SARSIM Model Output for the Distribution of Sardine in Canadian, US and Mexican Waters.

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The information presented below was taken from a model that I presented at the 2004 CalCOFI Conference. The paper was submitted for publication in CalCOFI Reports and the editor informed me that the paper exceeded the normal page limits for CalCOFI Reports. Given the options available I withdrew the paper as I was shortly leaving for a consultation in Portugal and would not be able to make the major revisions necessary to meet the page limitation in time for the CalCOFI deadline. Shortly thereafter I retired from the NMFS so very few people have seen the MS; however, I have given several seminars in central California based on the paper. The distribution of biomass by Country was not presented in the original paper but the output described here was output from the 2004 model.

Summary:

I had not looked at the output data from a Country perspective and I was amazed to find that the model resulted in an average 88% of sardine biomass in US waters; almost identical to the 87% value used in the original and current harvest guidelines (Table 1). The minimum annual value for US waters was 66.6% in 1972 and the maximum was 96.6% in 1973. I also looked at 3 year running means to assess the multiyear affects of sea surface temperature on geographical distribution. The average 3 year percentage of sardines in USA waters was essentially the same at the annual percentage (88%); however, the minimum 3 year percentage was higher than the annual (76% vs 67%) and the maximum 3 year percentage was lower than the annual (93% vs 97%). The average annual percentage occurring in Canada was 2.45% and 9.5% in Mexico. Maximum percentages in Canada for the annual and 3 year averages were 16% and 8%; values for Mexico were 23% and 6%.

Table 1 Annual and Three Year Percentage of Sardine in Canada, USA and Mexico from SARSIM Model. (model run TS F: 1967-2002 simulation with observed environmental data time-series and modeled fishery)

	Canada	USA	Mexico
Annual			
Average	2.45%	88.05%	9.50%
Minimum	0.00%	66.64%	2.99%
Maximum	16.15%	96.59%	31.80%
3 Year Periods			
Average	1.79%	88.18%	10.03%
Minimum	0.05%	76.35%	5.58%

Maximum	8.12%	93.37%	22.79%

The modeled average biomass distributions suggest that the current 87% distribution parameter was well selected. Interyear variation in the percentage of annual biomass in US waters is unlikely to be a problem for management. However, multiyear periods with a higher than average percentage of sardine biomass in Mexico, which occurred in the model during the cold regime in the early 1970s, could be a problem. The correlation analyses of SST vs the percentage of sardine biomass in US waters suggest that Southern California SST in the winter, i.e. the Nov-Feb preceeding the model year (R=0.70), is a reasonable predictor of an anomalously high percentage of biomass in Mexican waters.

MODEL DESCRIPTION:

The model has 9 roughly latitudinal regions; 2 in Canada, 5 in the USA and 2 in Mexico (Figure 1). Sardine are forced by sea surface temperature (SST), size, and nonlinear functions to move seasonally between regions. In addition, eggs, larvae and juveniles are advected by wind driven transport. The time step of the model is bi-monthly; 24 time steps per year. Monthly environmental data are used for two time steps for each month.

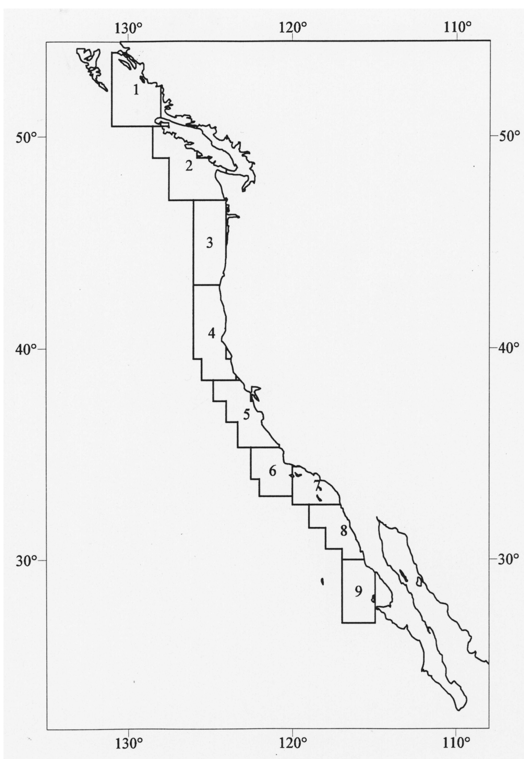


Figure 1. Regions included in the sardine model.

