Proc. Int. Rockfish Symp.
Oct. 1986, Anchorage, Alaska

Ocean climate influences on groundfish recruitment in the California Current

Jerrold Norton
NMFS, Southwest Fisheries Center
Monterey, California

1. Introduction

In this study, patterns of rockfish (genus *Sebastes*) recruitment variation are shown to be similar to patterns of variation in physical parameter values which describe the rockfishes' environment. The patterns of similarity occur at interannual and longer scales in the 1965 - 1980 period. Although it is important to obtain detailed knowledge of the rockfishes' complete reproductive cycle, including physiological and behavioral adaptations of the young-of-the-year, the approach used here does not depend on having this knowledge.

Studies that link groundfish recruitment success to variation in the physical environment are not new (Ketchen 1956, Templeman 1972, Cushing 1973, Parrish et al. 1981). A number of interesting relationships have been at least partially illuminated. It is hoped that the present investigation will augment the ongoing exploration process that will lead to scientifically based resource management methods.

The focus of the present study is on the large amplitude recruitment fluctuations that remain apparent years and even decades later in the data obtained from commercial fishery samples. The course of the investigation was determined by the following considerations and assumptions.

1. Because of specific adaptations, rockfish population size and structure reflect physical environmental events occurring during the life history

of the population's members (Darwin and Wallace 1858). It is unlikely that co-occurring species can react identically to the range of physical variability occurring in the California Current environment.

2. Probable recruitment success of discrete cohorts of a given species of rockfish can be inferred from catch-age (catch-at-age) composition data derived from otolith (sagittae) readings for a population subset (Hightower and Lenarz 1986, Henry 1986). Imprecision in determining the calendar year of otolith initiation (fishes first year) increases as specimen age increases (Boehlert and Yoklavich 1984).

3. Time series of physical environmental measurements exist that delineate events of diel to decadal time scales. These may have amplitudes of several standard deviation units and may extend over tens of degrees of latitude. (Mooers and Robinson 1984, Norton et al. 1985, Chelton et al. 1982). This study is focused on events of interannual and longer time scales because these events are easiest to define and rockfish recruitment variability at these scales is evident in catch-age composition data.

4. Because of uncertainties in aging and the lack of knowledge concerning the effects of environmental change on all stages of rockfish development, the best chance of showing relationships will be found by examining physical conditions during the first year of the fishes' life (Hjort 1914, Hunter 1982). Extremes in first year success (as determined from catch-age composition data) and physical events are important as possible single factor maxima that stand above "noise" that obscures underlying relationships. The rockfish parturition date is taken as January first. So, the calendar year is taken as the fishes' first year.

5. The effects of variation in any particular physical parameter on the young-of-the-year is unknown. So, the approach used in this study is to describe each year in terms of several physical parameters. Because of the reduction of quantitative time series into three bins ("+," "0" and "-"), short time series and qualitative nature of some of the data sets, pattern matching is emphasized.

The major data relationships are seen in Table 1 which organizes the information into binned data series to emphasize common patterns. The physical data are binned by numerical magnitude into three groups relative to the long term means. In general, the bins are labeled "+" for above average or positive anomaly, "0" for a defined average range where random anomaly might be assumed and "-" for below average or negative anomaly. Extremes are labled "++" and "=." Widow (S. entomelas) and chilipepper(S. goodei) rockfish recruitment and zooplankton abundance data series are given in Table 1 with the highest values indicated by "W," "C" and "Z" respectively. Asterisks show extremes and lowercase letters indicate above average values. The "x" symbol indicates low values of recruitment or abundance. For all series "n" means that the data for this period is not available. Relationships between high first year survival (population recruitment) and various physical parameters are shown for widow and chilipepper rockfish (RF) in Table 1. Row 12 of Table 1 gives a summation of the physical parameters and may be taken as a combined physical indicator. Note that widow RF and chilipepper RF have most successful recruitment under different environmental conditions. Widow RF recruitment appears enhanced during "warm" years which have positive values in row 12 and chilipepper RF have their best recruitment during "cool" years that have negative values in row 12 of Table 1.

Sections two and three of this report are intended to explain and give additional background on the physical and biological data series used in Table 1. Sections four and five expand and discuss the results given by Table 1.

2. Biological Data Series

A zooplankton abundance data series is presented with the widow and chilipepper RF recruitment time series to allow consideration of the young-of-the-year rockfishes' biological environment. All biological systems are affected by physical environmental changes. Comparison of the three series (rows 1,7 and 11 in Table 1) supports this.

