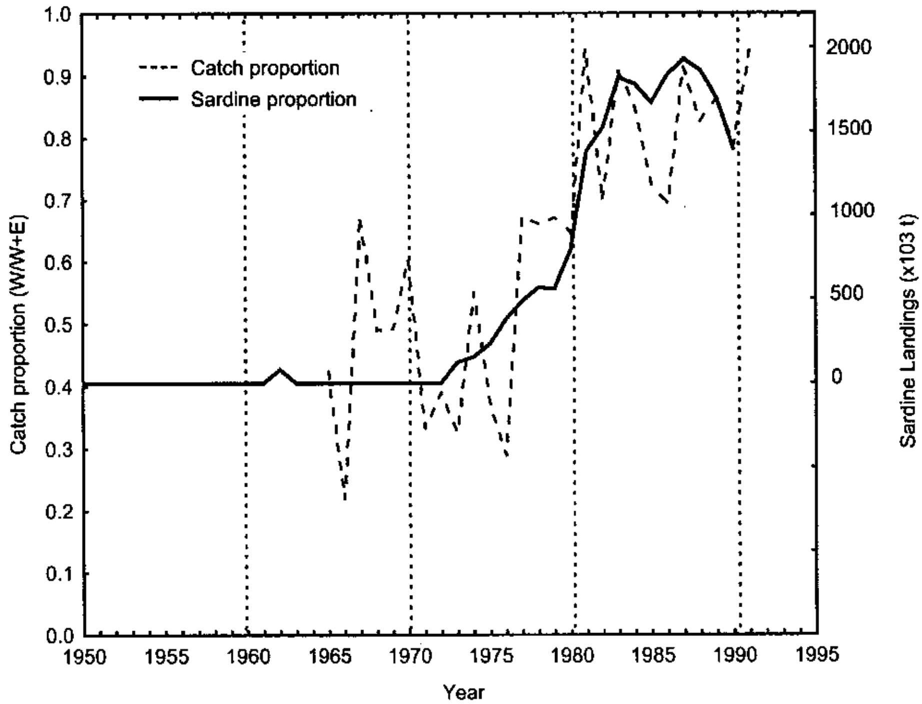
Tuna, as any other animal, seeks to achieve a maximum net energy gain to maximize its lifetime reproductive success, or fitness. The total energy consumed as food minus the energy costs of obtaining it (e.g. staying in the western Pacific or migrating to the eastern Pacific) is the net energy gain. The way in which bluefin tuna is achieving a long-term maximum net energy gain has resulted in such a foraging strategy.



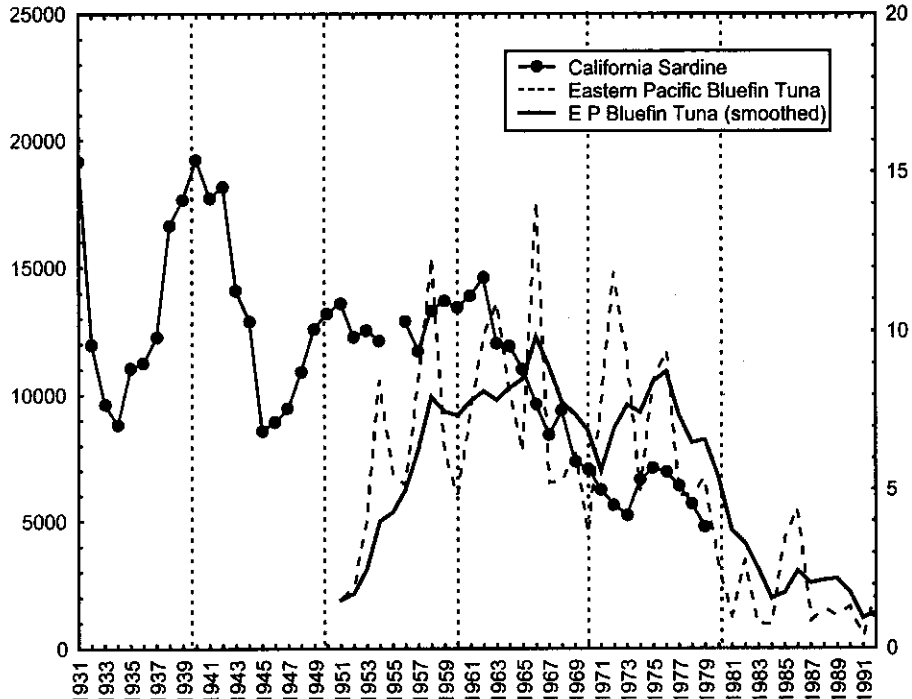

A model for northern bluefin migration in the Pacific Ocean (taken from Bayliff 1980)




Landings of northern Pacific bluefin tuna (short tons) from the western and eastern Pacific Ocean 1951-1992 (Taken from Polovina, 1996)




Proportion of age 1-4 northern Pacific bluefin caught in the western Pacific relative to combined eastern and western Pacific catches overlaid with north Pacific landings of sardine (Taken from Polovina, 1996)




Pacific bluefin tuna caught in the eastern Pacific overlaid with California sardine CPUE in the California Current

## *Towards an Ecosystem Management Plan for the Northern California Current: The Role of Coastal Pelagic Species*

**John Field, Robert Francis, and Lorenzo Ciannelli, University of Washington, Seattle, Washington**

In recognition of the need for a broader approach to fisheries management, the 1996 Sustainable Fisheries Act established an advisory panel of experts to develop recommendations to expand the application of ecosystem principals in fishery conservation and management activities. Among the recommendations of that panel's report were that the regional Fisheries Management Councils develop demonstration Fisheries Ecosystem Plans (FEP's) for the ecological systems under their jurisdictions, in the interest of advancing the ability to quantitatively employ the holistic objectives of ecosystem management principals (EPAP 1999).

Among the key elements that should be included in such plans were : delineating the geographic extent of the ecosystems that occur within Council authority, including characterization of the biological, chemical and physical dynamics of those ecosystems; developing conceptual models of the food webs in those systems; calculating total removals (including incidental mortality) and showing how these removals related to standing biomass, production, optimum yield, natural mortality and trophic structure. Using the Northern California Current as a test case, we intend to develop some of these elements of a draft FEP.

One of the most significant human effects on marine ecosystems is the alteration of biotic communities by fishing activities, which are often directed at the middle or near the tops of food webs. Actual structural changes to trophic webs could occur in heavily fished marine ecosystems (Apollonio, 1994; Parsons, 1993), thus the ecological effects of fishing could be substantially greater and more complex than the reductions in the biomass of the target species themselves. Both contemporary process-oriented research and paleo studies have clearly demonstrated that the productivity and abundance of populations in the Northern California Current are associated with large scale variability in various physical properties. However, this does not necessarily preclude alterations or perturbations to the ecosystem resulting from biological removals.

The NCCE has a lengthy history of exploitation; beginning with the depletion of marine mammal populations in the 19$^{th}$ century and the sequential development of major fisheries for salmon, sardine and herring, groundfish, shellfish and hake over the past 150 years. Currently the cumulative removals from the system approach five hundred thousand metric tons per year. Because the potential consequences of these removals are uncertain, one of our goals is to refine our understanding of how trophic structure could change depending both upon the magnitude of the removals and the climatic regime under which those removals occurred.

In terms of defining the system, Bottom et al (1993) divided the California Current Ecosystem into two major subregions north and south of Cape Mendocino, CA, and suggested that the northern region (or the northern California Current Ecosystem, NCCE) is an appropriate ecological unit for regional resource management. As a first step in evaluating both the consequences of fishery removals and the potential varying states of the system in response to climate forcing, we have constructed a simplified numerical model of the NCCE food web using Ecopath software to amass critical food habit and other trophic data. The general assumption in this approach is that over an appropriate period of time (perhaps a decade, or decades which have been identified as regimes) a mass-balance model can be generated to represent basic trophic interactions between the major components (species or species assemblages) of an ecosystem. Balanced models are a framework for summarizing information over trophic levels and comparing the trophic structure, flux rates and construction of food webs both within and between ecosystems.

The basic Ecopath interactions were constructed by Polivina (1984), and developed into an interactive software package by Christenson and Pauly (1992). The model is essentially little more than a series of linear equations, where the production of each component is equal to its withdrawals by other components in the system (predation mortality, natural mortality and flow to detritus) and removals from the system due to fishing mortality or migration (for details, see also www.ecopath.org). There are quite significant and very real constraints in attempting to construct any mass balance model which purports to represent the steady state of any system, particularly a transition environment best characterized by the enormous level of physical and biological variability on broad spatial and temporal scales. Amongst the major constraints include the lack of abundance or production data for a vast majority of species assemblages, uncertainty over key biological rates, and the inability to account for the disconnect between population stability and recruitment processes. Perhaps most troubling would be the high degree of aggregation of parameters over species (and populations), age and size classes, and spatial structure.

Despite these limitations, a mass balance approach is a useful starting point for evaluating the amount of energy transferred through a system, and may be an effective tool for comparing different states of the ecosystem over time. As mentioned previously, systems may be affected both by climate variability and change (bottom up forcing) and by fishing pressure (top down forcing). As an example of the applications of this approach, Trites et al. (1999) used the Ecopath model to develop two snapshots of the structure of the Bering Sea ecosystem in 1950 and 1980, to assess the hypothesis that major changes in ecosystem structure were driven by the harvest of major predators (notably baleen whales) in the mid-20$^{th}$ century. Similarly, Jarre-Teichmann and Christensen (1998) developed a series of Ecopath models for Eastern Boundary Current Ecosystems to compare differences in productivity, primary production requirements and energy transfer efficiencies in upwelling ecosystems. In all these models forage fish such as capelin, anchovy and sardine are critical links in the transfer of energy and biomass from producers and consumers to higher trophic levels. Accounting for the estimated consumption and energy transfer of forage fish has also proven to be among the most significant challenges in modeling large-scale changes in ecosystem structure and efficiency.

We believe that there are numerous ways in which a successful mass balance approach may help both managers and researchers understand the magnitude and consequences of changes in the trophic structure in the NCCE. Such an approach may also offer insights regarding the effects of the historical removal of species and populations from the NCCE system over the last 200 years, to assess whether top-down forcing could be a significant factor in maintaining stability in trophic structure. Similarly, the model might also be used to compare climate regimes, and could be useful in accounting for changes in productivity and/or transport of nutrients and plankton which may be necessary to account for large-scale changes in biomass or fisheries production. A model may also be useful to assess the extent to which the high biomass levels of pelagic species estimated by paleo studies to have occurred in the early 20th century, such as sardine and hake, are in balance with concurrent estimates of zooplankton production. Ultimately, we hope to reveal insights as to how the potential interactions of fishing and physical forcing alter both ecological structure and stability, and in doing so further the search for new directions in sustainable fisheries management.

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# *Sardines in the Ecosystem of the Pacific Northwest*

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The Pacific sardine (*Sardinops sagax*) has been one of the most dominant pelagic fishes in the California Current system over the last several millennia and its abundance has fluctuated greatly over time (Baumgartner et al. 1992). During peak abundance periods, this population is capable of supporting major fisheries. The main population and fishery is centered in central and southern California, but during periods of high abundance and warmer ocean temperatures, some portion of the population resides off Oregon, Washington, and British Columbia, with some schools or individuals making it as far north as southern Alaska (Hart 1973, Wing et al. MS). At these times, commercial fisheries develop for sardines, or pilchards as they are called locally, in the Pacific Northwest (PNW) and off British Columbia. In order to effectively manage a fish stock, it is necessary to acquire some basic biological parameters on the stock; however, we are generally lacking any such information on sardines in the PNW.

Sardines were first landed commercially in Oregon during the 1935-36 fishing season and a year later in Washington, well after the commencement of fisheries in both California and British Columbia (Chapman 1936, Schaeffer et al. 1951). Fish were landed in Gray's Harbor, Washington, Astoria and Coos Bay, Oregon, and were generally rendered to oil and fishmeal. Following the collapse of the fishery in the late 1940s, there have been few reports of sardine captures in the PNW. Reid (1960) reported the catch of a single male in Winchester Bay, Oregon in August of 1957. In purse seine surveys off the coast of Oregon and Washington from 1979-1985, five sardines were caught between June and September of 1984, all off central Oregon (Brodeur and Pearcy 1986, Pearcy and Schoener 1987). Ermakov and Stepanenko (1996) also reported that some sardines were caught in the PNW in the 1980s. These sporadic occurrences are apparently connected to warm ocean conditions and anomalous northward advection associated with El Niño (Pearcy and Schoener 1987). These warm years were generally followed by cool years that may have inhibited the growth of the northern sardine population.

Beginning in 1992, sardines increased dramatically in the PNW as first reported by Hargreaves et al. (1994), again apparently in response to 1992-93 El Niño. This time, however, they continued to increase and even reproduce in the PNW up to the present time (Bentley et al. 1996, McFarlane and Beamish 1999, Busby et al. MS). This change followed an apparent regime shift and coincided with a dramatic increase in overall pelagic fish biomass off the PNW (Emmett and Brodeur 2000). Using a variety of data sources, we describe biological characteristics such as the distribution, life history and ecological relations of sardines during this recent population increase.

**Results**

Egg and larval distribution related to environment – The National Marine Fisheries Service (NMFS) conducted ichthyoplankton surveys off the coast of Oregon and Washington for five years (1994-1998) sampling a similar grid of stations every July. The sampling consisted of a vertical tow with a CalVET net to a maximum depth of 70 m (Bentley et al. 1996). Sardine eggs were distributed over a substantial proportion of the study area and extending well offshore (Fig. 1). In some cases (e.g. 1995) the entire range of the distribution was probably not effectively sampled. Eggs were generally distributed between the 14° and 16° C isotherms, except in 1995 and 1997 when these isotherms were pushed close to shore (Fig. 1). The distribution of sardine larvae was similar to that of the eggs, although they were slightly farther offshore in most cases (Fig. 2).

Adult distribution and size – To describe the adult distribution of sardines, we used three different data sources more fully described in Emmett and Brodeur (in press). It should be noted that none of these surveys were specifically targeting sardines and the distribution of sampling effort was mostly at predetermined station locations.

The first comes from the NMFS West Coast triennial groundfish bottom trawl surveys that began in 1979 (data courtesy of Mark Wilkins, AFSC, Seattle). We examined catches only from the U.S.-Canada border south to 42° N, although many sardines were caught outside this region. Sardines were first caught beginning in the 1992 summer survey, with the highest catches mainly around the Columbia River (Fig. 3). Sardines were distributed mainly over the middle and outer shelf regions. In the 1995 survey, sardines appeared to be more spread out occurring both farther to the south and more inshore compared to 1992, although the overall abundance was lower. In 1998, catches were lower still and occurred predominantly in the vicinity of the Columbia River (Fig. 3). Biomass caught in this survey has shown a steady decline in both the U.S. Vancouver and Columbia statistical regions since 1992 (Fig. 5). Several age-classes are apparently represented in these catches in 1998 (Fig. 4). There is a progression of the dominant size mode from south to north, with a second smaller group appearing off northern Washington.

During the summer and fall of 1998 and 1999, NMFS conducted near-surface surveys for juvenile salmon along transects off the Washington and Oregon coasts (Emmett and Brodeur 2000). Sardines were collected in all five surveys although the catch varied greatly (Fig. 6). They were widely caught during the May, 1998 cruise from Gray's Harbor south to the Central Oregon Coast. The next three surveys caught relatively few sardines but by the September cruise, they again occurred in very high numbers, but at stations mainly north of the Columbia River (Fig. 6). The size distribution in 1998 was generally very broad compared to the 1998 triennial survey (Fig. 7). In 1999, however, there was a narrow range of individuals represented, although there were relatively few fish caught in May and June.

The last survey examined was a series of biweekly cruises in the area of the Columbia River plume in spring and summer of 1998 and 1999 (Emmett et al. MS). These generally used the same trawl as the salmon surveys but were targeting predators so they mainly fished at night. Sardines ranked third in abundance in 1998 but was the dominant species caught in 1999, making up more than a third of the total catch. No sardines were caught in April or May but were caught rather consistently beginning in June through August (Fig. 8).

Food habits -- Collection of Pacific sardines from research trawls off of La Push (LP transect) and Willapa Bay (WB transect), Washington, during September 1999, has allowed for an initial investigation into the trophic role of sardines in this region. Immediately after collection, stomachs were preserved by either freezing or placing in 10% buffered formalin. Five sardine stomachs were analyzed from each station. The two anterior-most compartments were used in the analysis. Contents were removed and washed through a series of 500, 200 and 100μm sieves to separate phytoplankton from animal contents for volumetric measurement. Volume was measured by settling contents in a volumetric test tube for approximately 24 h.

Phytoplankton and marine-snow like material made up between 50 and 70% of the volume of total contents (Table 1). All stages of copepods (*Acartia* spp., *Paracalanus* spp. and *Pseudocalanus mimus*), euphausiid eggs, and the appendicularian, *Oikopleura* spp., were the primary animal prey items. Copepodites, copepod nauplii, and euphausiid eggs were found in higher abundance from offshore stomachs, while the appendicularian, *Oikopleura* spp., was generally found more frequently in nearshore stomachs (Table 1).

Table 1. Average percent phytoplankton and average number of animals per sardine stomach.

| STATION | Phyto plankton (%) | Copepod (adult) | Copepod (cope podite) | Copepod (nauplii) | Copepod (egg) | Euphausiid (egg) | Appendicularian *Oikopleura* |
|---|---|---|---|---|---|---|---|
| WB 14 | 71 | 2 | 28 | 62 | 32 | 106 | 27 |
| WB 19 | 62 | 27 | 38 | 101 | 17 | 189 | 14 |
| LP 09 | 53 | 44 | 18 | 22 | 21 | < 1 | 15 |
| LP 22 | 63 | 15 | 33 | 70 | 3 | 55 | 12 |

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**Figure Legends**

Figure 1. Distribution of sardine eggs from NMFS 1994-1998 Ichthyoplankton surveys off Oregon and Washington. Also shown are isotherms at 3 m depth.

Figure 2. Distribution of sardine larvae from NMFS 1994-1998 Ichthyoplankton surveys off Oregon and Washington. Also shown are isotherms at 3 m depth.

Figure 3. Distribution of sardines from NMFS 1992, 1995, and 1998 triennial surveys off Oregon and Washington. Also shown is the 200 m depth contour.