The model was designed for the northern sardine stock the critical sea surface temperatures which determine the direction of migration, north or south are 13 degrees C.in the feeding season and 17 degrees in the spawning season (Figure 2). So the model has the same 17 degree separation between the northern and southern stock as that in recent sardine analyses. as sardine in the model always migrate northwards if the regional SST is above 17 degrees.

The simulation runs in this report were made with a starting biomass of 1 mmt in 1967 using the observed environmental variables and a fishery based on a CUTOFF of 150,000 mt a MAXCAT of 200,000 mt and a constant FRACTION of 0.15. The model has no spawner-recruit function and no density-dependence in recruitment, growth or reproductive output. The model simulates the sardine population from egg to death and the percentages of biomass by area listed below were calculated from a simulation with fishing occuring in regions 2, 3, 5.7.and 8.

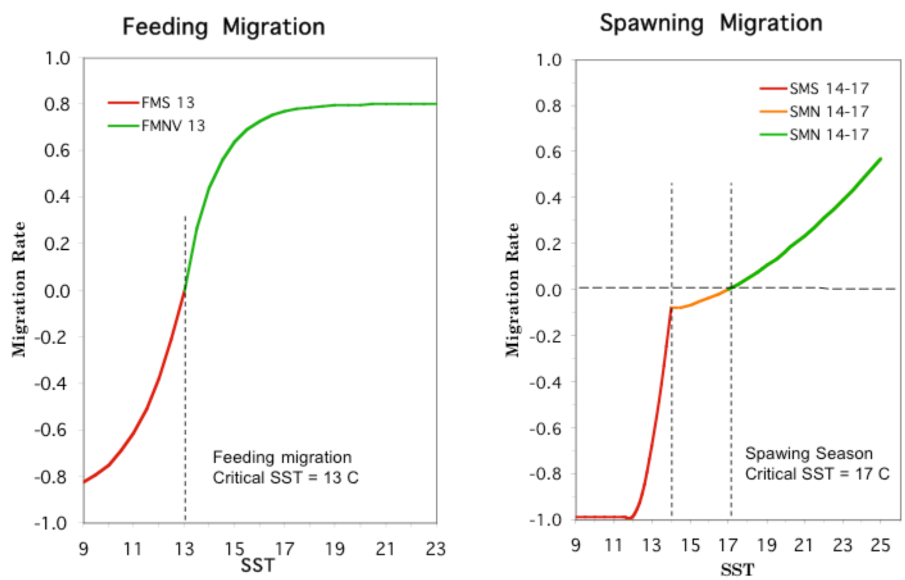
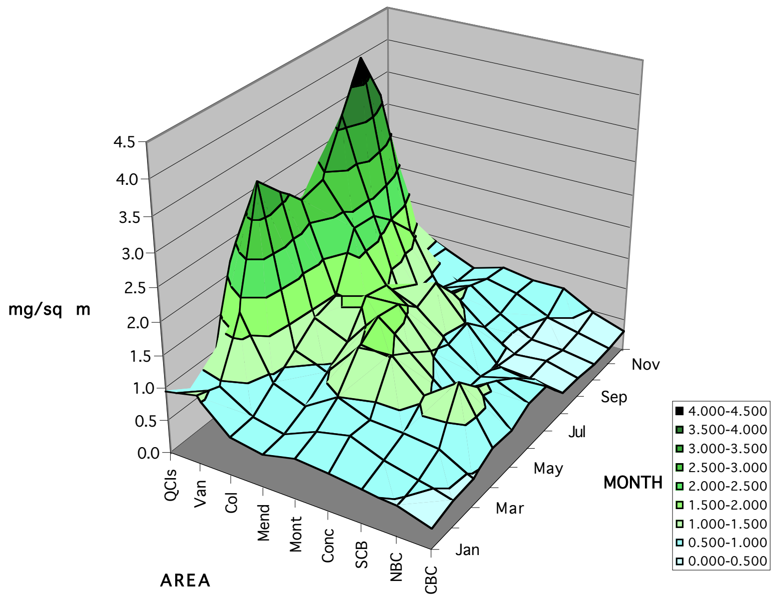