Widow rockfish (S. entomelas). Widow RF recruitment data (row 1, Table 1) were obtained from the cohort analysis of the 1980 - 1985 catch-age composition data from commercial fishery sampling in Washington, Oregon and California (Hightower and Lenarz 1986). These are summarized in Figure 1. Greatest population recruitment was in 1968 and 1970. The recruitment level shown for 1971 and 1969 may be overestimated because of imprecision in aging 10 and 12 year old fish, i.e. peak spreading. Widow RF are a component of the recreational fishery as far south as Santa Barbara (Love 1981), but the peak commercial catch has been off Oregon with only occasional commercial catch south of San Francisco.

Since 1978 widow RF have become the object of a targeted single species fishery. Unlike fishing methods for other RF species (e.g. chilipepper), which are by daytime bottom trawl, the adult widow RF are more vulnerable to nighttime mid-water trawling. Dense vertically-oriented schools form at night and disperse at dawn, when widow RF become incidental in the daytime bottom trawl fishery (Wilkins 1986). The dense single species aggregations were discovered in 1978. By 1980 annual harvest increased 20 fold to 21 thousand metric tons. The "boom" years of 1980 through 1983 were sustained by the highly successful 1968 and 1970 year classes. As these cohorts were exhausted in the absence of succeeding good year classes, the fishery

Table 1. Comparison of sequences of annual values for widow and chilipepper rockfish recruitment (rows 1 and 11), indicators of the physical environment (rows 2, 3, 4, 5, 7, 8, 9, 10) and a composite physical parameter derived by adding rows 3, 4, 5, 6, 8, 9 and 10 (row 12). Years from 1965 to 1980 are entered across the top. Row designations as follows: row 1(Widow RF), widow rockfish recruitment time series; row 2(EN/AL), occurrence of California Current warming event types, EN = El Nino and AL = Aleutian Low induced coastal warming; row 3(1st dif. 25m T), large scale coastal (32 - 50 degrees north) first difference winter temperature anomaly at 25m; row 4(AL index), Aleutian Low atmospheric pressure indicator, "+" means greater development; row 5(B. C. SST), British Columbia Sea Surface Temperature (SST); row 6(N. Transport) index of tendency to anomalous northward transport in the California Current; row 7 (Zooplank.), zooplankton abundance indicator; row 8(Downwelling), winter coastal downwelling indicator at 42 degrees north; row 9(Cen. Cal. SST), composite central California SST indicator; row 10(SF Sea Level), San Francisco sea level height anomaly; row 11(CP RF), relative chilipepper rockfish recruitment; row 12 (Sum), composite physical parameter. In the biological time series, capital letters mean largest values with the asterisks indicating maxima. Lower case letters (w, z, c) indicate above average values. The "0," "x" and "n" symbols are for average and low values and no data respectively. Blank means data inconclusive (row 11). Numerical values for physcial parameters were divided into three bins: "+" above average, "0" for average, "-" below average, "++" and "=" indicate extremes. Split symbols, e. g. "+/-", mean above the mean for at least 3 months at the start of the year, remainder "-." Note that the winter events or values shown in rows 2, 3, 4 and 8 that take place in two calender years are placed in the second calendar year. Widow rockfish (row 1) have most successful recruitment during "warm" years which have "+" values in row 12. Chilipepper rockfish appear to have better recruitment during "cool" years which have "-" values in row 12.

Year	1965	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Widow RF (1)	n	n	n	W	w	*W	w	x	x	x	x	x	0	W	x	w
EN/AL (2)		EN		AL		AL EN			EN				AL EN	AL (en)		AL
1st dif. 25m T (3)	=	+	0	+	-	+	=	-	+	-	+	-	++	-	-	++
AL Index (4)	=	-	0	++	-	++	+	-	0	-	-	=	+	++	-	+
B.C. SST (5)	0	+/0	+	+/-	-	+/-	=	=	+/-	0	-	-	+/0	++	0	++
N.Trans-port (6)	-/+	+	+	0	+	+/n	-	-/+	+/-	-	=	-/+	+	++	+/n	n
Zoo-plank. (7)	z	z	z	z	0	0/z	Z	z/x	*x	0	0	n	n	x	*x	n
Downwell-ing (8)	-	-	-	-	0	++	-	=	-	-	-	=	-	++	=	++
Cen. Cal. SST (9)	-/+	+	+	+	+	+	0	+	+/-	-	=	-/+	+	+/-	0/+	+/
SF Sea Level (10)	0	0	0	+	++	+/-	=	-	+	-	-	=	-/+	+	0/+	+
CP RF (11)	c				c		C	x	C	c	*C	0	x	x	c	n
Sum (12)	-5	+2	+2	+4	+1	+7	-7	-6	+1	-6	-7	-8	+5	+8	-1	+9