Figure 4. Size distribution of sardines collected in the NMFS 1998 triennial trawl survey by degree of latitude.

Figure 5. Estimated minimum biomass of sardines off the U.S. Vancouver and Columbia Statistical regions. Numbers on graph are the coefficient of variation for the biomass. These are considered minimum since the trawl was mainly on the bottom and may not have sampled the full population of sardines which was mainly in midwater.

Figure 6. Distribution of sardines from NMFS 1998 and 1999 surface trawl surveys off Oregon and Washington. The + signs indicate locations of each trawl.

Figure 7. Size distribution of sardines collected in the 1998 and 1999 surface trawl survey by cruise.

Figure 8. Catch of sardines from the 1998 and 1999 NMFS predator surveys off the Columbia River by cruise date.

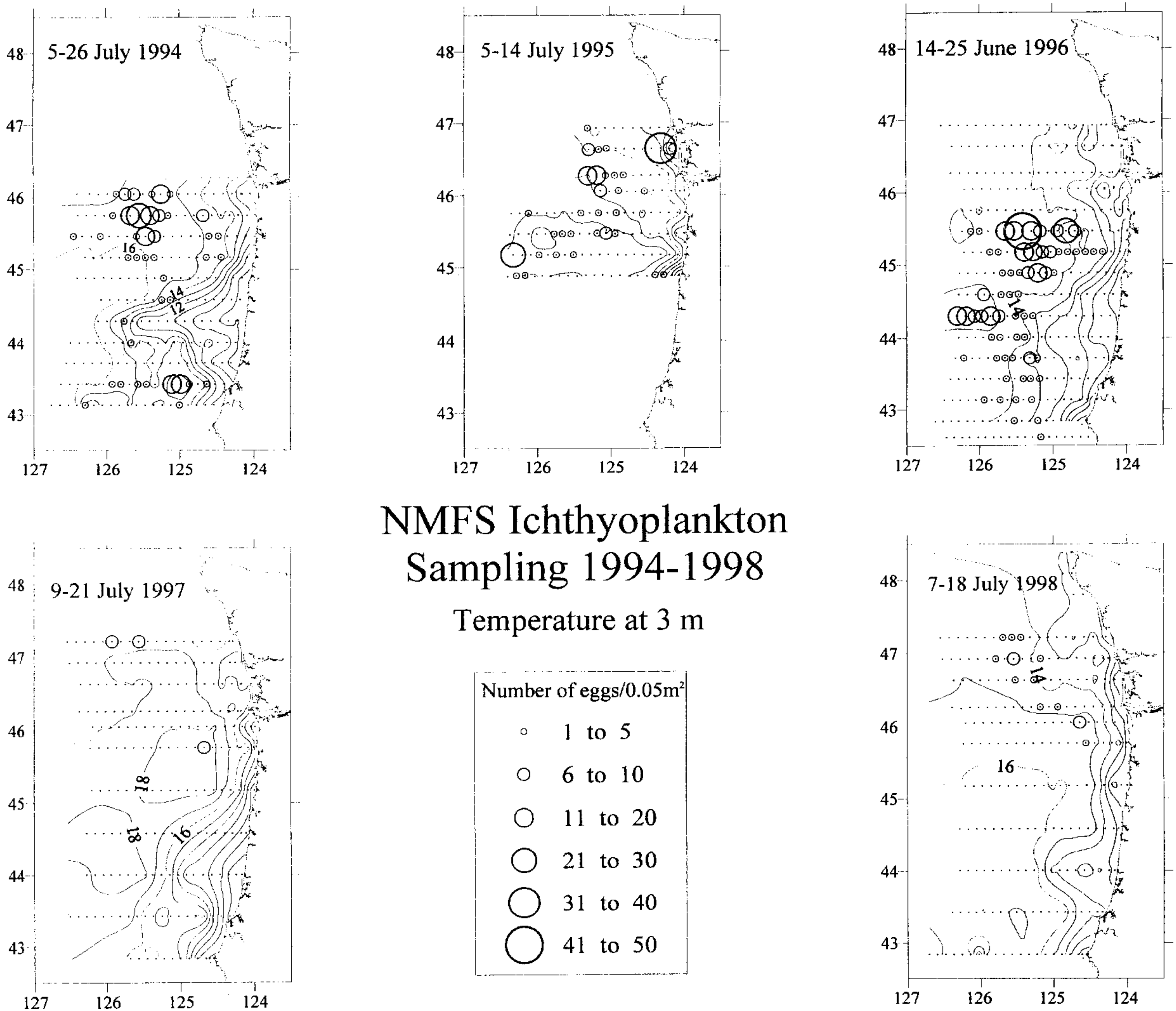
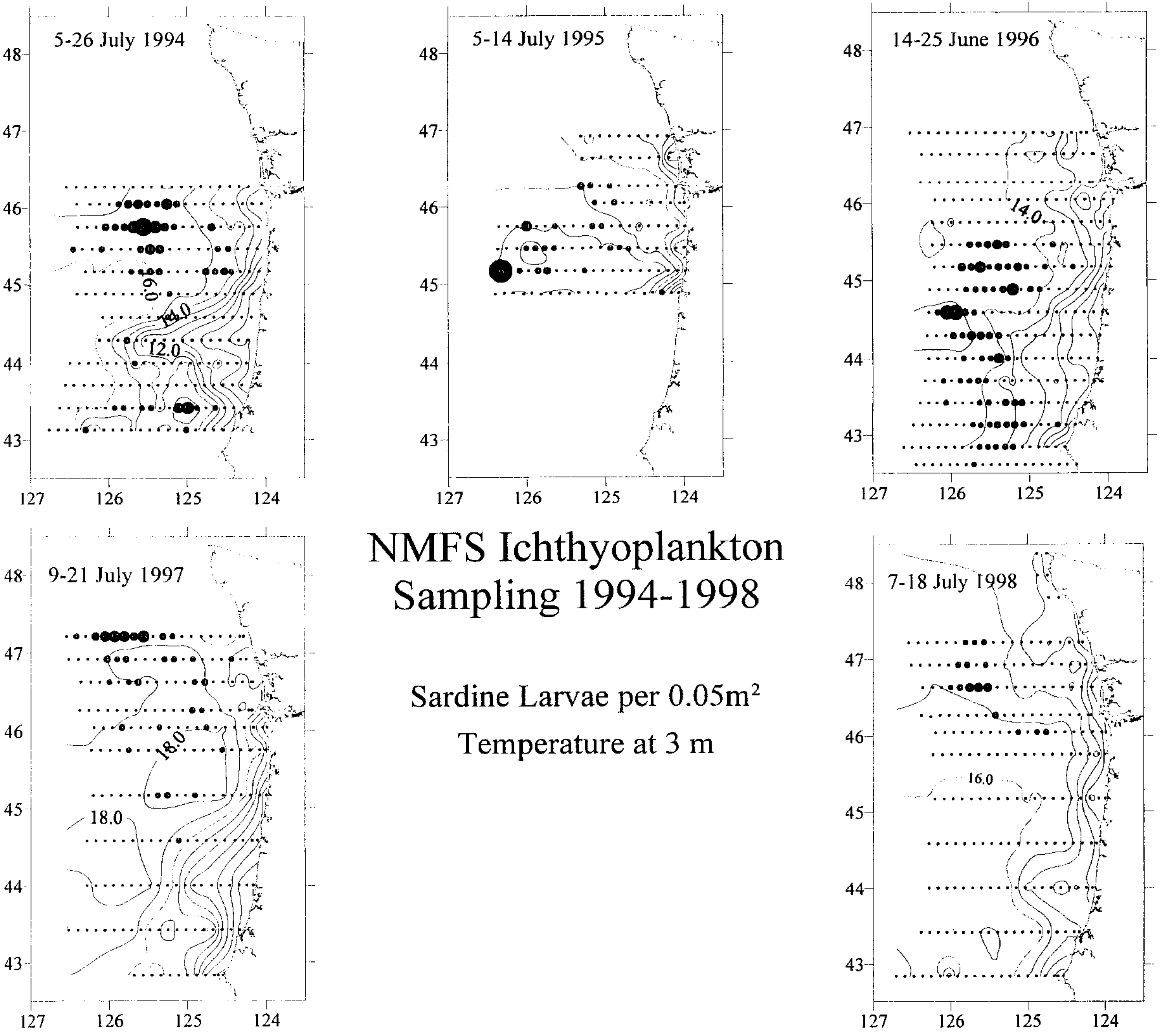

5-26 July 1994
5-14 July 1995
14-25 June 1996
NMFS Ichthyoplankton
Sampling 1994-1998
Temperature at 3 m
Number of eggs/0.05m²
1 to 5
6 to 10
11 to 20
21 to 30
31 to 40
41 to 50
9-21 July 1997
7-18 July 1998

**Figure 1**



NMFS Ichthyoplankton Sampling 1994-1998
Sardine Larvae per 0.05m²
Temperature at 3 m
5-26 July 1994
5-14 July 1995
14-25 June 1996
9-21 July 1997
7-18 July 1998
16.0
14.0
12.0
18.0
48
47
46
45
44
43
127
126
125
124


**Figure 2**

# NMFS Triennial Survey Sardine Catches

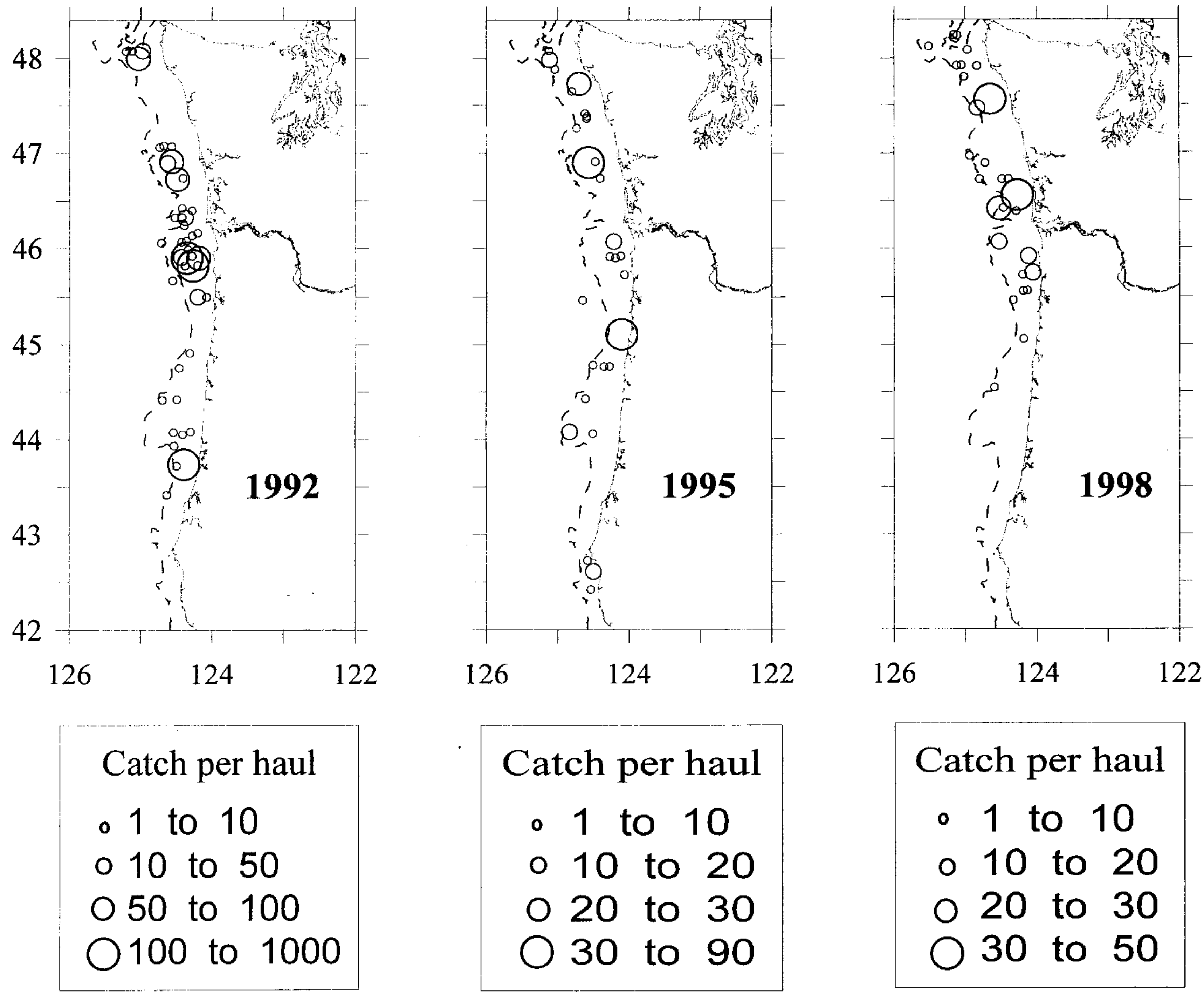



**Figure 3**

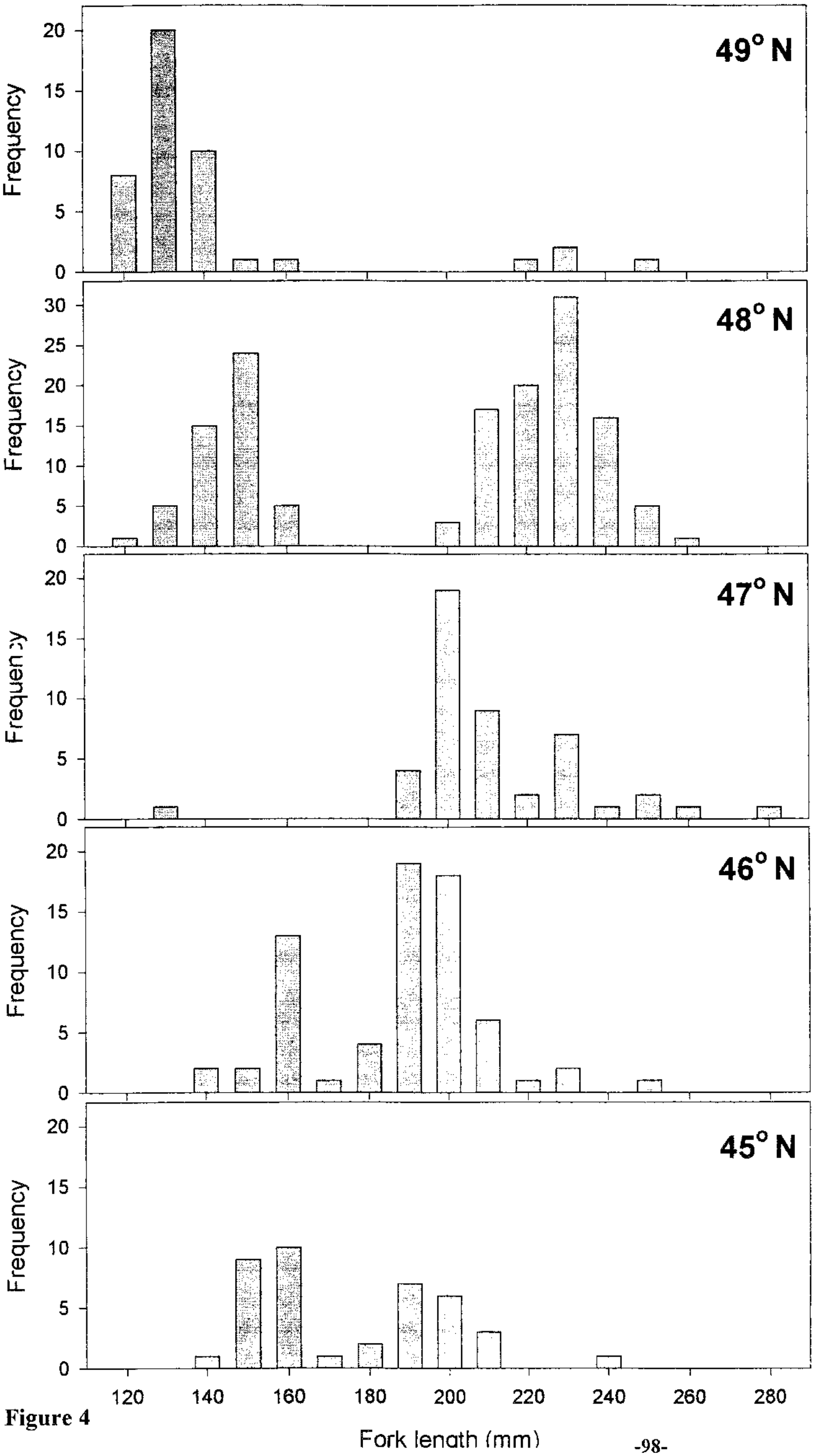
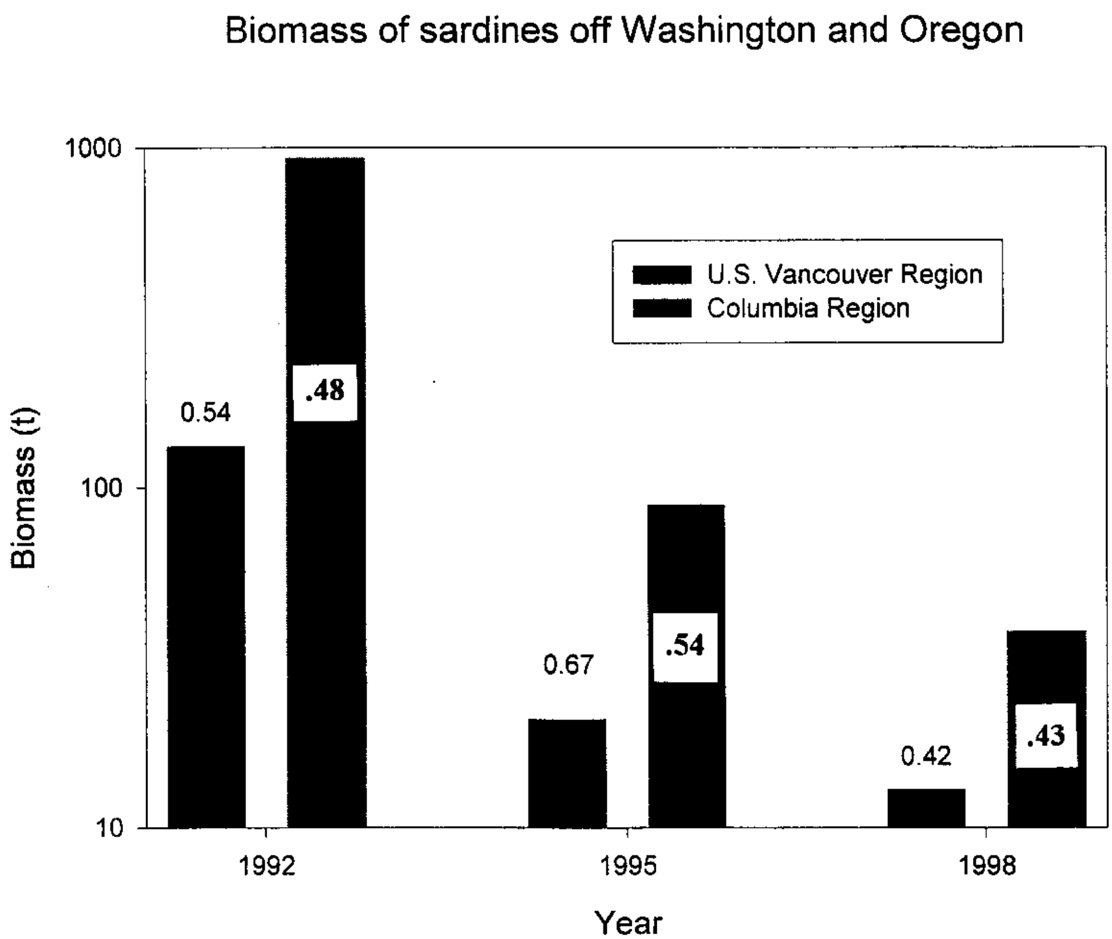