Figure 2. Temperature-dependent migration rates; positive northward and negative southward. A. Feeding migration. B. Spawning migration

It should be noted that the period since 2002 has not had sea surface temperatures as cold as the period prior to 1977, so the model would result in a slightly larger Canadian average percentage and a moderately smaller Mexican percentage for the 1967-2014 period than for the 1967-2002 period.

The present model cannot reproduce multi-year recruitment failures that are not associated with sea surface temperatures. The primary variable forcing population growth in the model, satellite chlorophyll, is the only environmental variable that uses climatology monthly means rather than a time-series of observed monthly data (Figure 3). This is because less than 7 years of satellite data were available when the model was developed. Obviously a time series of satellite chlorophyll would result in far less population stability and faster rates of change that simulations based on monthly climatology. The sea surface temperature affect on biomass is caused by altering the geographical distribution of sardine and thereby altering their position in the phytoplankton field. Essentially the model results in biomass growth if a significant porportion of the biomass reaches the satellite chlorophyll maximum that occurs during the summer and fall in the Columbia and Vancouver areas and the biomass falls if the majority of the biomass stays south of the

Figure 15. Satellite chlorophyll Sep97-Mar04 monthly means



Mendocino area.

Figure 3. Satellite chlorophyll Sep97-Mar04 monthly means.

The early life history stages are planktonic and advected based on monthly upper mixed layer transports calculated with Jim Ingrams (OSCURS) surface drift model. July transports are relatively consistent (Figure 4), differing primarily in the offshore componet which is not included in the model structure. January wind diriven transport is much more variable between years with the northern regions having primariluy northward transport and the southern regions having southward transport. In the Mendocino, Monterey, and to a lesser degree, the Conception regions, the transport can be either northwards or southwards in individual years. In the principal spring spawning months northward transport only occurs in the areas from Mendocino northwards. Note that without the southerly advection of early life history stages, the average biomass distribution would be further north.