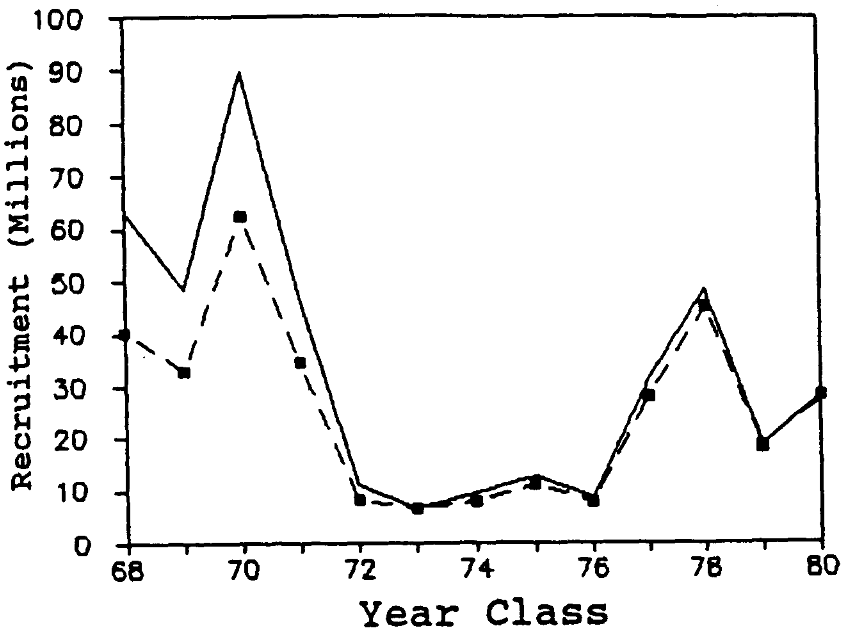

Figure 1. Cohort analysis estimates of widow rockfish recruitment at age 5 for the 1968 - 1980 year classes. Instantaneous rate of natural mortality was set at 0.15 (broken line) and 0.20 (solid line). The last three year classes may not be fully recruited to the fishery. Analysis and table from Hightower and Lenarz (1986).

slumped (Wilkins 1986, Gunderson 1984). Figure 1 shows poor widow RF recruitment for five consecutive years from 1972 through 1976. These were cool California Current years with mild winters (Table 1, rows 4, 5, 8). The 1976-1977 winter brought a climatic shift to conditions that were again favorable to widow RF recruitment.

Chilipepper rockfish (S. goodei). Chilipepper rockfish has commercial importance mainly in central California. Annual catch is 2,000 metric tons, all south of the northern California border. Except for zonal distribution, its ecology and also its morphology appear similar to Pacific ocean perch (S. alutus) (Adams 1980). Catch-age composition data submitted to the Pacific Fisheries Management Council by Henry (1986) are summarized in Table 2. Table 2 was abstracted to give row 11 of table 1. Table 2 lists the eight most important cohorts contributing to the total California commercial trawl catch between 1978 and 1983. Each column lists year classes in descending importance to the total catch. The number in parentheses is the number of thousands of fish in the most numerous cohort. Relative abundance of the seven other most important cohorts is indicated as percent of the most abundant contributor.

Table 2. Summary of the chilipepper catch-age data for 1978 - 1983. The eight most important year classes contributing to the total California commercial trawl catch are listed for each year. Each column lists year classes in descending importance to the total catch. The number in parentheses is the number of thousands of fish in the most numerous cohort sampled by the commercial fishery. Relative abundance of the seven other most important cohorts is indicated as percent of the most abundant contributor. For the entire series, the major contributing cohorts in descending order are given in column 7.