49° N
48° N
47° N
46° N
45° N
Frequency
Fork length (mm)
0
5
10
15
20
25
30
120
140
160
180
200
220
240
260
280

Figure 4



Biomass of sardines off Washington and Oregon
1000
100
10
Biomass (t)
U.S. Vancouver Region
Columbia Region
0.54
.48
0.67
.54
0.42
.43
1992
1995
1998
Year


Figure 5

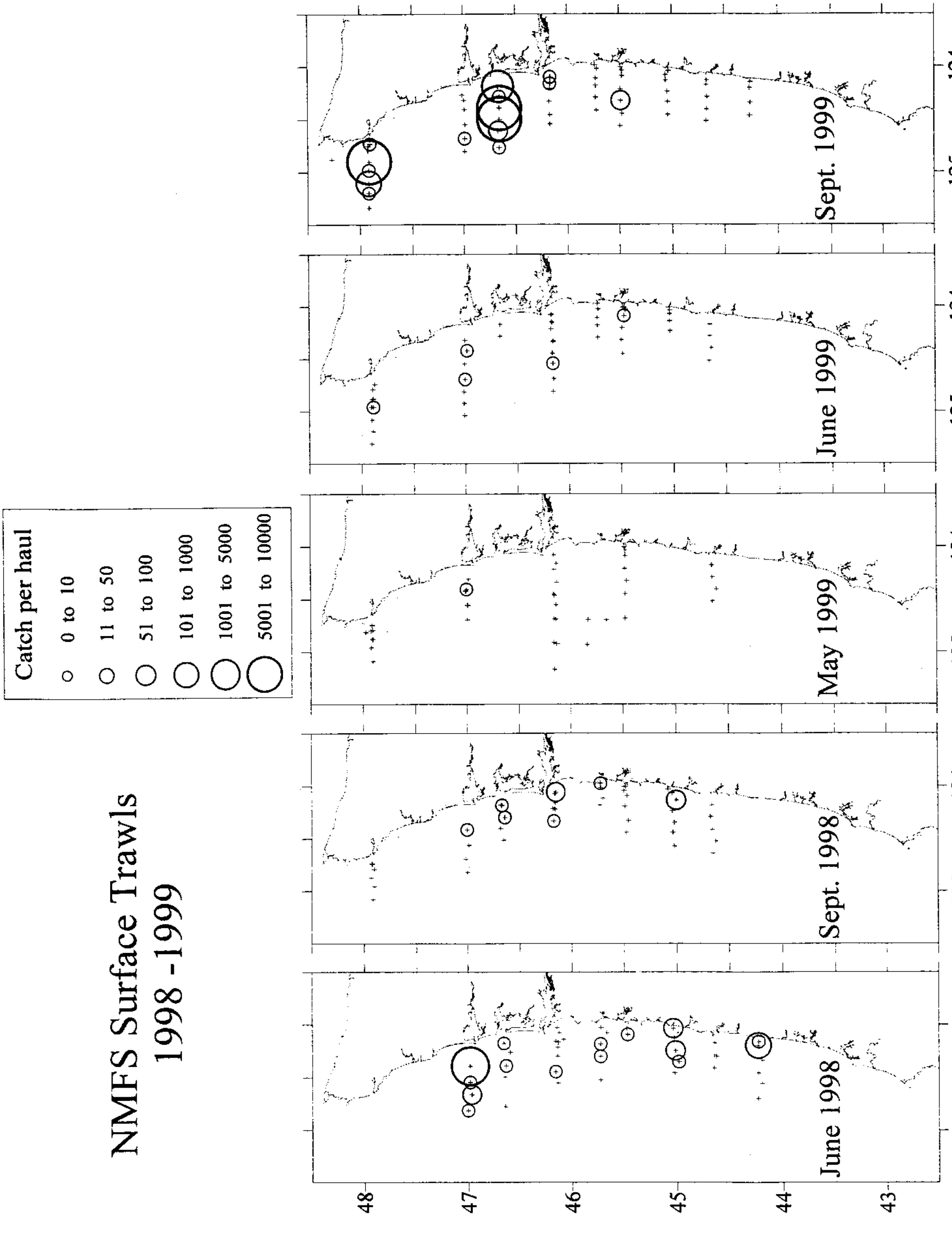

NMFS Surface Trawls
1998 -1999
Catch per haul
0 to 10
11 to 50
51 to 100
101 to 1000
1001 to 5000
5001 to 10000
June 1998
Sept. 1998
May 1999
June 1999
Sept. 1999
48
47
46
45
44
43
124
125

**Figure 6**

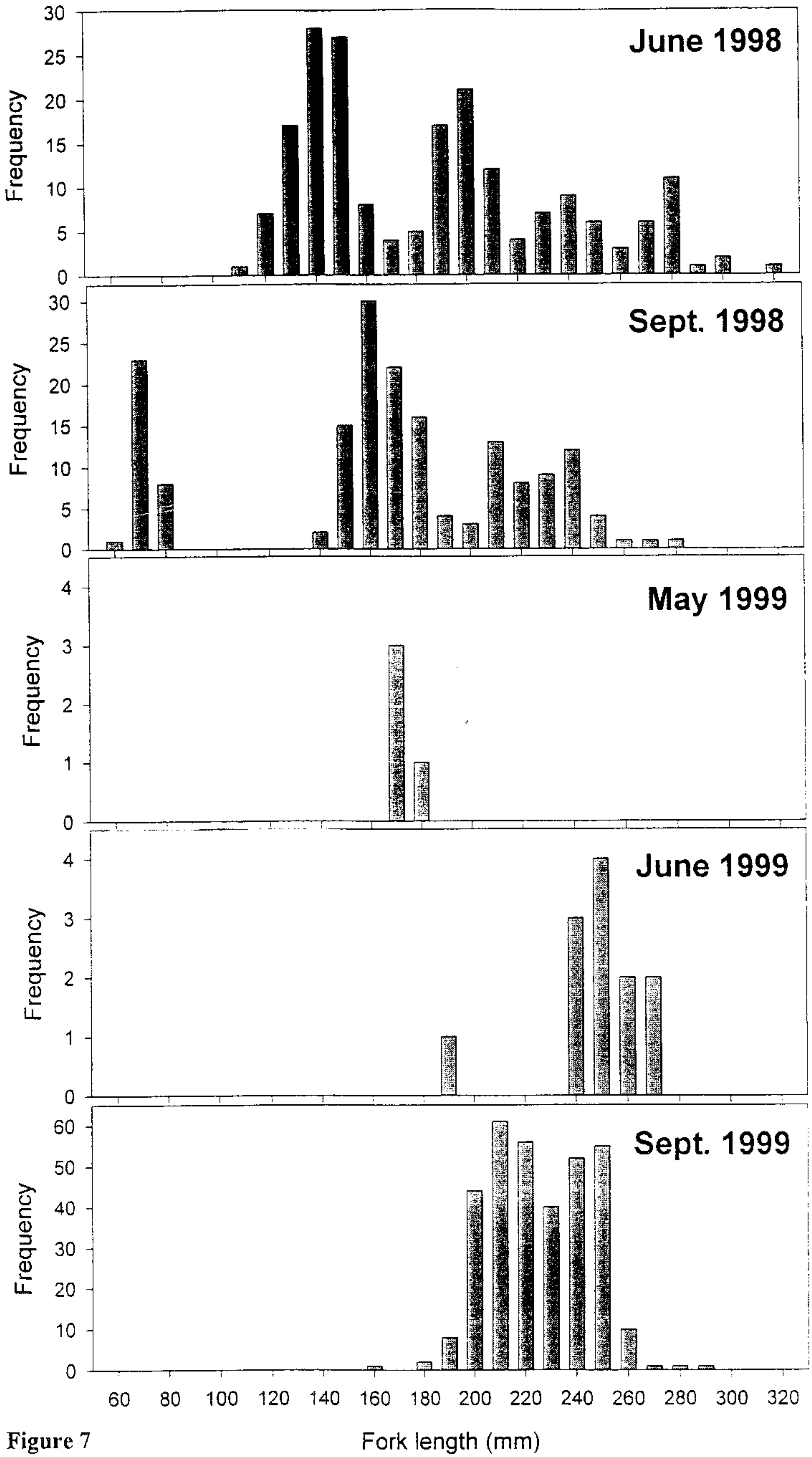

June 1998
Sept. 1998
May 1999
June 1999
Sept. 1999
Frequency
Fork length (mm)
60
80
100
120
140
160
180
200
220
240
260
280
300
320

Figure 7

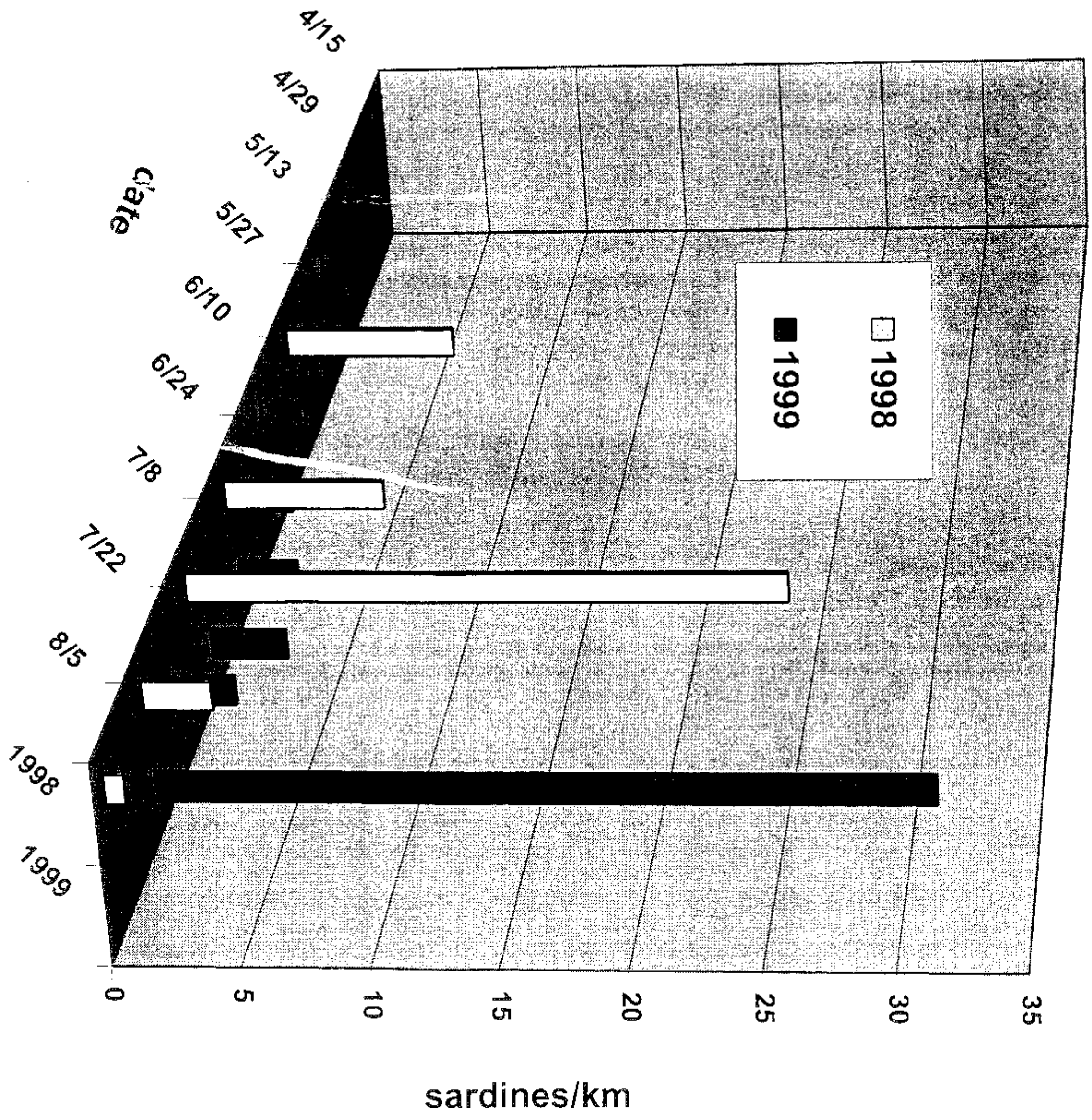

4/15
4/29
5/13
5/27
6/10
6/24
7/8
7/22
8/5
1998
1999
date
1998
1999
0
5
10
15
20
25
30
35
sardines/km

Figure 8

## *Overview of Coastal Pelagic Species Fisheries Management Plan*

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The Coastal Pelagic Species Fisheries Management Plan (CPS FMP) was proposed and implemented as Amendment 8 to the Northern Anchovy Fishery Management Plan, which was first developed in 1977, implemented in 1988, and amended several times. Amendment 8 was the most extensive amendment and resulted in the name change to CPS FMP. The impetus for developing Amendment 8 was an expression of concern by the State of California to the Pacific Fisheries Management Council regarding the increasing range of Pacific sardine to include British Columbia, Canada, and the Baja California, Republic of Mexico; the State's inability to implement transboundary international fisheries management, as well as, coordination of interstate fisheries management with Oregon and Washington. Another justification cited by California was the increasing involvement of fishing vessels from Oregon, Washington, and Alaska in the Southern California market squid fishery which was expanding at a high rate during the mid-1990's.

The CPS FMP added four species not covered by the northern anchovy FMP to include most of the species fished by the roundhaul fleet except for highly migratory species. Those covered by the CPS FMP:

| | |
|---|---|
| Pacific sardine | *Sardinops sagax* |
| Pacific mackerel | *Scomber japonicus* |
| Northern anchovy | *Engraulis mordax* |
| Market squid | *Loligo opalescens* |
| Jack mackerel | *Trachurus symmetricus* |

In this FMP, management is divided into "active" and "monitored" categories. Pacific mackerel and Pacific sardine are "actively" managed, requiring annual stock biomass assessments and setting of harvest guidelines (similar to a quota) based on MSY control rules (harvest formulae). The other "monitored" species are managed by the Council via annual status reviews and applicable management measures such as gear and area restrictions. An annual Stock Assessment and Fisheries Evaluation (SAFE) report will produced by the Council for all CPS stocks.

The CPS FMP is established as a framework process for operational aspects of management and revision. There are two mechanisms for promulgating change within the FMP: 1) a Point-of-Concern Framework used for resource or ecological issues and 2) a Socio-economic Framework for non-biological issues. Each of these mechanisms can be handled by the Council depending on potential magnitude as routine/automatic actions, notice actions, abbreviated rulemaking actions, or full rulemaking actions.

The CPS FMP establishes a limited entry fishery south of 39 degrees north latitude (Pt. Arena California) and a 125 metric ton landing limit for the four species of fish, but specifically does not include fishing for market squid. A five-year qualifying period (January 1, 1993 through November 5, 1997) was established during which a vessel must have landed 100 metric tons of CPS fish to obtain a permit renewable every two years. Permits are fully transferable during the year 2000 after which they transferrable only if the permitted vessel is lost, stolen, or incapable of fishing in a federal fishery. Sportfishing, bait fishing, and catches of less than 5 metric tons are exempted from limited entry provisions.

The general form for the MSY control rule for "actively managed" CPS stocks is designed to continuously reduce exploitation rate as biomass declines:

H = (BIOMASS-CUTOFF) x FRACTION

where H is the harvest target level, CUTOFF is the lowest level of estimated biomass above which a harvest is allowed and FRACTION is the fraction of the biomass above the cutoff that can be taken by the fishery. The default MSY control rule for "monitored" stocks sets ABC equal to 25 percent of the best estimate of the MSY catch level.

For Pacific sardine, the CPS FMP sets ABC based on estimated biomass for the whole sardine stock with CUTOFF equal to 150,000 metric tons, FRACTION between five percent and 15 percent (dependant on three year average water temperature), and a harvest target up to a MAXCAT of 200,000 metric tons (maximum harvest level allowed independent of estimated biomass). ABC is calculated from the target harvest for the whole stock and prorating the proportion of total biomass in US waters.

For Pacific mackerel the CPS FMP sets CUTOFF and definition of overfished stock at 18,200 mt and FRACTION at 30%. Overfishing is defined as any fishing in excess of ABC calculated using the MSY control rule. No MAXCAT is defined because the U.S. fishery appears to be limited to about 40,000 mt per year by markets. Harvest level is defined for entire stock in Mexico, Canada, and U.S. waters and U.S. target harvest level prorated based on relative abundance in U.S. waters.