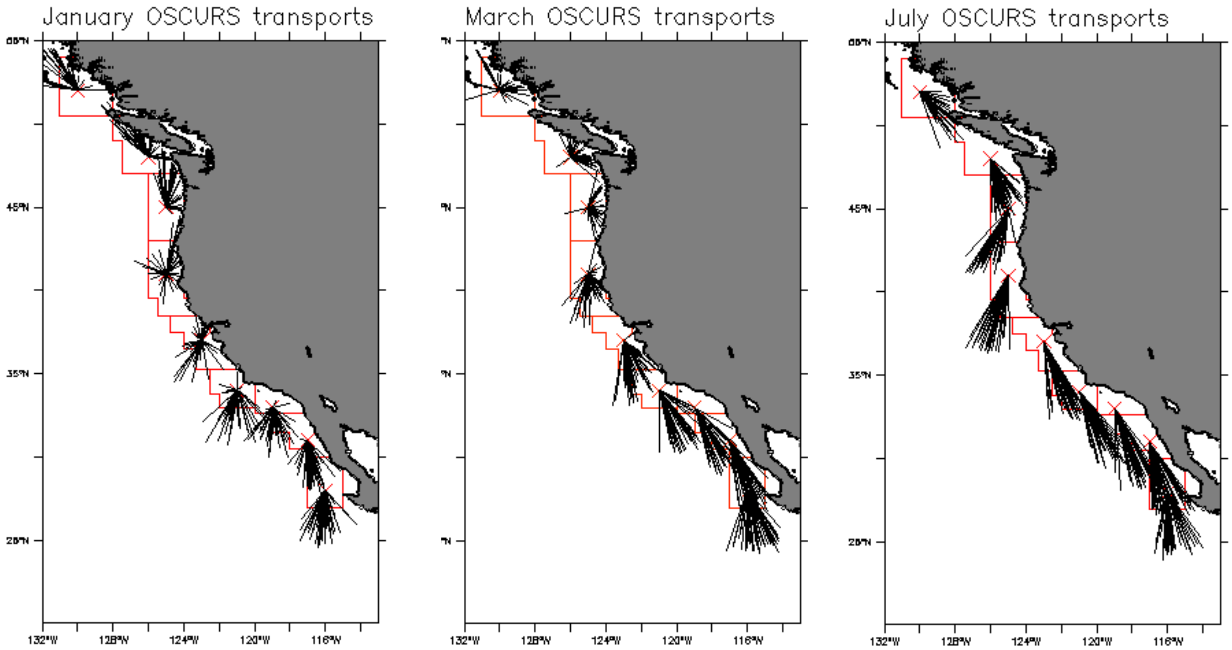


Figure 4. Bimonthly migration alongshore transport of eggs and larvae based on 1967-2002 monthly values from Jim Ingrams (OSCURS) surface drift model. (Three of 12 months shown).

The initial (1 MMT) model biomass declines sharply during the early 1970s cold period reaching a minimum of 0.242 MMT in 1979; it then rises slowly until the early 1990s and then increases to a peak of 0.859 MMT in 2000 (Figure 5).