Year	1978		1979		1980		1981		1982		1983		Total	
Rank	yr	%	yr	%	yr	%	yr	%	yr	%	yr	%	yr	%
1	69	(230)	73	(540)	75	(750)	75	(630)	73	(330)	71	(400)	75	(2536)
2	73	80	75	74	74	68	73	70	75	94	75	98	73	84
3	71	78	71	43	73	55	74	60	74	72	73	60	74	61
4	70	62	72	43	72	49	72	27	71	45	79	40	71	54
5	68	57	76	43	71	35	76	27	76	39	76	38	76	36
6	72	55	74	33	76	31	71	25	72	21	74	35	70	28
7	67	39	70	32	69	20	70	21	79	18	77	23	69	26
8	74	39	68	26	70	17	77	10	70	18	70	18	68	16

An average or better year class will enter the list of eight most numerous year classes in its third, fourth or fifth year. It will be found in the four most abundant year classes for three or more years (e.g. 1974). Finally, the cohort will drop from the list of most numerous year classes as its numbers are depleted by fishing (e.g. 1972). Relative year class strength can be estimated from the time dependent ranking of cohorts and the persistence of its residence among the top catch contributors (Table 2). The results of quantitative catch-at-age analyses (Deriso et al. 1985) are comparable to the results developed below (Henry 1987).

For the entire series, the major contributing cohorts in descending order are: 1975, 1973, 1974, 1971, 1976, 1970, 1969, 1968 (column 7, Table 2). The 1975 year class became the second most important cohort in its fourth year and remained a top contributor for the entire period. This was an unusually successful recruitment year and was the most abundant year class in the record high landings of 1980. The 1973 cohort was not sampled until its sixth year, but its place as second overall suggests that it also was an unusually abundant cohort. The 1974 year class was optimally sampled by the 1978 through 1983 period and there is probably some spreading of the 1973 and 1975 modes into 1974 because of aging imprecision. There is insufficient information to conclude that the 1974 period was much better than a high average year in terms of recruitment. The 1971 cohort appears strong in that it was a major contributor to the fishery throughout the period even though it was not sampled until its eighth year. The increase in importance of the 1971 cohort from sixth in 1981 to first in 1983 may be the result of deeper trawling necessitated by the 1982 -83 El Nino conditions. The 1976 cohort became important in its third year, but its ranking in the catch has always been lower than fourth. Aging imprecision probably lead to the overestimation of this year class because of its proximity to the very strong 1975 year class. There may have been a moderately good year class in the 1968 - 1970 period, possibly 1969. The cohorts of 1972, 1977 and 1978 are weak, in this order of decreasing abundance. The 1979 cohort is unusually numerous compared to the two predecessors (Henry 1986). It was seventh in importance in its third year and fourth the following year (Table 2).

Results of fishery-independent trawl surveys by the Northwest and Alaska Fishery Center/NMFS suggest that the 1965, 1969, 1974 and 1975 chilipepper RF year classes have been more successful than average (Coleman 1986). This is in general agreement with the results presented by Henry (1986) and has been used to complete the 1965-70 section of the chilipepper recruitment time series.

Zooplankton abundance. Continental shelf rockfish are known to feed on zooplankton (Brodeur and Pearcy 1984). Overall zooplankton abundance in the California Current south of San Francisco as given by Chelton et al. (1982) is summarized in row 7 of Table 1. The years thought to be most successful for both widow and chilipepper RF were average zooplankton years. This may represent a balance in caloric competition at the planktonic level. That is, a balance between having low enough planktonic predation to survive and having high enough planktonic food to grow may be important in rockfish planktonic stages. The zooplankton index is not included in the combined physical parameter (Table 1, row 12).

3. Physical Parameters

The physical parameters used in this study were chosen for completeness in the 1965 - 1980 period, for possible generality in reflecting physical conditions in areas of greatest chilipepper and widow RF abundance, and for general availability. The following subsections will give additional detail on the abstracting and binning of the physical data sets used in Table 1. Table 1 row headings are included with the subsection headings.

California Current Warming Events(EN/AL). Although the Sebastes environment in the California Current region is over the continental shelf and slope, the forces that affect this environment may originate thousands of kilometers distant in the tropical and north Pacific (Quinn 1978, Uda 1962, Norton et al. 1985, Mysak 1986). Row 2 in Table 1 indicates the occurrence of two warming event types (EN = El Nino, AL = Aleutian Low Intensification). The observed coastal impacts of the El Nino and Aleutian Low warming occur in fall and winter thus extending over two calendar years (Breaker and Mooers 1987), e.g. 1972-73 or 1976-77. In Table 1 the notation for these events are placed in the second year, 1973 and 1977 respectively.