There are several issues which are currently being deliberated by the Council mainly because the CPS FMP is new having been implemented January 1, 2000. Briefly those issues are:

1. Bycatch provisions: these are being redrafted for the plan to better describe bycatch in the CPS fishery,
2. Market squid MSY: a definition is being prepared,
3. Market Squid ABC: the 25 percent default rule is being considered for change possibly to a higher level,
4. Limited Entry Capacity or Number of Vessel Goals: these are being defined along with mechanisms for achieving and maintaining them,

5. Vessel Transfer Rules: being reviewed to exam whether they can be modified to better accommodate fishermen fishing in both the CPS limited entry fishery and the State of California's market squid fishery,
6. North-South Allocation: a separate CPS allocation for Oregon and Washington is being discussed.

## *The Effects of a Resurgent Sardine Population on Marine Mammals in the California Current*

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There is relatively little in the marine mammal literature which indicates the importance of sardine in marine mammal food habits. This occurs because most of the food habits studies along the Pacific coast of North America have been conducted during the past 40 years while sardine has been in very low abundance. During this time the northern anchovy was the abundant forage fish in the California Current System and was well represented in the food habits of marine mammals.

The decline of the anchovy population and the resurgence of sardines during the last decade have created an opportunity for marine mammals in the California Current to utilize a prey species which has many advantages over anchovy. Sardines are distributed more widely than were anchovy, occurring at higher latitudes and both on the continental shelf and well offshore in more pelagic habitats. Sardines also have much higher energy density than do anchovy (sardines have 65% more energy in each unit of wet weight than do anchovy (Sidwell 1981). The wider distribution makes sardine available to marine mammals species that are more oceanic and have the center of their distribution at higher latitudes in the north Pacific.

In the presentation, we review the distribution and food habits of several species of marine mammals, both cetacean and pinnipeds, and make a case for marine mammal shifting their food habits to include significant amounts of sardine. We begin by reviewing the distribution of several cetacean species, humpback whales (*Meganapteris novenglis*), Dall's porpoise (*Phocenoides dalli*) and white-sided dolphins (*Lagenorhynchus obliquidens*) to illustrate that although these species are distributed both on the continental shelf and shelf break, white-sided dolphin and Dall's porpoise are also found further offshore where they can be expected to utilize more pelagic prey species. The diet of humpback whales is dominated by euphasids followed by several species of small forage fish. In the northern part of the California Current both white-sided dolphin and Dall's porpoise feed on small schooling forage fish, with anchovy being a dominant component of both species diet. Yet in areas where sardine was available at the time food habits studies were conducted, they played a very important role in cetacean food habits. This is shown most strikingly in a food habits study of Dall's porpoise conducted in the southern Sea of Ohkotsk where Walker et al (1986) reported that sardine occurred in 97% of the stomach contents examined. This occurred at a time when the sardine populations had recovered in the western Pacific, but when there were few sardine available in the California Current System outside of the small remnant population in Mexico. It seems clear that if sardines were present they were the preferred prey for Dall's porpoise. Because of the high energy content of sardine we suspect that both Dall's porpoise and white-sided dolphins have shifted to a major dependence on sardine throughout the California Current System where and when sardine occur.

In a study of California sea lion (*Zalophus californianus*) adult female foraging behavior conducted in 1995 and 1996 using satellite telemetry (Melin and DeLong 2000), we found that adult females tend to feed on the continental shelf during the summer breeding season and on the shelf and seaward over deep water during the winter, non-breeding season. During summer the predominant prey were market squid, Pacific hake, sardine and rockfish. During the non-breeding season when animals were feeding farther offshore, we recorded an increased dependence on Pacific hake and sardine and decreased dependence on market squid as principal food. Lactating female sea lions appear to switch to a fish dominated prey assemblage during the winter, even though squid is abundant and available in the northern Channel Islands as evidenced by the conduct of the commercial fishery during that season. The shift in foraging behavior apparently reflects that the high energetic demands of lactation were being met by shifting to high-energy content prey, predominantly sardine.

Northern fur seal (*Callorhinus ursinus*) populations that breed on islands in the Bering Sea and migrate to waters of the California Current during the winter have declined by more than 60 % over the past three decades. Causes of the decline are not completely understood. We advance a hypothesis that the resurgence of the sardine population provides a high-energy food source that will improve the general health of fur seals and lead to population recovery. We suggest that the improved health should be detectable and measurable in increased pup production and juvenile survival.

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# *The Development of a Precautionary and Economically Viable Sardine Fishery in British Columbia*

**Dennis Chalmers, Department of Fisheries and Oceans, Nanaimo, British Columbia, Canada**

## HISTORICAL

Pacific sardines are a transient visitor to Canadian waters migrating north from California in the summers and returning in the fall to spawn. Abundance in BC waters is dependent on two factors, the abundance of the northern California population and water temperatures off our coast. In years of high abundance and warmer waters, it is estimated that on average about 10% of the population can be found off BC during the summer between July and October.

Commercially, sardines have a long history in BC and constituted one of our largest fisheries. The fishery itself dates back to 1917 when 73 tons were caught and canned for the European war effort. This "canned fishery" continued until 1925 when regulations were amended to allow for reduction of the sardines. The average catch for the period 1917-1924 was 1,786 tons with a maximum catch of 3,992 tons, taken in 1921.

In 1925 a change in the fishery regulations allowed for reduction of the sardines and resulted in a rapid expansion of the fishery. Catches increased to 14,470 tons in 1925 and to 78,377 tons by 1931. The largest catch in any one-year occurred in 1944 when 80,504 tons were landed. The fishery was concentrated off the West Coast of Vancouver Island where 80% of the catch was taken. Small amounts were also caught in Hecate Straits, Queen Charlotte Sound and Georgia Strait. At the peak of the fishery there were 26 reduction plants situated on the WCVI between Barkley Sound and Kyuquot.

The fishery collapsed in 1947 as a result of changing environmental conditions and a high exploitation rate. In 1947 only 445 tons were landed and there were no recorded catches in BC until 1993 when 5 sardines were caught in 4 separate groundfish tows off Barkley Sound. In 1993 sardines were also observed in samples taken during the roe herring test fishery in Georgia Straits.

## TEST FISHERY

In 1995, approximately 5,000 tons of sardines were identified in Kyuquot Sound on the West Coast of Vancouver Island. One of the local residents from the Kyuquot Indian Band requested through the Aboriginal Fishing Strategy that DFO issue an experimental licence to fish and market sardines. A licence for 100 tons was issued in 1996 to look at the potential for economic development in this community. Approximately 80 tons were harvested and delivered to Vancouver. Lack of knowledge by the harvester and processor regarding the transportation and refrigeration requirements of sardines resulted in a poor quality product and the fish were not suitable for commercial sale.

## PILOT EXPERIMENTAL FISHERY

As part of a federal/provincial memorandum of understanding (MOU) on fisheries and seafood diversification, a pilot experimental fishery for sardines was proposed. A three-year pilot fishery was implemented in accordance to the draft Policy for Development of New Fisheries in BC. The policy requires a precautionary approach to fisheries development that collects biological, by-catch, and fisheries information to support sound fisheries management decisions. To address quality issues experienced in the previous test fishery, participants in the experimental fishery had to demonstrate a knowledge of the species, and have suitable vessels which provided adequate storage conditions for the catch.

In November 1996 DFO, along with the Provincial Ministry of Fisheries (MOF), initiated a pilot fishery to further develop the potential for sardine as a commercial fishery. Six additional licences were issued for a three-year period. The licences were given to individuals who had written to DFO expressing an interest in exploring the potential for this fishery and had carried out some initial research into possible markets and methods of handling the sardines to ensure high quality standards. Initially, each applicant was issued an experimental licence for 80 tons annually for the three-year period (1997 –1999).

The initial year (1997) of the fishery consisted of a few small landings for market demonstration purposes, stock assessment and biological assessments. A total of 35 tons of the 560-ton quota was harvested for commercial purposes.

The second year continued with stock assessment activities, and the development of a research and quality control program for handling of catch on vessels to meet the stringent standards established by the potential customers. The fishery engaged in a full-scale commercial operation to supply niche markets that had been identified and secured the previous year. The fishery was conducted between September and December, when fat content and quality are maximised to achieve top market value. Landings for the 1998 fishery were 565 tons.

In order to further develop the potential for this fishery and test additional market opportunities, the individual quota of 80 tons was increased to 160 tons in 1999 bringing the total TAC to 1120 tons for the seven licence holders. The rational for this increase was based on the assumption that additional raw material was required to provide some confidence to the buyers that this fishery will be developed on a sustainable basis. In addition, the processing sector required extra product to justify expenditures for necessary processing equipment. It was also believed that the small increase in TAC would be well within the guidelines for precautionary development of the fishery.

## Market Opportunities

While all age classes are represented in the BC sardine population, there is an abundance of larger older fish in the migratory population. Samples of individual fish have averaged 160 – 200 g. by weight, with some samples over 225 g. These large fish are creating interest in Japan, Korea, Taiwan and Australia. The Japanese market potential is for sushi while the Australian Korean and Taiwanese markets are for first class bait. The bait market is for feeding penned tuna in Australia and tuna longline bait. The longevity and magnitude of the market is presently unknown and further development if the market is required to assess the full potential for this fishery.

To-date buyers have indicated that the current potential market for BC sardines is in the 6,000 – 8,000 tons range provided fishers can deliver a high quality product. There is also some competitive advantage in the bait market because the average size of the fish caught in BC is considerably larger than that caught in California.

## Quality Control

The fishermen and processors participating in the sardine fishery are finding the market very specific in terms of the quality of the product. Sardines are known for their tender skin and flesh and can be easily damaged through poor handling practises. To-date vessels capable of freezing at sea, having refrigerated seawater (RSW) or champagne systems have been able to land the best quality product. Superchilling or RSW systems have to be capable of holding temperatures at 28*F or lower and have sufficient refrigeration to prevent "spiking" any higher than 30*F. Freezing sardines, either at sea or at a fish processing facility also has to meet critical standards for successful marketing. The arrest period of latent heat during the freezing cycle (the period of time when a change of temperature cannot be recorded) should be less than two hours in order to produce top quality sardines. To assist with the further development of the fishery and achieve optimum market acceptance, DFO and MOF, in co-operation with the present participants are developing a manual which will outline quality control standards (guidelines) for on-board handling and procedures for shore-based processing

## FUTURE DEVELOPMENT OF THE SARDINE FISHERY

The experimental sardine fishery is completing its third year and the Department is assessing the potential for expansion in the year 2000. The Pacific Stock Assessment Review Committee (PSARC) has carried out a review of the available sardine stock assessment information, and provided recommendations for the potential expansion of the sardine fishery. PSARC recommended that that the harvest rate for the British Columbia fishery will not exceed the US harvest rate.

Any expansion of this fishery must take into consideration two critical factors. The first one is that sardines in BC are transitory and there is no guarantee on how many will migrate to our coast in any given year. The last thing we want to do is set the stage for failure by issuing too many licenses. We must proceed cautiously and expand the fishery at a rate that allows for slow development. In years when we have cooler waters off our coast and very few sardines migrate up here we don't want a large fleet scouring the coast trying to catch the last sardine in the bay. This would not make sense for economic reasons but also from a conservation perspective as well.

The second factor relates to the economic viability of the fishery. The industry in still in the process of trying to establish a niche in the world market for sardines. If we expand too fast we could end up with a number of vessel landing poor quality sardines. This could have a long term detrimental affect and jeopardise our ability to market the fish.

The primary goal for expansion is to set the stage for developing an economically self sustaining market driven fishery. To this end we should be looking at a 2000 quota of about 5,000 tons. This would allow for a modest expansion of the fishery to somewhere around 25 vessels while still maintaining a precautionary harvest level.

# *Analysis Of Sardine Markets*

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## Introduction

This presentation will investigate sardine markets from a global perspective and the role Pacific sardines, harvested off the U.S. west coast, play in the global market. I will start out by reviewing world harvests and production of sardines over the 1984-98 period. I will then narrow the focus to global production and trade of Pacific sardine. Finally, I will look at U.S. landings and trade in Pacific sardine, and conclude by noting market opportunities that potentially exist for west coast landings. The analysis relies on international harvest and trade data from the U.N. Food and Agricultural Organization's global harvests and trade databases; the Pacific Fishery Management Council's PacFIN Management Data Base for west coast sardine landings and the NMFS foreign trade data base for U.S. international trade in Pacific sardine.

## Global Harvests, Production and Trade

Globally there has been an appreciable decline in overall harvests of small pelagics since 1994 (Figure 1), with sardines and anchovies contributing most to this trend. Global sardine harvests began a significant decline in 1988, falling 64% from 14.0 million metric tons to 5.0 million metric tons by 1998. The sardine decline was offset by a sharp rise in anchovy harvests starting in 1991. Anchovy harvests peaked at over 14.0 million metric tons in 1994, and by 1998 had fallen 64% to just over 5.0 million metric tons. Global herring harvests have also declined in recent years, while mackerel harvests have increased.

Following the pattern in harvests, global production of sardine products dropped more than 80% from 3.6 million metric tons to 0.7 million metric tons from 1988 to 1997. After a sharp drop initially, foreign trade in sardines has trended upwards since 1992 (Figure 2). Countries that relied on domestic harvests for the bulk of their sardine production before the decline have had to turn to foreign sources to supplement domestic production.

The decline in global sardine harvests has occurred almost entirely in the Pacific. This reflects the collapse in Japanese and South American sardine resources, even with the recovery of the Pacific sardine off the U.S. west coast. Harvests in the Atlantic and Indian Oceans actually increased between 1994 and 1998 (Figure 3). Japan, Chile and Peru have been the major harvesters in the Pacific, joined more recently by Mexico. Between 1984 and 1998, Japan, Chile and Peru depended on the Pacific for 100% of their total sardine harvests, Mexico 99%. In 1984 these nations accounted for over 80% of the sardine harvest from the Pacific; by 1998 their combined share had declined to just over 60%. Japan and Chile have suffered the most severe harvest declines; harvests by Mexico and Peru increased over the period (Figure 4).

The decline in Pacific harvests most noticeably reflected in the production of meal and oil and frozen sardines. Global meal and oil production decreased from 1.3 million metric tons in

1984 to about 0.1 million metric tons in 1997; global production of frozen sardines fell from 1.2 million metric tons to 0.3 million metric tons over the same period. As a share of total production, meal and oil fell from 35% to less than 15%, while frozen production held at about 40% of total production for the period after peaking at 63% in 1993 (Figure 5).

Japan, Chile, Peru and Mexico were the leading producers of sardine commodities over the 1984-97 period, averaging about 80% of total production. Japan was by far the leading producer, even though its total production fell from over 2.0 million metric tons at the beginning of the period to just over 0.3 million metric tons by the end (Figure 6).

International trade in sardine commodities is dominated by frozen sardines that are consumed directly or used in the production of a number of processed products. At the beginning of the 1984-97 period, Japan was the world's leading exporter of sardine commodities, primarily frozen sardines, with over 50% of the total (Figure 7). However by the end of the period Japan's share of global exports had shrunk to less than 5% of the total, with Ecuador, predominately canned sardines, becoming the new leader. Brazil and the Philippines, frozen sardines for canning, and Malaysia, canned sardines, accounted for the greatest combined share of global imports during the 1984-97 period (Figure 8).

**U.S. Harvests and Trade of Pacific Sardine**

U.S. harvests and trade of Pacific sardines are relatively minor from the global perspective. U.S. landings of Pacific sardines have climbed from virtually nothing in 1989 to nearly 60,000 mt in 1999 (Figure 9). The bulk of landings are destined for export, most of the balance goes into domestic markets for canned sardine.

Exports are primarily in the frozen form, although exports of fresh Pacific sardines rose from near zero in 1997 to almost 5,000 mt in 1999. Exports of preserved Pacific sardine have been relatively minor (Figure 9). Exports of frozen Pacific sardines increased significantly in 1995 and in 1998. By 1999 over 30,000 mt of Pacific sardines were being exported, mainly to Australia (Figure 10). The Philippines has been a major purchaser of fresh, U.S.-caught, Pacific sardines; more recently, Australia has become the primary export market (Figure 11). Western Samoa, Malaysia and Panama have been the major markets for preserved exports, although there is no consistent purchase pattern (Figure 12).

Price trends for U.S. exports of Pacific sardines have been relatively stable for frozen and preserved exports over recent years, but much more variable for fresh exports. The real price (1997 dollars) for frozen exports decreased over most of the 1989-99 period, but has held fairly steady at about $.20 per pound since 1995 (Figure 13). This reflects the dominance of frozen exports to Australia where they are used as lower valued animal feed in bluefin tuna grow-out operations. (As a rule of thumb, frozen prices greater than $.50/lb indicate human consumption.) The real price for fresh exports has been more erratic, indicating use for both human consumption, Philippines, Japan and others, and for non-human consumption i.e. animal feed in Australia (Figure 14). The real price for preserved exports has averaged about $.80 per pound over the 1989-99 period (Figure 15).

For most of the1989-97 period, the price (1997 dollars) of U.S. exports of frozen Pacific sardines was greater than the average global price (Figure 13). This was also true for fresh exports (Figure 14). This suggests a relatively stronger demand for U.S. frozen and fresh Pacific sardines in the global market, that there is a quality difference that makes these products more preferred. On the other hand, the U.S. price for preserved Pacific sardine exports did not differ as much from that of the global average during 1989-97, suggesting that preserved Pacific sardine products may be more of a substitute in the global market.

**Concluding Comments**

- Even though there has been a significant decline in global sardine harvests and production since 1988, global sardine commodity prices have remained fairly stable, even moving downward. This suggests that other species and products are being substituted for sardines in the major global markets, otherwise one would expect upward pressure on prices.

- In major sardine harvesting and producing nations such as Japan, production and exports have declined and imports have increased. The sardine sector of the economy would be expected to concentrate on the highest valued uses within the country. This may present market opportunities in countries that have relied on Japan for sardine exports, as well as within Japan itself.

- A comparison of U.S. Pacific sardine frozen and fresh export prices with global averages suggest that U.S. products are of relatively high quality.

- U.S. exports of frozen Pacific sardine have cornered the market for bluefin tuna food in Australia. The U.S. has shipping advantages in the Australian sardine fish food market, because reasonable freight charges and frequent service; Pacific sardines caught off the west coast are high in oil, and because they are caught close to shore are of higher quality which promotes rapid growth in bluefin.

- Mexican labor costs low, but lack freezing capacity therefore unable to supply substantial quantities of frozen sardines to Australian tuna farms. U.S. has advantage over Mexico due to reliability of source.