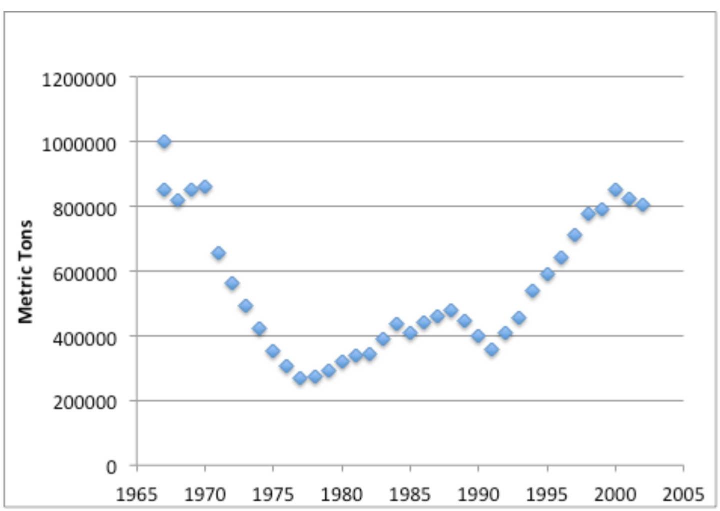
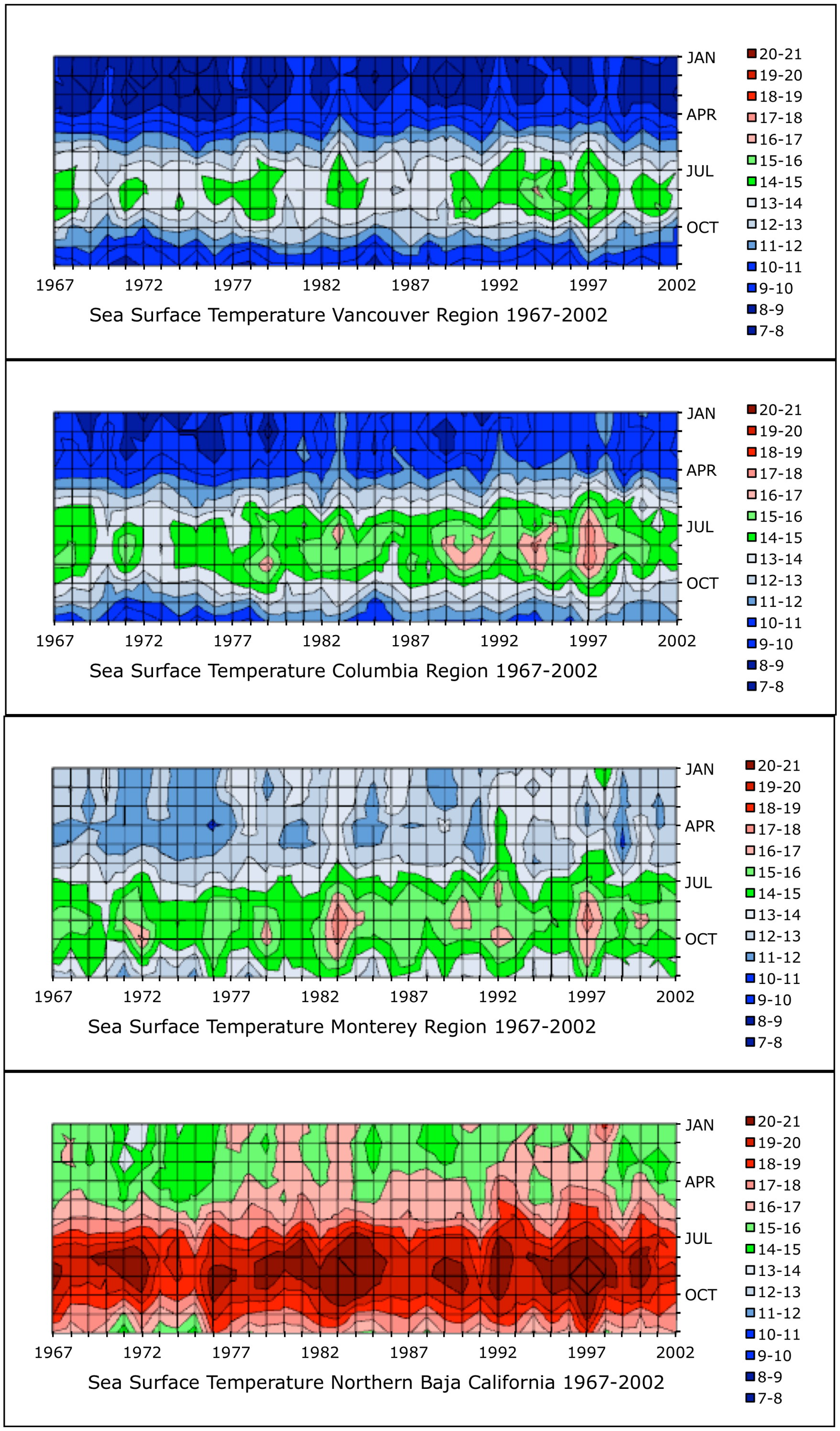


Figure 5. Biomass with observed 1967-2002 environmental data and fishery.

The SST regional matrices show the temporally coherent variability in the sardine habitat and the general increases in SST that occur after the 1976-77 regime shift (Figure 6).



Figgure 6. Sea surface temperature fields used for migration (4 of 9 areas shown)

ADDITIONAL ANALYSIS OF THE PERCENTAGE OF BIOMASS BY COUNTRY:

The minimum annual percentages in the USA and the maximum annual percentages in Mexico primarily occurred prior to the 1976-77 regime shift (Figure 7). The maximum percentages in Canada were after the regime shift and widely spread out in time.