The California Current System (CC) is a broad eastern boundary system of weak but persistent north to south surface flow off the west coast of the United States (Hickey 1979). The CC inner boundary is the coast and the outer boundary is a broad transition zone 3-400 km offshore The origins of two California current warming event types are diagramed in Figure 2. El Nino effects are carried into the CC region from the tropics by poleward traveling coastally trapped downwelling wave packets which depress the thermocline and cause coastal warming. (Huyer and Smith 1985, Chelton and Davis 1982, Enfield and Allen 1980, Picaut 1985, Mysak 1986). These El Nino perturbations that originate as equatorially trapped Kelvin waves (Cane 1983) are denoted by the solid arrows in Figure 2. Coastal bathymetric and bathythermal irregularities cause the eastern boundary trapped waves to leak energy to the west as downwelling baroclinic Rossby waves. (Rienecker and Mooers 1986, Mysak 1986)

The second warming event type is associated with an intensification of the Aleutian Low Pressure System and its counterclockwise circulation (around "L" in Figure 2).

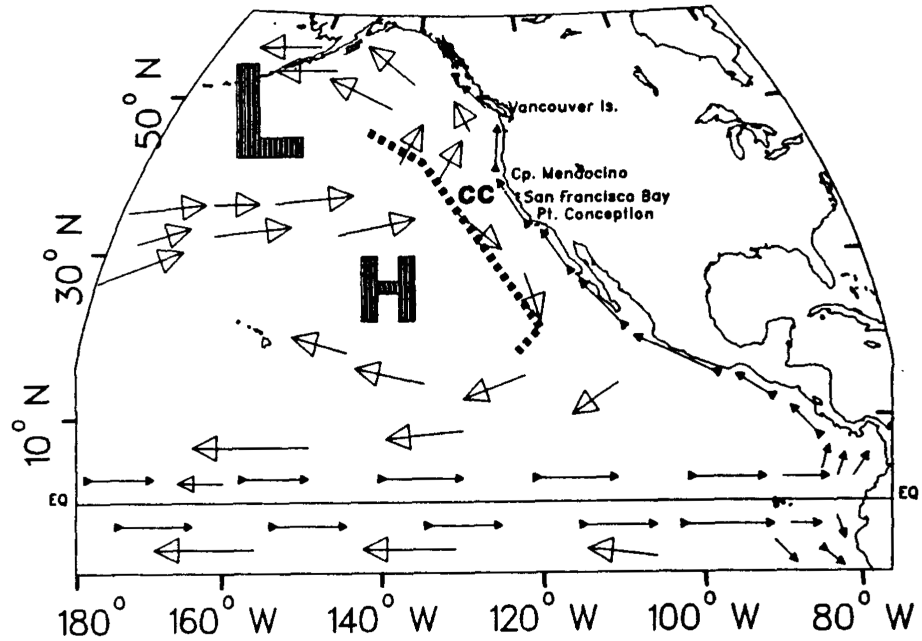

Figure 2. Origins of two California Current (CC) warm event types. The outer boundry of the CC transition zone is indicated by the dotted line. El Nino effects are brought to the CC region by poleward traveling coastally trapped waves originating as equatorially trapped Kelvin waves (small solid arrows). Intensification of the Aleutian Low atmospheric pressure system (block L) affects the CC throughout its range by intensification of winds that oppose its normal flow to the south (open arrows). As the low expands, the eastern limb of the cyclonic circulation brings anomalous south to north winds to the coast which enhance winter downwelling. The atmospheric pressure pattern shown in this diagram is representative of the early March mean.

Intensification of the Aleutian Low pressure system is a deepening or increasing magnitude of negative pressure anomalies in the lower atmosphere (Wallace and Gutzler 1981). This has effects throughout the north Pacific. The California Current is affected throughout its range by anomalous winds that oppose its normal flow to the south. As the Low expands, the eastern limb of the cyclonic circulation brings south to north winds along the coast. Then local and remote wind forcing combine to augment processes that depress the thermocline in the California Current and warm the coastal ocean, but this effect is usually limited to the upper 150m (Norton et al. 1985, 1987).

There is a tendency for deep Aleutian lows to develop during El Nino years when there is extensive equatorial warming as in the winters of 1969-1970 and 1976-1977 (Wallace and Gutzler 1981), but sometimes the low does not intensify even when there is extensive equatorial warming as in 1965 and 1972 (Douglas et al. 1982). The Aleutian Low may also intensify without apparent tropical warming as in 1967-1968 and 1979-1980 (Norton et al. 1985).

Patterns of dependence among physical parameters. Patterns of dependence among physical parameters are shown in Table 3. This table shows the association tendency among the physical parameters discussed in this study. The three interannual event types distinguished in this paper are shown. During an El Nino year (Table 3, col. 1), the warming effect on the California Current (CC) may be called the "California El Nino." During the California El Nino the sea level height and northward transport anomalies increase (Huyer and Smith 1985). Along parts of the coast there is northward surface flow as a persistent year-round feature (Bird et al. 1984, Hickey 1979.)