- Mexico also farms bluefin and this could become a significant market for California sardines in the future. Japan imports frozen sardine from U.S. mainly as feed for farmed yellowtail.

- Strong demand for large frozen sardines in hand laid boxes for tuna longline bait.

- Promote consumption of Pacific sardines for health and nutritional purposes.

**Figure 1. Trends in global Coastal Pelagics Species harvests, 1984-98.**

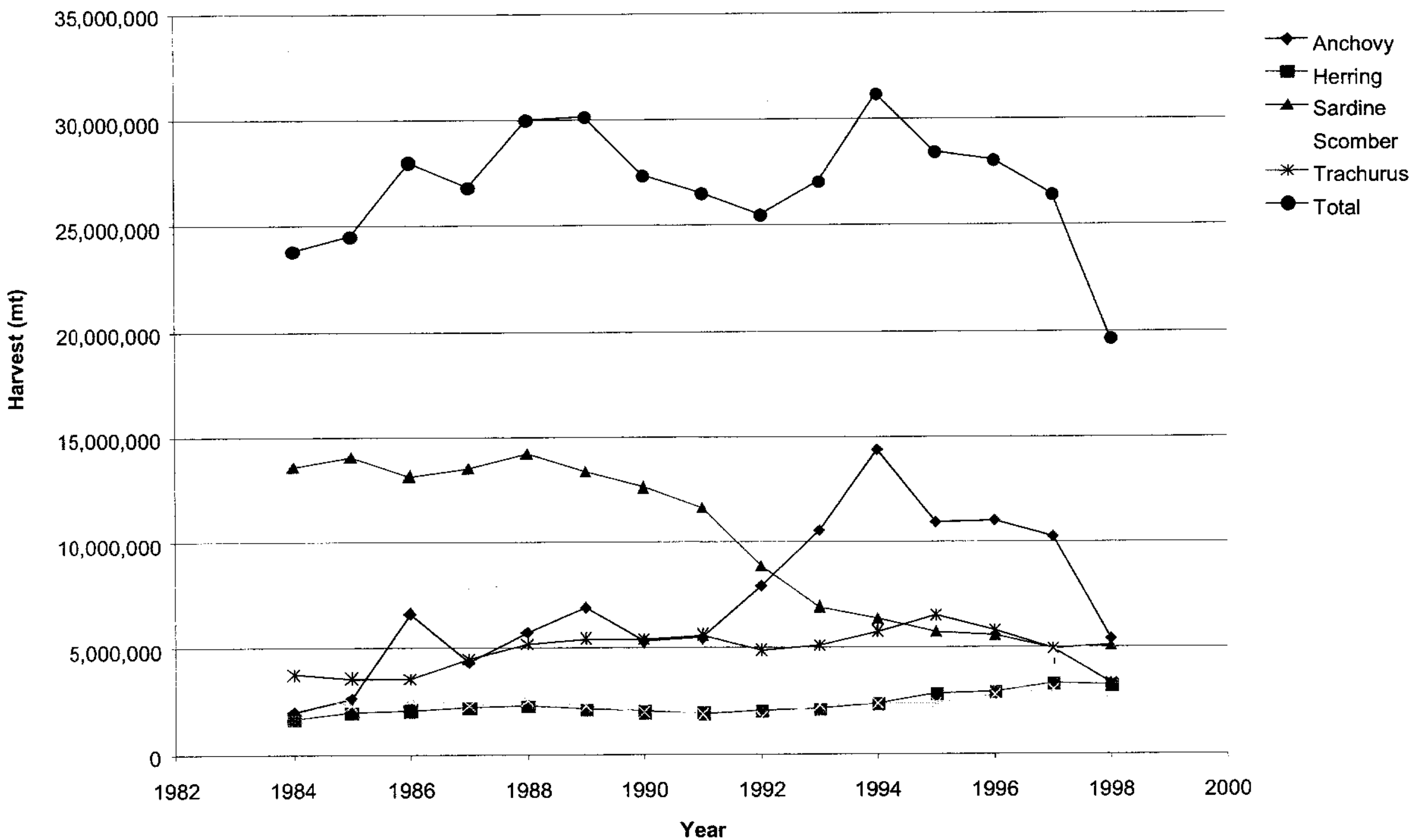


**Figure 2. Global sardine harvests, production, exports and imports, 1984-97/98.**

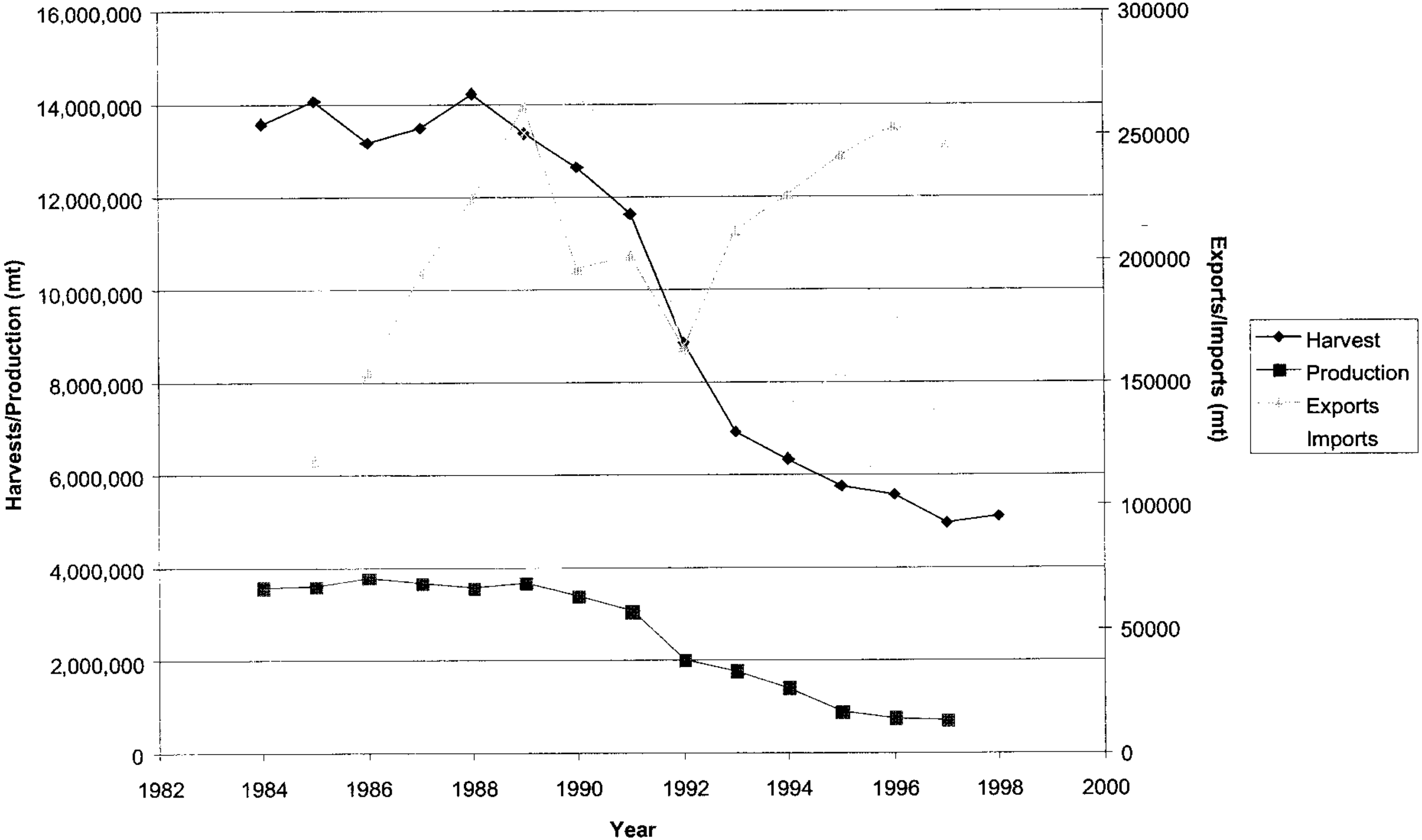


**Figure 3. Global sardine harvests by ocean, 1984-98**

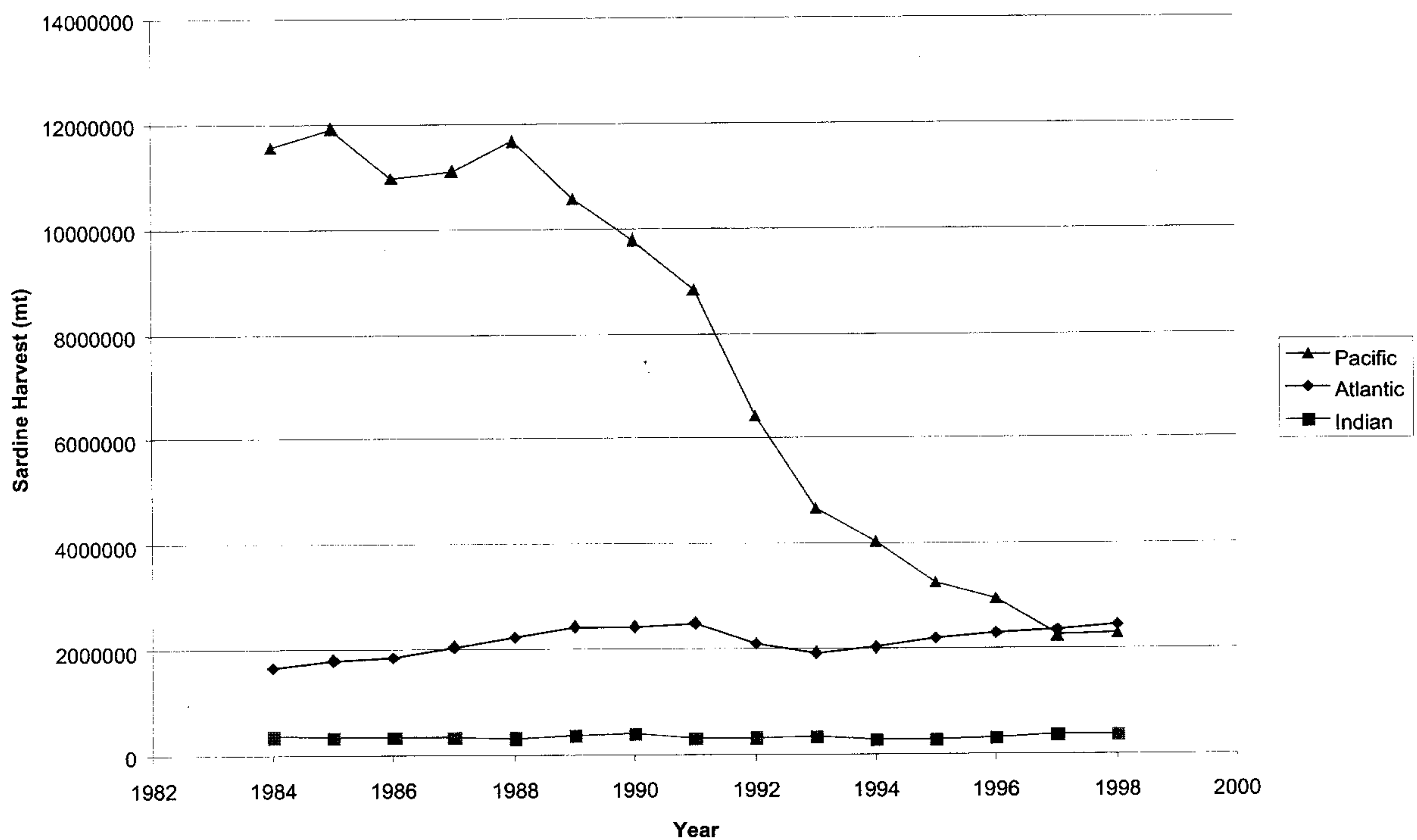


**Figure 4. Pacific Ocean sardine harvest shares by leading harvesters, 1984-98.**

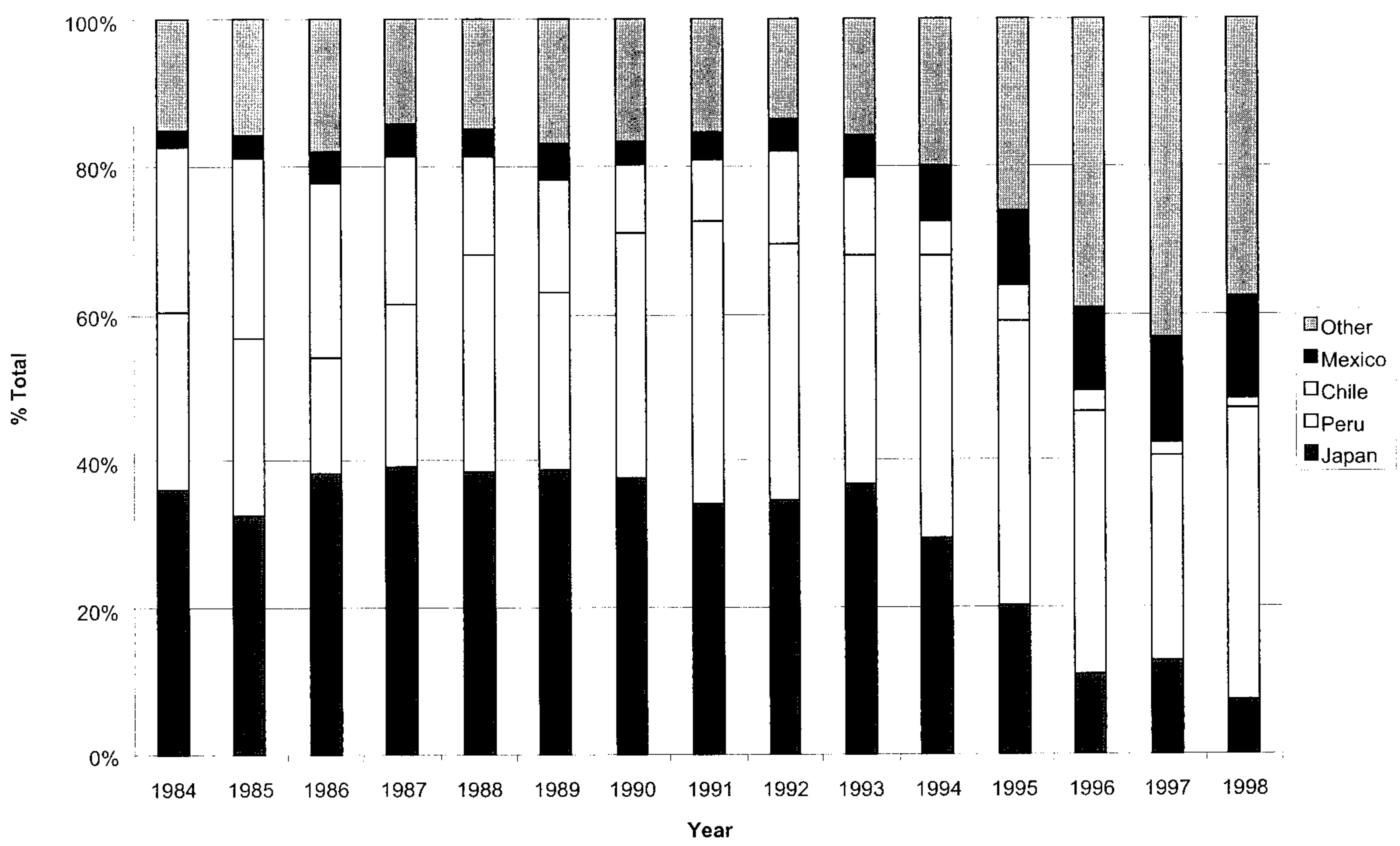