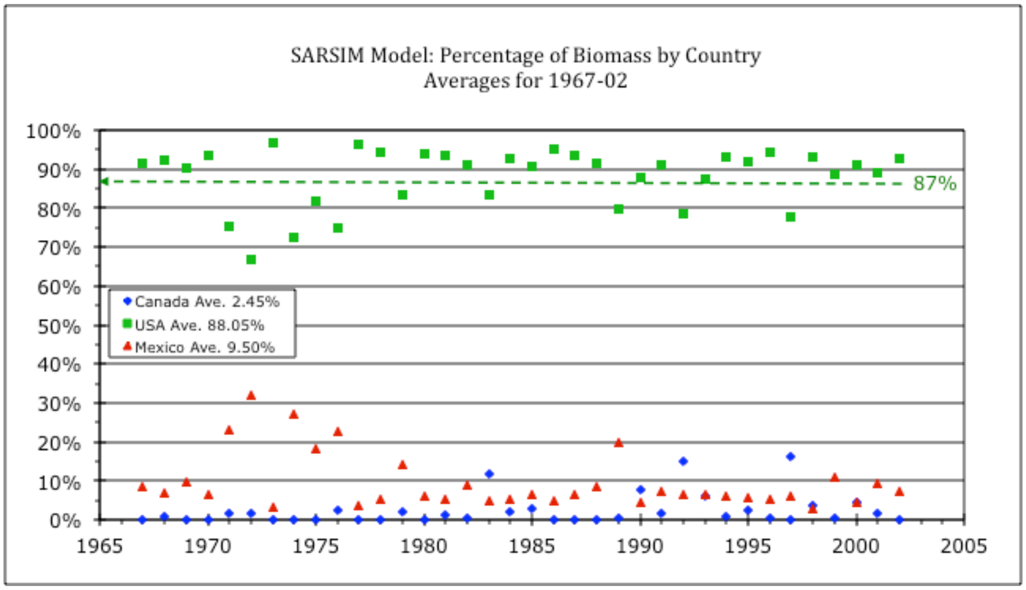


Figure 7. Annual percentage of biomass by Country

Another way of looking at sardine distribution is to plot the percentage of sardine in each country using the bi-monthly distributions from the model output (Figure 8). The difference between the annual distribution and bi-monthly distribution is striking. In 10 of the 35 years there were periods lasting from 2 weeks to 4 months when less than 50% of the sardine biomass was in US waters. More than 50% of the biomass was in Canadian waters for two months in 1997 and more than 50% of the biomass was in Mexican waters for 4 months in 1972.

The SARSIM model output suggests that there are years when it is physically possible that either Mexico or Canada could land a significant proportion of the USA Harvest Guideline even when the annual distribution percentage in the country is relatively low. Note: however, that a high percentage abundance in Mexico is associated with low abundance in Canada and visa versa so it is unlikely that both Canada and Mexico will have higher percentages of sardine biomass in the same year.

A brief correlation search was made and the highest correlation found (R=0.70) was between the southern California winter SST and the annual percentage of sardine in US waters (Figure 9). The time series of the percentage of biomass in US waters again shows the low percentages that occurred during the early 1970s (Figure 9.)