The Aleutian Low Index (AL Index in Table 1) may be above or below average during a California El Nino and coastal downwelling may be above or below average(Tables 1 and 3). Since the California El Nino brings warm water into the coastal zone, the north to south flow tendency of the CC is decreased. During Aleutian Low warming (Table 3, col. 2), the Aleutian Low index will increase indicating intensification of the north Pacific Low pressure system. Unusually strong coastal downwelling is common during an Aleutian Low warming. Other effects will be similar to those of the California El Nino. One of the several definite relationships shown in Table 3, is the connection between winter downwelling (row 3), onshore transport of surface water and increased transport to the north. If coastal wind stress is from south to north along the coast, surface water will be transported onshore (row 6) and downwelling will occur. As an adjustment to redistribution of water, northward flow will be increased (row 5). Increased northward flow is the result of onshore flow, which may result from California El Nino, Aleutian Low or local forcing. Onshore flow may be important in producing conditions leading to increased widow RF first year survival. During the CC cool event (Table 3, col. 3), all the parameters will tend to reverse (become "-") in value except transport to the south, which will increase. Onshore transport usually brings warmer water to the coast. Consequently, SST (row 1) and sea level (row 4) will be increased. Table 3 represents an idealized view of the relationships among physical parameters presented in Table 1.

The relationships among the physical parameters involve the change from one point to another on a functional surface which results in increased or decreased variable value. Many combinations of binned variable

Table 3. Idealized representation of three California Current Interannual Events (columns) in terms of common parameter anomalies (measurements). The rows are: Sea Temperature, row 1; Aleutian Low index, row 2; winter downwelling, row 3; Sea Level height anomaly, row 4; Northward Transport tendency, row 5; Onshore Transport, row 6 and CC southward flow. The warming events will have positive anomaly measurements except for California Current transport to the south which will be reduced. Anomalies will have reverse tendency during cool events (col. 3). The "+/-" entries reflect opposite possibilities. The California El Nino may occur with or without Aleutian Low induced warming (row 2) and enhaced winter downwelling may or may not occur during Aleutian Low warming events (row 3).

Event > / Measurement		California El Nino warming	Aleutian Low warming	California Current cool event
Sea Temp.	(1)	+	+	-
AL Index	(2)	+/-	+	-
Downwelling	(3)	+/-	+/-	-
Sea Level	(4)	+	+	-
N. Transport	(5)	+ (north)	+	-
Onshore Trans.	(6)	+	+	-
Cal. Cur.	(7)	-	-	+ (south)

values are possible in a given event type, even when scaled to long term means (Table 1). Observed combinations will depend on the event intensity and the state of the CC and north Pacific atmosphere when the signals arrive. For instance, the 1972-73 El Nino was intense in the tropics, but an intensified Aleutian Low did not develop, and northward flow tendency increased during the 1972-1973 winter. Then flow shifted strongly to the south in late 1973 (Chelton et al. 1982, Huyer et al. 1978).

<u>First difference 25 meter temperature(1st dif. 25m T)</u>. The first difference of the standardized temperature anomaly at 25 meters depth for a 200 km wide coastal strip extending from 30 to 50 degrees north latitude is shown in row 3 of Table 1. Data in this area were also averaged for a period from October through March (Norton et al. 1987). The year designation is the same as for the associated January. First differences are the average standardized temperature anomaly for a given year minus the value from the preceding year. This procedure emphasizes interannual change. A "+" entry means the current year is warmer than the preceding year and "++"("=") means that the warming was maximum (minimum) or within 10% of the maximum (minimum) value. Note that the first difference coastwide standardized anomaly is positive for every warming event in the 1965-80 series (Table 1). That is, each of the "EN" and "AL" years produced a signal in the coastwide anomaly that indicates warming over the preceding year(Table 1, rows 2 and 3).

Aleutian Low (AL Index). Aleutian Low Intensification (Table 1, row 4) was measured directly by the negative mean monthly anomaly of the 500 millibar atmospheric height at 45 degrees north latitude by 165 west longitude ("L" in figure 2). The sign of the anomaly is reversed and bins assigned according to the conventions of Wallace and Gutzler (1981). A "+" notation in row 4 indicates intensification of the Aleutian Low Pressure System over the mean. The "++" notation indicates a particularly intense Aleutian Low. The "0" means average Aleutian Low development. An Aleutian Low that is more intense than average will also be larger than average. As it expands, the Eastern Pacific High is shifted southward and winds from the south become more common over the CC System (Figure 2). The deepest Aleutian Lows were coincident with the best years for widow RF recruitment.