**Figure 5. Trends in global sardine production, 1984-98.**

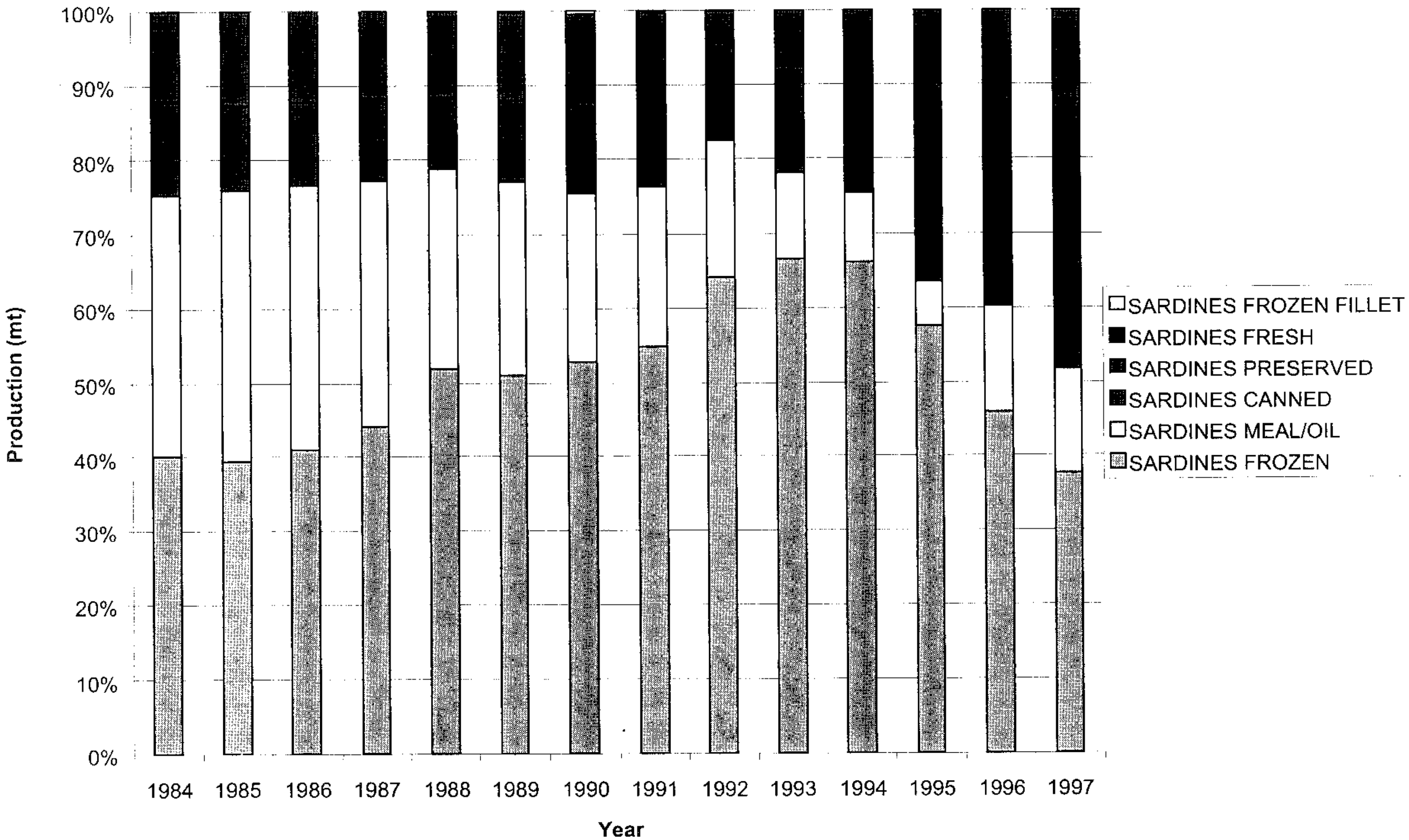


**Figure 6. Global sardine production shares by leading producers, 1984-97.**

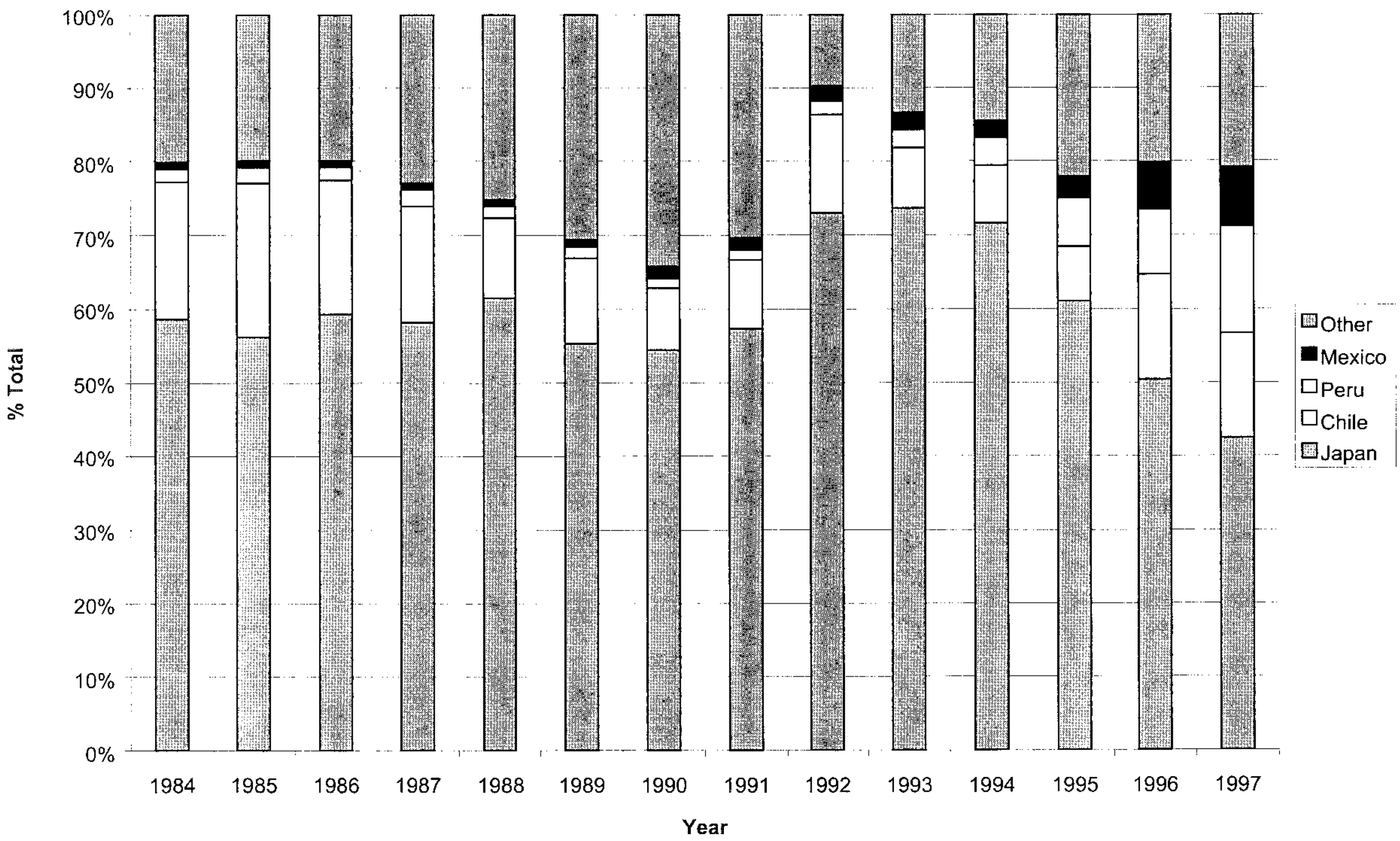
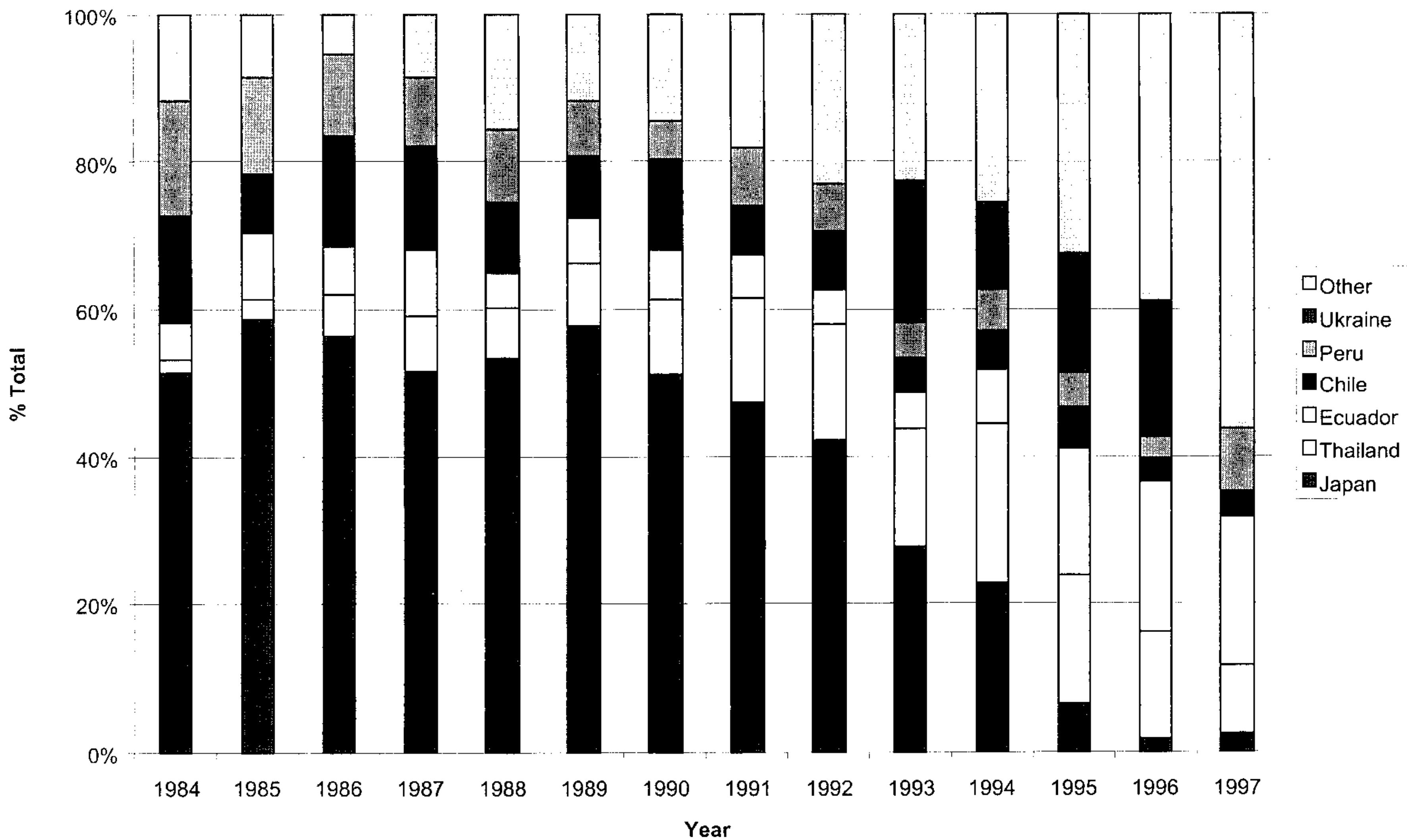


**Figure 7. Global sardine export shares by leading exporters, 1984-98.**



## Figure 8. Global sardine import shares by leading importers, 1984-97

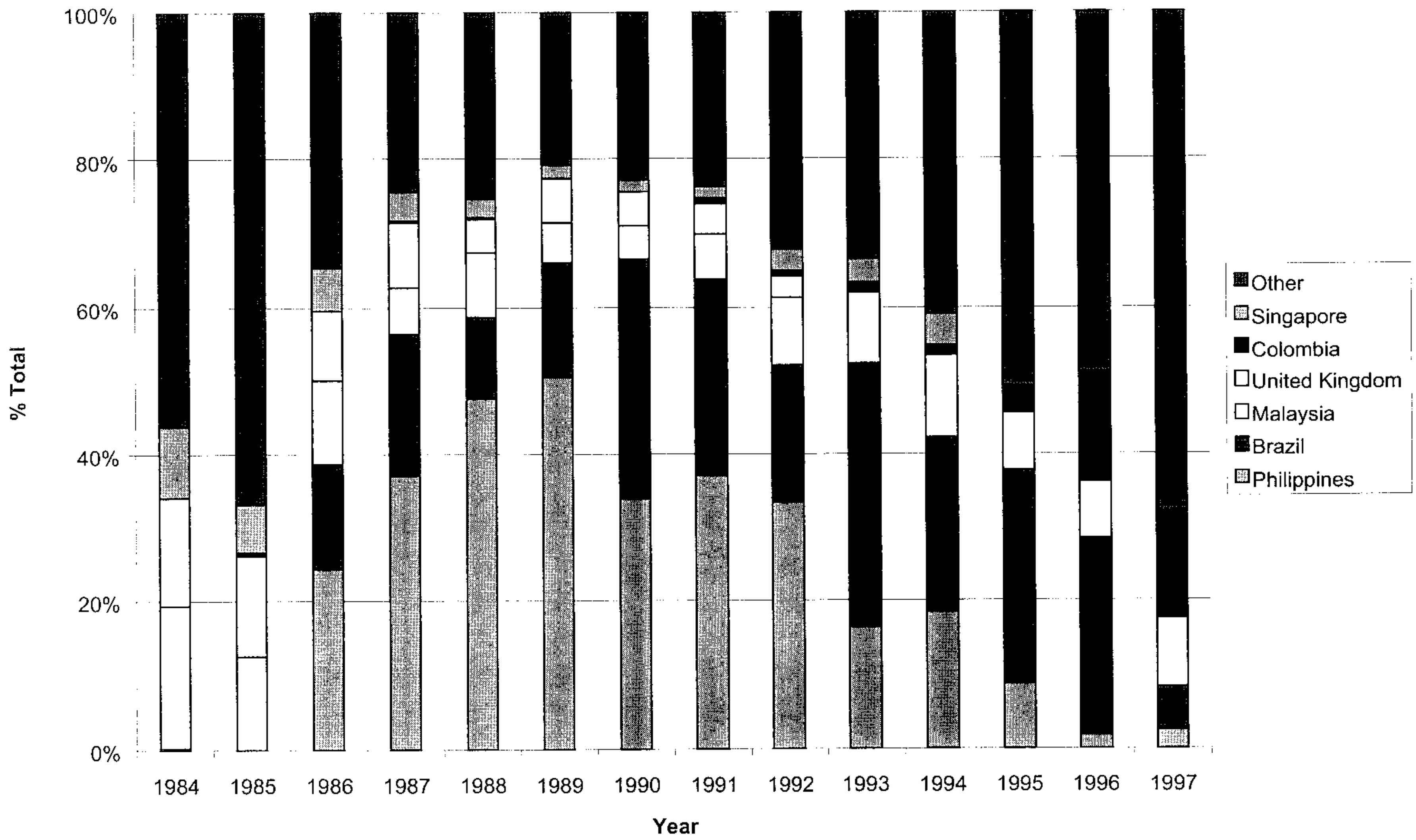


Figure 9. U.S. landings and exports of Pacific sardine, 1989-99.

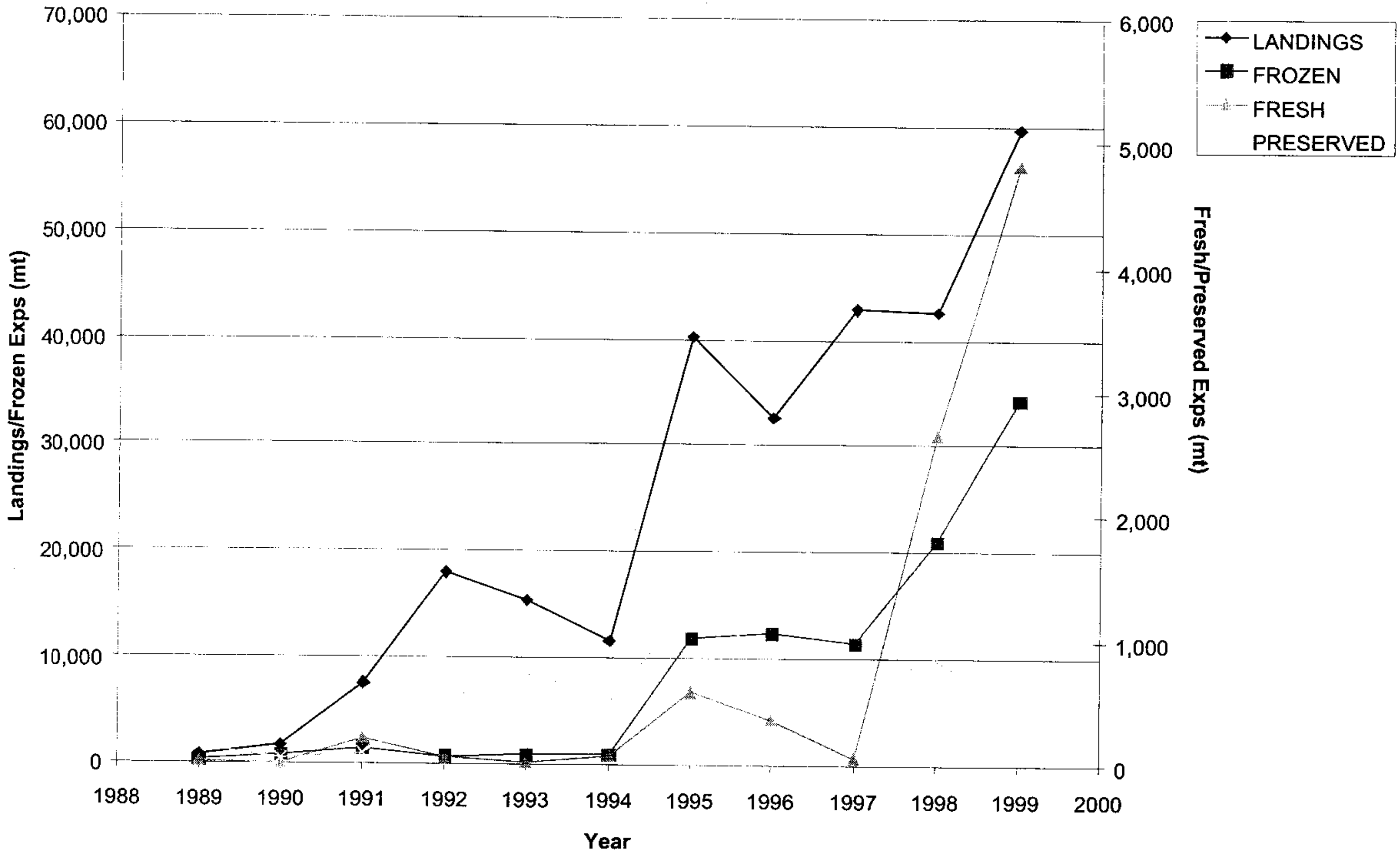


**Figure 10. U.S. export shares of frozen Pacific sardine by major destinations, 1989-99.**

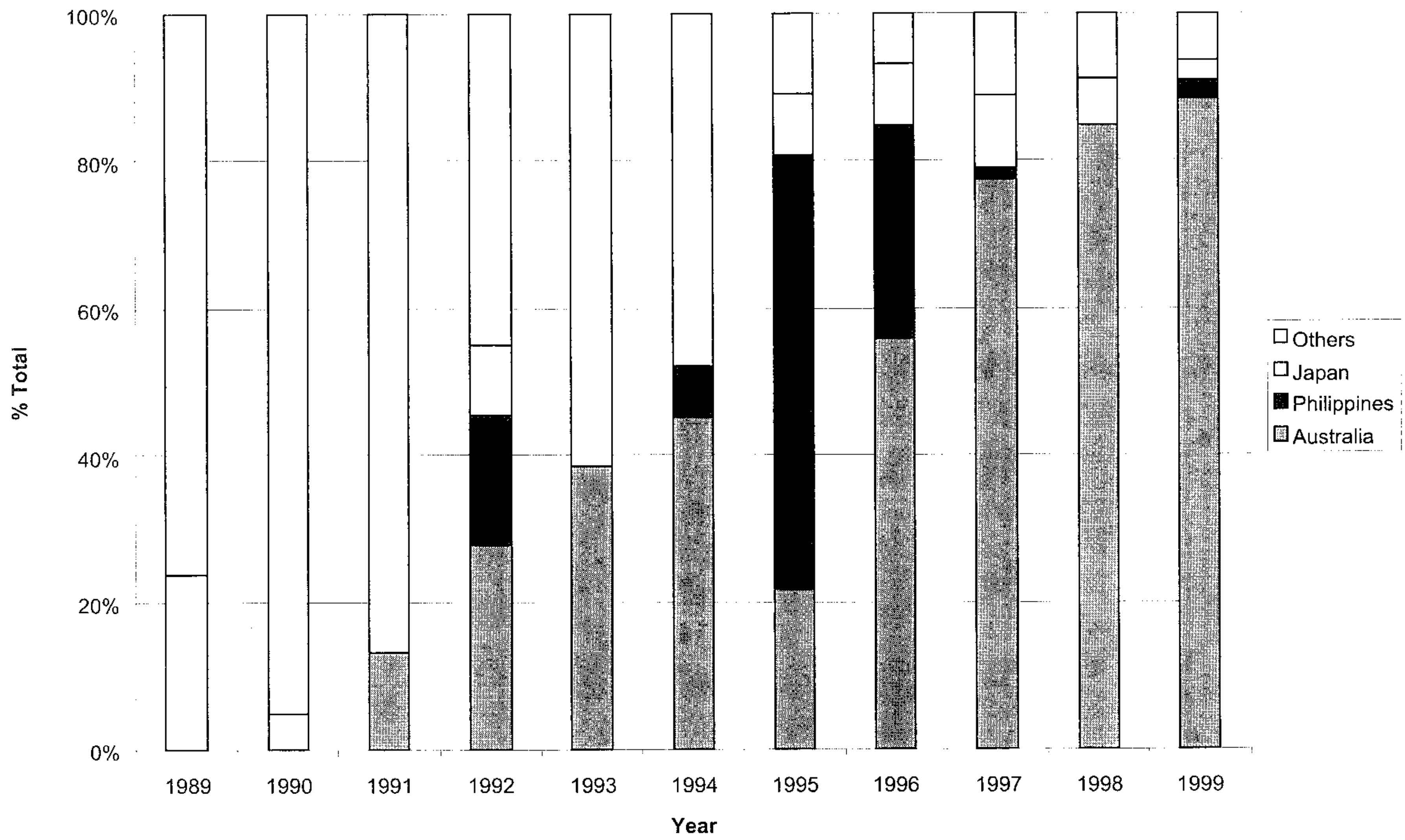


Figure 11. U.S. export shares of fresh Pacific sardine by major destinations, 1989-99.