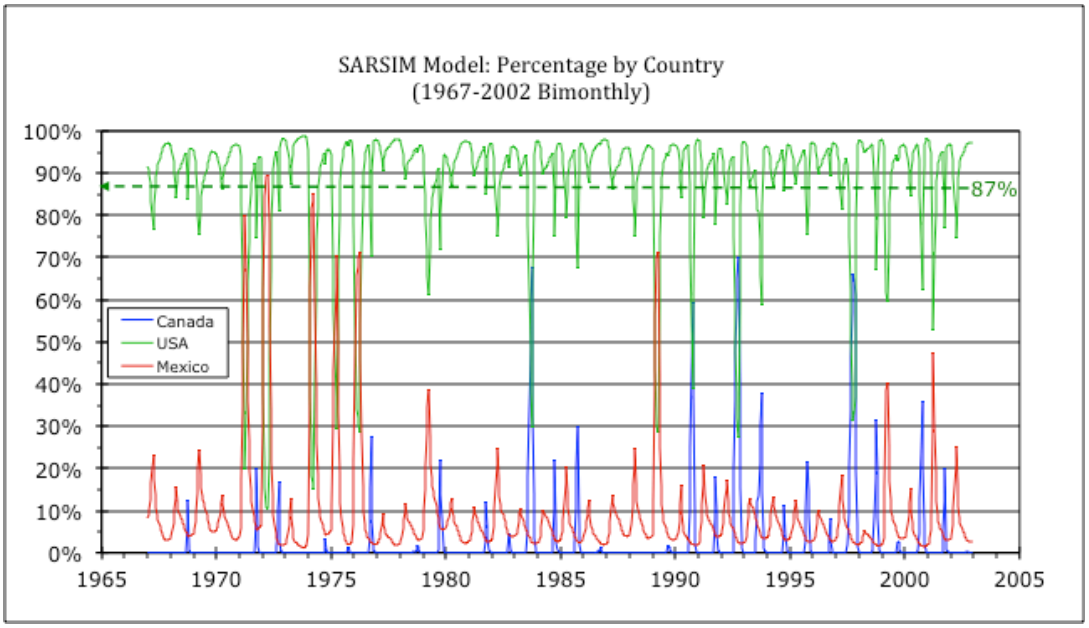


Figure 8. Bi-monthly percentage of biomass by Country.

Winter temperatures in all of the regions, except region 1, were correlated with the annual percentage of sardine in US waters at values above R=0.50 (Figure 9). The lowest percentage of sardine biomass in US waters was in the period before the 1976-77 regime shift and these low values were caused by increased percentages of sardine in Mexico during the very cold years of the early 1970s.

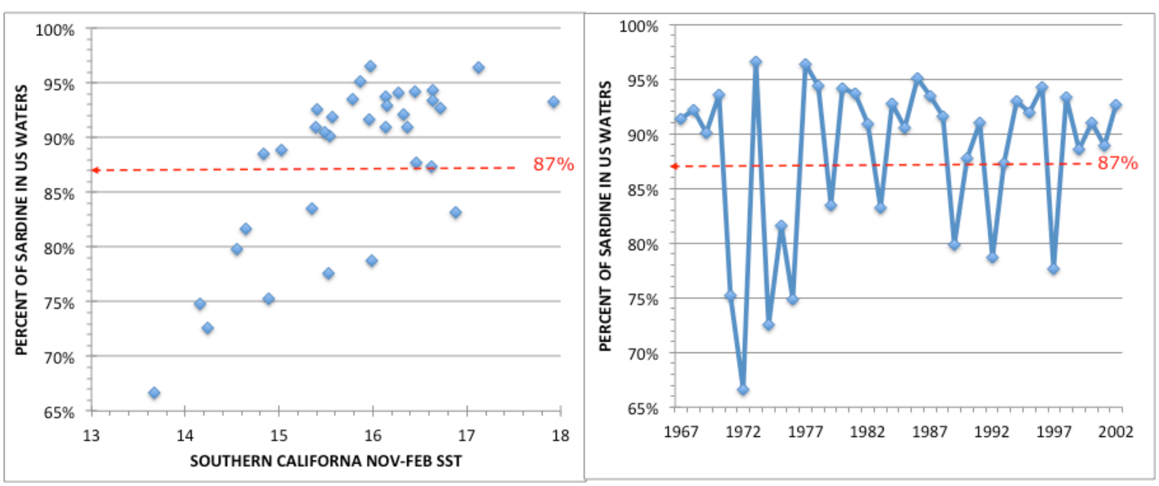


Figure 9. Annual percentage of biomass in US waters vs winter SST and 1967-2002 percentage of biomass in US waters.