British Columbia Sea Surface Temperature (B. C. SST). British Columbia SST (row 5 in Table 1) was derived from monthly mean temperature anomalies (from a 30 year monthly mean) at Race Rocks on the southern tip of Vancouver Island (Tabata 1985). Symbols were assigned to divide the data into three bins as follows: "+," anomaly greater than +.25 degree Celsius; "0" for anomalies of absolute (unsigned) value less than .25; "++" and "=" indicate extreme values. In some cases it was not possible to unambiguously state that the entire year was above or below average. So, "+/-" means that the first part of the year (at least three months) was above average temperature and the last part of the year (at least three months) was below average temperature. Note that "-" values typical of the 1971 - 1976 period correspond to the best recruitment years for chilipepper RF.

Northward California Current Transport (N. Transport). An integrated index of northward CC flow (row 6, Table 1) in an area 200-400 kilometers from shore extending from 26 to 38 degrees north is extracted from Chelton et al. (1982). The symbols "+" and "n" mean northward transport and no data respectively. Fortunately, this unique time series is nearly complete in the 1965 to 1980 interval of interest. Although its exact meaning might be subject to considerable interpretation, agreement in independent measurements over the continental shelf and slope (Huyer et al. 1978, Mclain and Thomas 1983, McLain et al. 1985) suggest that this transport tendency index has some applicability in assessing the rockfishes' environment. In general it appears that, northward transport has favored widow RF recruitment and southward transport has favored chilipepper RF recruitment.

Winter Season Downwelling Index (Downwelling). An annual index of coastal downwelling (row 8, Table 1) during the winter season at 42 degrees north was derived by Norton et al. (1985) by accumulating the monthly mean upwelling index values of Bakun (1973) and reversing the sign. The convention of plus and minus symbols is similar to the parameters already discussed. In terms of percent of the highest value, the bins were assigned as follows: 0-25%, "=;" 25-60%, "-;" 60-80%, "0;" 80-95%, "+;" 95-100%, "++." The numerical average value was at about 68% of the maximum value. The three extreme downwelling years, 1970, 1978 and 1980 were favorable to widow RF recruitment.

Central California Sea Surface Temperature (Cen. Cal. SST)
The central California SST indicator (row 9 of Table 1) was derived from monthly mean anomalies at the Southeast Farallon Islands, 46 km west of San Francisco and at Pacific Grove at the southern end of Monterey Bay 100 km south of San Francisco (Anon. 1981). These two stations represent different coastal environments and the combined data is presented as a temperature indicator closely associated with the chilipepper environment. Combination of the data allowed a complete data set to be derived from two nearly complete data sets. Binning conventions are generally the same as for British Columbia sea surface temperature (above). The most extremely negative value in 1975 corresponds to the most successful (known) chilipepper year class, but this relationship does not appear to hold for all other chilipepper year classes.

San Francisco Sea Level (SF Sea Level). The detrended San Francisco sea level was adapted from McLain (1983) for row 10 of Table 1. Sea level anomaly is an indicator of coastal current tendencies and integrated sea temperature (higher sea level anomaly suggests more northward flow and higher integrated temperature anomaly of the water column) (Chelton and Davis 1982, Norton et al. 1985). The division of the anomaly range into three bins and extremes was based on taking the range of anomalies less than 5 cm absolute value as average or "0." Extremes and anomalies within 10% of the extremes are given "++" and "=" symbols. In several cases, negative anomaly corresponds to good chilipepper RF first year survival and positive anomaly appeared to favor enhanced widow RF first year survival. The role of sea level extremes does not imply a direct relationship between sea level at San Francisco and rockfish recruitment.

4. Results

The individual measurements of the physical environment have been combined in a simple straightforward way by first dividing the data series values into three categories or bins to show patterns. Then the binned values were added together to give an overall representation of the pattern. The result of this process is given in row 12 of Table 1. This combined parameter was then compared to the recruitment data for widow and chilipepper rockfish (table 1, rows 1 and 11). The major results of these pattern comparisons are listed below.

1. Different physical conditions are required for optimum widow and chilipepper RF recruitment. Certain intermediate years, in terms of the combined physical parameter (Table 1, row 12), may support moderate recruitment in both species.