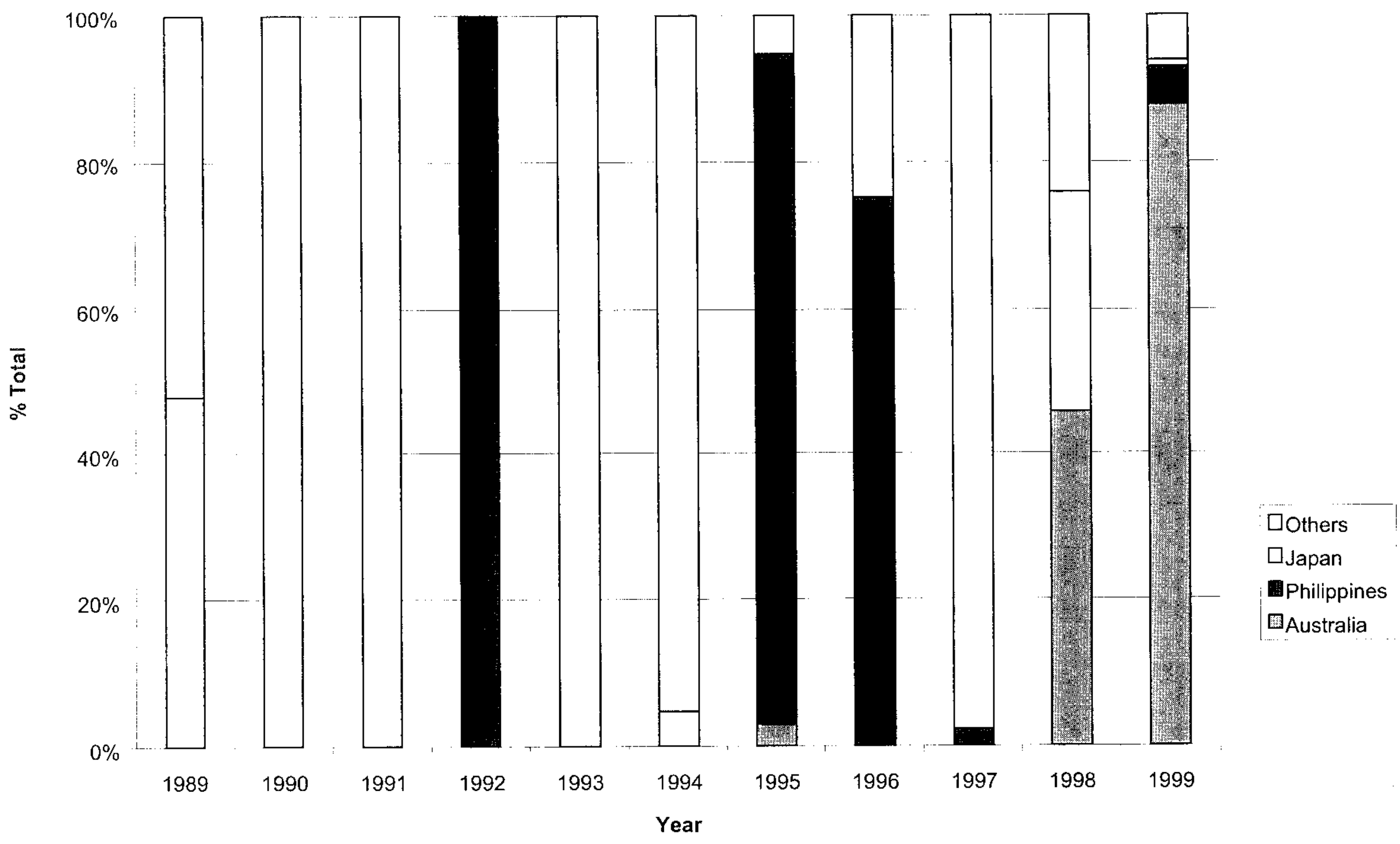


**Figure 12. U.S. export shares of preserved Pacific sardine by major destinations, 1989-99.**

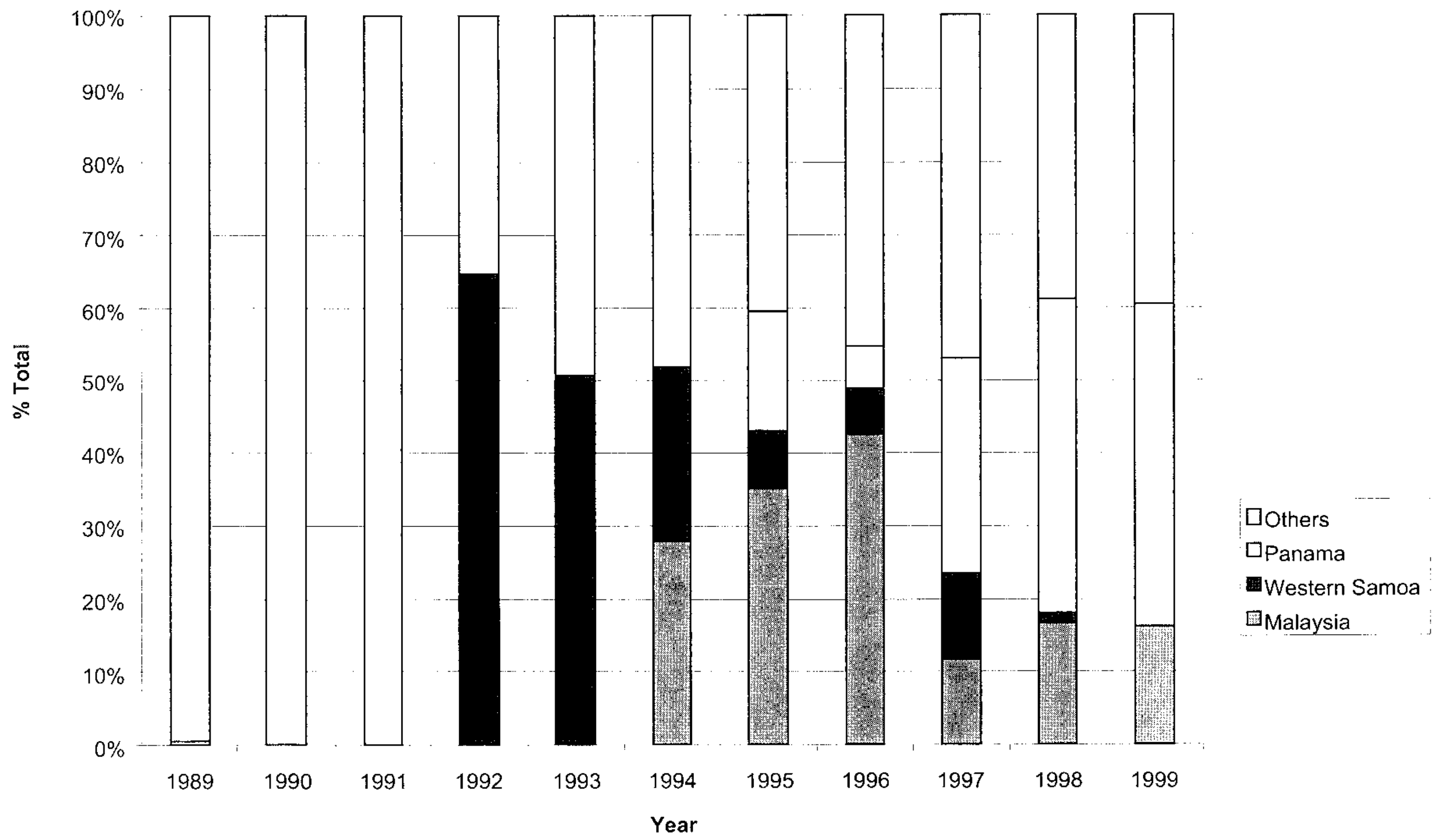


**Figure 13. Trends in global frozen sardine export prices and U.S. frozen Pacific sardine export prices, 1989-97.**

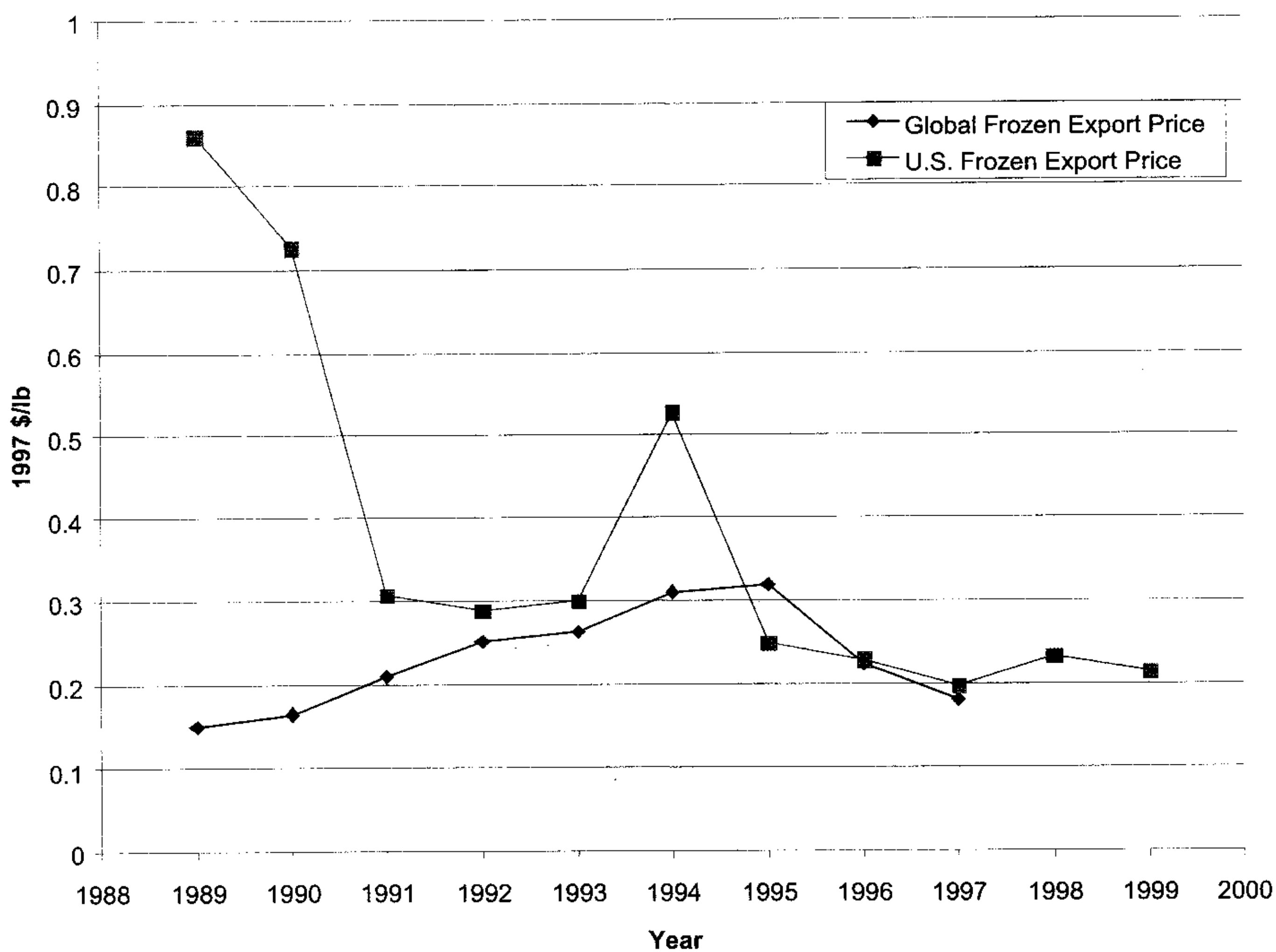


**Figure 14. Trends in global fresh sardine export prices and U.S. fresh Pacific sardine export prices, 1989-97.**

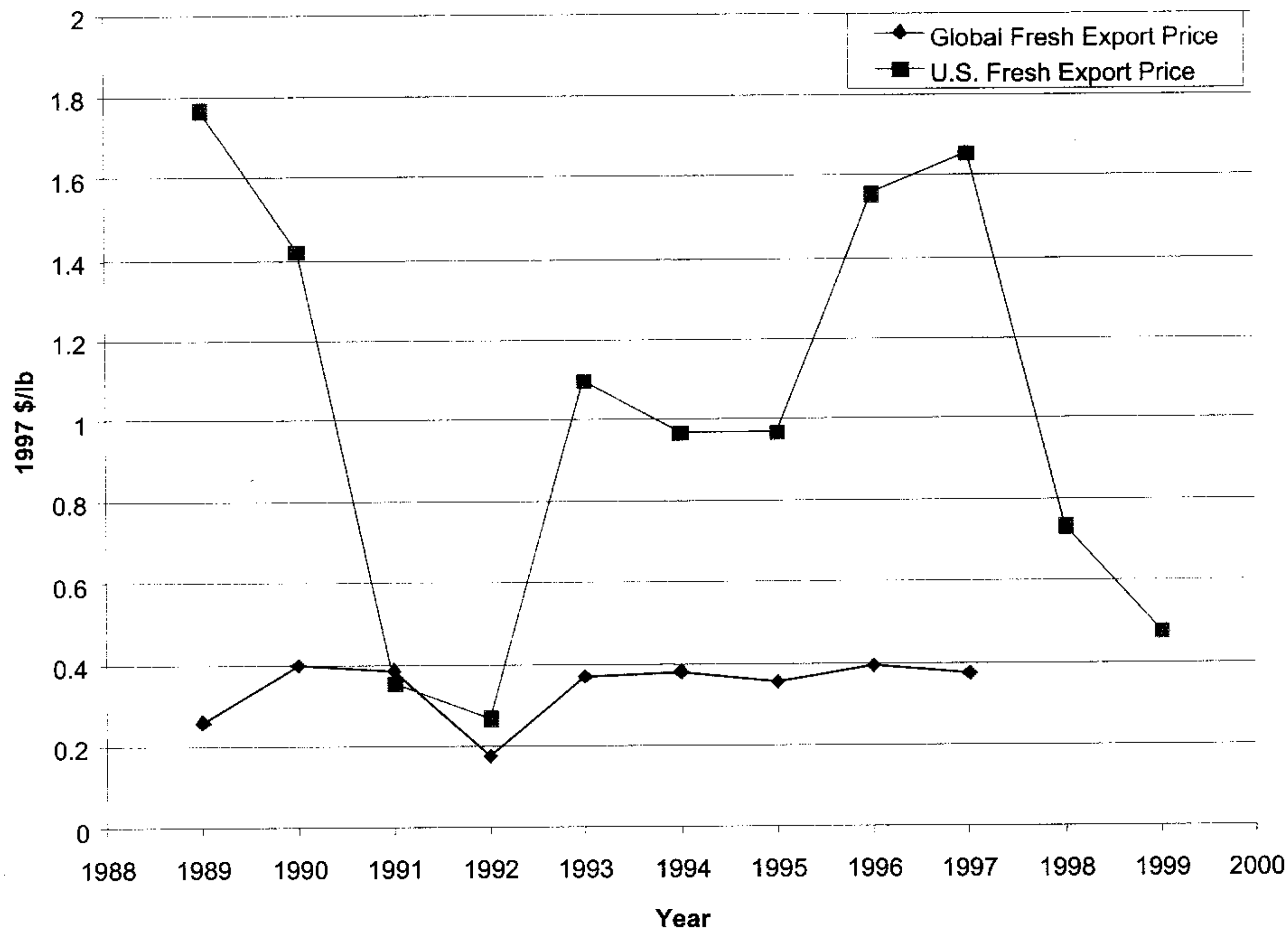
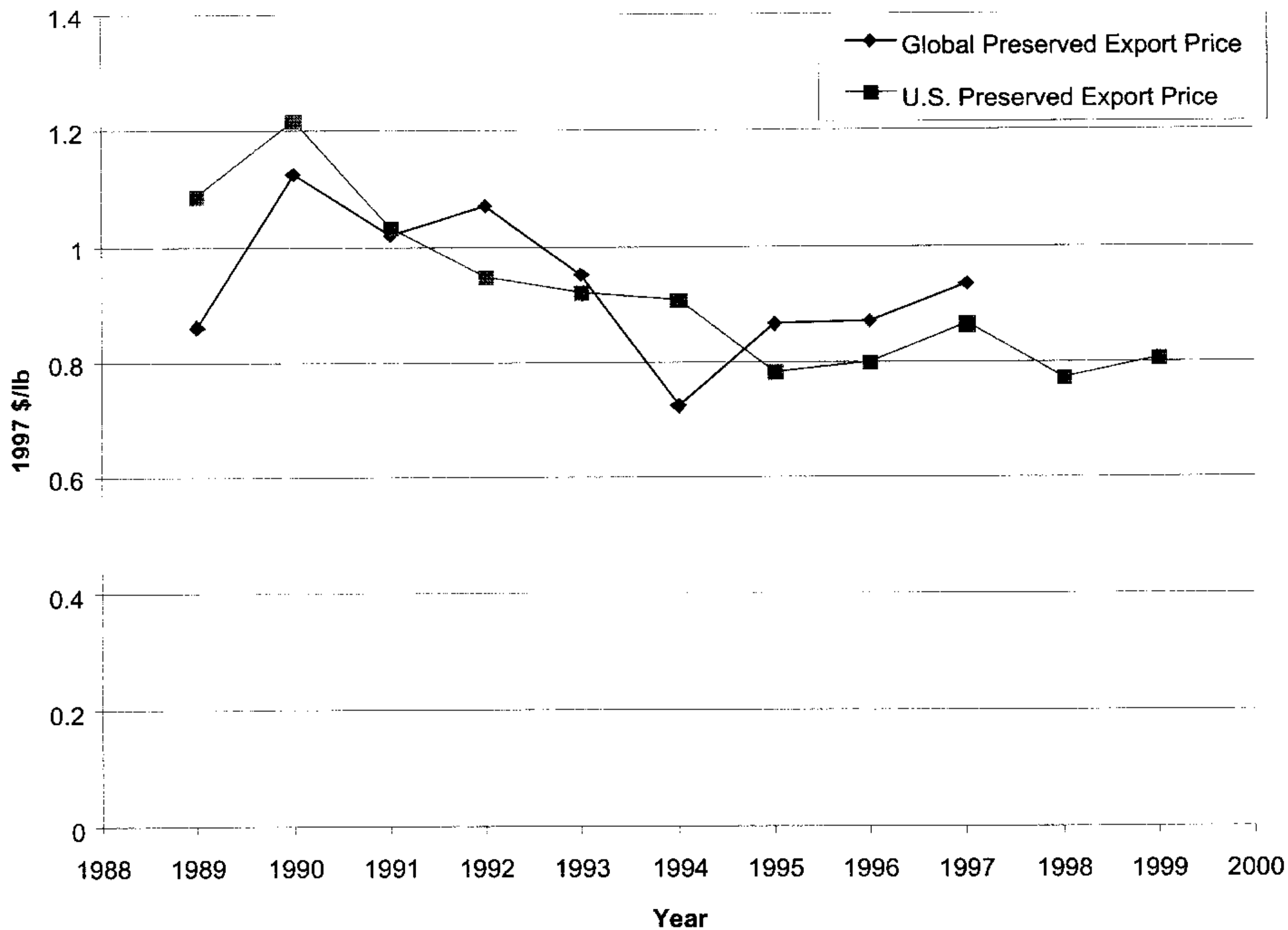


**Figure 15. Trends in global preserved sardine export prices and U.S. preserved Pacific sardine export prices, 1989-97.**



**Acknowledgments**

I would like to thank Steve Koplin, NMFS, Fishery Statistics, and Bill Jacobson, NMFS, Southwest Region for their assistance in assembling the data used in this presentation.

## *Fishing Industry Perspective*

**Don Pepper, Pacific Sardine Association, Richmond, British Columbia, Canada**

Don Pepper noted that fishermen used the scientific information provided by the scientific community but that their information needs were simplistic. The BC situation was unique in relation to sardines as they were "fish of opportunity", appearing in BC waters when mature. Thus, indicators that predict their presence were needed. Stock dynamics, water temperature and range of the biomass were some on the indicators BC fishermen would like. Many of these are supplied but the desire for the "one true indicator" was still present.

From this perspective, fishermen want as little government intervention as possible and would only require the science. Management regimes unfortunately go from the science to socioeconomic objectives which leads to political solutions which may not always be the best for the biomass. None of this is new but it is a mantra that should be restated. Finally , conferences such as Sardine 2000 are important in getting "all the actors in the drama" in one place to exchange views and information.

# III. WORKSHOP BREAKOUT SESSIONS AND RECOMMENDATIONS

Following the plenary session, the Symposium broke into two workshops: *Stock Assessment and Management* and *Ecosystem Consequences.* The groups were guided by the following:

- 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.

- 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.

- Fishery/Economics and Management: Evaluate the economic value of sardines and potential value markets, ecological and management influences on markets.

## *STOCK ASSESSMENT AND MANAGEMENT WORKSHOP*

**John Hunter and Doyle Hanan, Chairs**

Sardine fisheries exist once again along the entire coast of North America from Baja California Mexico to British Columbia, Canada. An accurate coast wide assessment of this widely distributed stock is not possible at present for a variety of reasons: 1) the fishery independent measures of abundance cover only a fraction of the full range of the population; 2) the sardine fishery takes only a near-shore, often younger, fraction of the stock leaving the offshore fraction, of presumably larger and older fish, un-sampled; 3) age and growth measurements are confounded by movements along the coast which are presently largely unknown; and 4) basic life table information are lacking or need validation. The group discussed a variety of measurements and monitoring approaches that would help remedy the situation but set no priorities (Table 1). It was considered unlikely that new money would be available to expand the extent of coastal monitoring and research on sardine throughout its range. Thus, future advances in stock assessment will depend upon pooling of information, and in-kind contributions from industry and fishery agencies. In this regard, U.S. and Canadian Fishing Industry representatives expressed a willingness to contribute to the coast-wide collection of information needed to assess the sardine population. Since neither the Mexican sardine industry, nor the Instituto Nacional de Pesca (INP) attended this session, the extent of their interest in this international collaboration is not known. Mexican academic scientists who attended the session strongly supported such an international collaborative approach.

The consensus of the workshop was that an international forum was needed to implement and coordinate coast wide collection of the data for sardine stock assessment, and to exchange information, and keep abreast of trends in the fishery. The forum, called here FISCIE for Forum for International Sardine Collaboration and Information Exchange, should have regularly scheduled annual meetings and be attended by industry, fishery agency and academic scientists from Canada, Mexico and the U.S. FISCIE would establish collaborative protocol, facilitate in-kind contributions from industry, share and archive information, coordinate coast-wide sampling periods or surveys involving industry and agencies, share and discuss the most recent stock assessment information, and provide coast-wide standards for measurements. An *ad hoc* steering committee was established for organizing the first meeting of FISCIE (Table 2).

Another issue discussed in this breakout group was the need to modernize the U.S. sardine fleet. Fleet modernization is needed for the fleet to meet Hazard Analysis Critical Control Point (HACCP) requirements, meet new environmental requirements such as a sea disposal of transport water, and to produce a higher quality and more valuable product. While fleet modernization is primarily a U.S. industry matter, beyond the scope of Sardine 2000, two appropriate science policy issues were identified. First, when control rules are considered for the sardine fishery by U.S. management, the need for fleet modernization should be considered as a value as well as the traditional conservation-based value of reducing fishing effort. The group recommended that this report draw attention to this issue to scientists and managers involved in U.S. Coastal Pelagic Fish Management. Secondly, it would be advantageous to consider upgrading the collection of fishing information using shipboard electronic data logging systems as part of such a fleet modernization program. Presently, agency biologists are working with data collecting systems as obsolete as the fishing vessels.

## ACTION ITEMS

1) Convene first meeting of 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.

**Table 1.** Research activities suggested by the working group that would increase coast-wide knowledge of sardine needed for a coast-wide stock assessment. Practicality of items were not determined and no priorities were set; items are listed in no particular order.

Increase sampling for age structure in northern and southern end of the range.

Convert Oregon-Washington egg surveys carried out by NWFSC to biomass by estimating adult parameters (batch fecundity and spawning frequency).

Improve existing southern California spawning biomass estimates based egg surveys by measuring adult spawning parameters (batch fecundity and spawning frequency).

Conduct aerial surveys of sardine schools using spotter pilots to provide coast wide indices of sardine abundance and estimate the extent of offshore distribution.

Add airborne school detection using lidar to the above aerial surveys.

Conduct coast wide inventory of sardine biomass using CUFES.

Conduct acoustic-trawl survey coast wide to provide coast wide estimate of biomass.

Carry out an industry/agency tagging program using conventional tags or button archival tags. (Idea not well supported by group because of expected low return rates and costs).

Conduct a coast-wide intensive sampling periods using industry and multiple agency contributions resembling the URICA biomass surveys of Peru, except the focus would be on age structure and reproductive rates. One suggestion was to focus on the April since the April CalCOFI survey provides the longest fishery independent time series for sardine; a summer focus would also be useful since the northern fishery occurs in the summer.

Conduct short fishing vessel cruises to establish offshore limit to sardine distribution and to obtain age structure information.

Examine micro-constituents of sardine otoliths to determine the origins of fish (a low cost alternative to tagging).

Implement electronic logbooks with GPS and time stamp to improve locality and time data on catches.

Establish a network to archive industry derived estimates of size specific oil yield to be used in estimating seasonal reproductive output of stock.

Investigate feeding selectivity and the role of diet to determine the causal factors of bursting abdomens (the hot tummy phenomena).

# *ECOSYSTEM CONSEQUENCES WORKSHOP*

**Gordon Swartzman, Chair**

**Recommendations**

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;

**Discussion**:

**Theories on causes of expansion and contraction of the sardine fishery**

Are there specific conditions precipitating the California sardine crash/expansion? Consider conditions allowing a geographic expansion (invasion) vs. conditions allowing a numerical expansion (persistence). We reviewed evidence given in talks by Sandy MacFarlane, Ruben Sanchez-Rodriguez, David Checkley and John Field. Various decade-scale/regime shifts in 1925, 1947, 1977 and 1989 provided correlative evidence. Why was there no response of California sardine in 1977 when both Peruvian and Japanese sardine populations expanded then? Perhaps comparative studies with other Pacific sardine stocks would help explain sources of expansion/declines. Shifts in sardine population abundance north and south appear to depend on both conditions for spawning and feeding. Temperature interacts with advection in that the sardine spawning areas are limited by temperature, while advection must be present to allow northward migration of juveniles and adults. Also, regime shifts can produce differences in prey species mix that can affect grazing success of adults and resultant gonad development. Contraction may accompany cooler temperatures that prevents reproduction in the northern part of the range (i.e. Canada), and results in poor food resources north of Baja California. The population may move south in cooler conditions and replace tropical foraging species that had moved north under warmer conditions. Thus expansions and contractions may be associated with changes in temperature, advection and food availability. These in turn may influence spawning habitat, fecundity/body condition, juvenile survival and adult migration patterns. All are thought important. Other factors of possible importance are the influence of predators and the fishery in the decline phase?

**Modeling**

We reviewed the ECOPATH model. Bob Francis described, in lay terms, how ECOPATH computes trophic efficiency given biomass, production, and consumption and diet composition for each component. In our opinion the ECOPATH model seems over-determined. The whole modeling exercise is balancing the inputs and outputs to make the trophic efficiencies realistic. ECOPATH can be useful for examining the relative effect of the fishery and predators on sardine. Also, the parameter estimation process provides insight into the relative importance of different parameters to biomass balance. One suggestion, by Julia Parrish, was to use energy in addition to biomass flow, to get a different perspective on trophic dynamics. ECOPATH's limitations are that it has no dynamics (i.e., it has no temporal component) no spatial component and no age or size distribution information.

We discussed alternative modeling approaches that might address other questions. We agreed that a model framework should be chosen based on the question of interest. We decided that a seminal question for sardine is what factors are most important in the expansion and contraction of sardine populations (also the north to south shift in the sardine spatial distribution). We considered individual based and process models as options to address this question.

To focus energy and participants on amassing information and developing a model to investigate the relative importance of factors cited above to sardine expansion/contraction Bob Francis suggested we propose a National Center for Ecological Analysis and Synthesis (NCEAS) working group. Academic and agency scientist from Mexico, California, Oregon, Washington, and Canada all expressed interest in working in such a group. The group focus would be development of an IBM model framework, including rules for feeding and migration (i.e., the Parrish model) as a function of size/age, temperature-defined range of spawning areas, diet and prey selection, juvenile condition and migration, energetics component with growth, fecundity, condition and decision rules for gonad development. Oceanographic conditions will be included through movement of major fronts as barriers to migration, upwelling as a source of food, regime influence on temperature and currents, the role of El Niño in its effect on temperature and currents. A great deal of information must be synthesized, including Oceanographic, energetics, migration, and life-history information and predator feeding, diet and distribution.

**Data Availability and Missing Data**

We listed available data, with an eye to addressing questions of sardine expansion-contraction and trophic role (e.g. effect on prey, effect on predator diets and feeding rates). Available data sets:

1. **CALCOFI** – Physical data, sardine eggs and larvae, plankton (physical data soon on CDROM);

2. **Newport line (Bill Peterson)** – only 1970's and mid 1990's to present provides sardine and zooplankton density and distribution;

3. **Mexican data** – age and growth data (1990's from Magdalena Bay); also sardine eggs and larvae from incidental cruises along Pacific Coast and Gulf of California; over the last 3 years these data extend to the N. Baja California outer coast (eggs and larvae ( ~25 cruises both west coast and Gulf of California). Descriptive diet data (one cruise); Ensenada diet data (it was suggested that these data might have problems);

4. **Morphometry data** – shows 2 length-based switches in sardine morphology (28 mm & 150 mm standard length) – unpublished (in a thesis);

5. **Triennial survey data** – National Marine Fisheries Service bottom trawl and acoustic surveys give fish abundance distribution, since 1977. In 1998 an egg pump was deployed to sample the distribution of sardine eggs;

6. **Purse seine data (Bill Pearcy)**- 1979-1985 – mostly gives salmon distribution. These data can show what the system looked like without sardines;

7. **BPA study** – A current study conducted by National Marine Fisheries Service scientists near the mouth of the Columbia river and its environs can provide information of sardine eggs and larvae, and diets or sardines and sardine fish predators (1998+);

8. **GLOBEC** – The U.S. GLOBEC (Global Ecosystems) project has monitored 5 transects since 1998. These provide Oceanography and zooplankton data. They will also have fish sampling from 2000-2002;

9. **Canadian data** – 1960's and 1970's midwater trawl for herring can provide information on the environment without sardine. Triennial midwater trawl and acoustic surveys 1977+, annual midwater trawl and acoustics 1986+. Annual larval trawl surveys, neuston ('82-89,92,93), plankton (annually and all seasons (1985+) sporadic before that. Water samples for phytoplankton species composition 1970s+ along West Vancouver Island – being worked up for 1980's. Surface trawls all seasons 1996+ focussing on salmon and sardines (high-speed midwater trawls);

10. **Mark Lowry** – CA sea lion scat data 1981+ can provide some indication of changes in diet and importance of sardine in diets;

11. **Bob DeLong** - Ca Sea lion and fur seal scat data scattered through 1980's;

12. **Indian midden data** – channel Islands and Alaska can provide some information on the periodic abundance and distribution of sardine as available to an artisinal fishery;

13. **Genetic data** – Hedgecock, CALCOFI reports Mexico and S. Calif. only. NOT micro-satellite study;
14. **Tagging studies** – 1930's and 1940's provides information on sardine abundance and migration during the last period of abundance;

15. **Tuna bait boats catch (Observer and logbook reports)** – Sanchez Rodriguez – provides an excellent, continuous time record of small pelagic fish (e.g. sardine and anchovy) distribution and abundance from California to Southern Mexico.

**Spin-off projects considered (with relevant data sources from above)**

1. IBM model development – In addition to the NCEAS workshops (recommended below) additional funding is needed to allow a modeling effort to proceed, since resources will be needed for model development

2. Comparison to other Pacific sardine systems – life history comparison, morphometric comparison, migration comparison, synchronicity of abundance cycles.

3. Analysis of juvenile sardine size and condition data – data to be obtained from the tuna bait fish fishery and other ships of opportunity. Little is currently known about sardine juveniles because they are not fished (except for the bait fish fishery). This study could establish a baseline and juvenile condition could be a precursor for expansion or contraction of the population.[3,6,15]

4. Analysis of diet, size at age and condition index data from surveys of opportunity. This study would involve processing sardine data obtained from recent and ongoing BPA surveys, NMFS groundfish surveys and acoustic surveys. Stable isotope analysis could be done on historic sardine data to indicate in general what they are eating (diet trophic structure).[3,5,8,9,14]

5. Comparison of forage quality and size range of sardine with other forage fish. This study would be useful in examining possible shifts in bird and marine mammal diets with the advent or decline of sardine and could help to predict possible condition changes in these upper trophic predators.[3,5,6,7,9]

6. Multi-satellite genetic comparison of sardines in N and S. Is the northern stock derived from the southern (Mexican) stock or from residual populations in California? Hedgecock did a similar study w. electrophoresis, and there already may be a micro-satellite study done (1998). What did it show? All one stock? If possible this study could compare with genetics of sardine stocks in the 1940's and with other Pacific sardine stocks [13]

**Table relating possible research projects suggested to available data sources:**

| Research Project → Data Source | A – IBM Model | B – inter regional comparison | C – juvenile sardine size & condition | D adult diet, size and condition | E – forage quality size comparison | F – Multi-satellite stock comparison |
|---|---|---|---|---|---|---|
| 1 CALCOFI | x | | | | | |
| 2 Newport line | x | | | | | |
| 3 Mexican | x | | x | x | x | |
| 4 Morphometric | | x | | | | |
| 5 NMFS triennial | x | | | x | x | |
| 6 Purse Seine | | | x | | x | |
| 7 BPA egg-larvae | x | | | | x | |
| 8 GLOBEC | x | | | x | | |
| 9 Canadian | x | x | | x | x | |
| 10 CA SL scat | x | | | | | |
| 11 mar mammal | x | | | | | |
| 12 Indian middens | | x | | | | |
| 13 Genetic data | | x | | | | x |
| 14 tagging | | | | x | | |
| 15 tuna bait-fish | x | x | x | | | |

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