2. Widow RF recruitment is favored by winters with deep Aleutian Lows, violent winter storms on the coast, above average sea temperatures, enhanced northward flow in the the California Current and anomalously high coastal sea level. Widow RF recruitment seems to be facilitated by the common large scale warming events (Table 1, row 2). However an El Nino alone, unaccompanied by anomalously deep Aleutian Low development as in 1966 and 1973, does not appear to favor enhanced widow RF recruitment. The Aleutian Lows that expand over the coast and bring frequent winter storms with strong winds from the south to intensify coastal downwelling seem more important than the Californai El Nino in enhancing widow RF recruitment (Table 1).

3. Chilipepper RF fish recruitment appears to be facilitated by cool water, and increased southerly CC flow conditions as described ideally in table 3, column 3, or more realistically in table 1 under 1971 and 1975. Exceptionally good chilipepper recruitment does not occur in years of exceptionally good widow RF recruitment.

4. The coastal ocean from central California to Vancouver Island has undergone three climatic shifts in the 1965 - 1980 period. First, there was a warm period of five years which included two California El Ninos and two Aleutian Low events. In 1970 the two warm event types combined to create conditions that appeared exceptionally favorable to widow RF recruitment. After 1970 a shift to an ocean climate of cool sea temperatures and increased southerly flow in the CC occurred. This cool period lasted until 1976 and included all the most numerous chilipepper RF cohorts contributing to the 1978 to 1983 catch. In 1976 the ocean climate shifted back to the warmer regime. Again young-of-the-year widow RF survival appears to have been enhanced as CC warming events became more frequent.

The catch-age composition data suggest that 1969 and 1971 were moderately good recruitment years for widow RF. These were also at least moderately good years for chilipepper RF recruitment. It is probable that because the very successful 1968 and 1970 widow RF cohorts were not aged until they were over ten years old, there is some peak spreading due to aging imprecision. The 1969 year class would be most likely to be overestimated if aging imprecision is Gaussian, since it is between the two most numerous cohorts. However, if it is more likely that annular otolith rings will be missed more frequently than erroneously added, then the 1971 year class would be the most likely to be overestimated because it follows the most numerous cohort. The 1969 year class will be second most likely to be overestimated. Combining this reasoning about aging imprecision with the findings that chilipepper RF recruitment is facilitated during cool events (Table 3), can lead to the not unreasonable conclusion that the apparent ambiguity in recruitment data for 1971 is the result of overestimation of the size of the 1971 widow RF cohort. The physical environment of 1971 appears favorable to chilipepper RF recruitment (Table 1).

Environmentally, 1969 and 1971 were very different. If better than average recruitment was to occur in both chilipepper and widow RF in the same year, it would be expected to occur in a year such as 1969 when the sum of physical parameters is not conspicuously in the minus or plus domain. The catch-age composition data for chilipepper RF does not give definite information about the strength of this year class compared to the strong year classes of the 1970s. It is likely that the 1969 widow RF year class was also overestimated, but the extreme positive sea level anomaly suggests that this year was more favorable to enhanced widow RF recruitment. High coastal sea level is consistent with increased northward flow along the coast. This is confirmed by the northward flow index (Table 1, rows 6 and 10). Increased northward flow may be the factor in common with Aleutian Low warming events that facilitate widow RF recruitment (Table 3). Chilipepper RF recruitment may have been enhanced in 1969 relative to 1968 and 1970 and may have been poor compared to 1973 and 1975.

Results of the Northwest and Alaska Fishery Center's 1980 Bottom Trawl Survey show that the 1965 chilipepper RF cohort was especially numerous (Coleman 1986). This is consistent with the relationships which are also evident during the 1971 - 75 period (Table 1).

The 1972 year class is conspicuously weak in the chilipepper catch-age composition data of Henry (1986), but the environmental data appears favorable to a strong chilipepper year class. The inshore CC was affected by the 1972-73 El Nino in the spring of 1972 (Enfield and Allen 1980, Chelton and Davis 1982, Huyer and Smith 1985) and this may have had an impact not reflected in the physical parameters presented. Likewise the 1976-77 El Nino may have curbed survival of the 1976 year class of chilipepper RF. The 1965 and 1969 chilipepper year classes, however, appear as though they may be exceptions to the reasoning just used to explain poor recruitment in 1972 and 1976.

5. Discussion

The combined physical parameter developed above gives a numerical value to the ideal California Current event types : Aleutian Low induced warming, California El Nino coastal warming and California Current cool events (Table 3). The larger unsigned values belong to years with warm or cool events undiluted by opposite event types (Table 1). The best years for chilipepper and widow rockfish recruitment occur when the value of combined parameter is at or near its maximum unsigned value. Negative anomalies favor recruitment in chilipepper rockfish, while positive anomalies favor widow rockfish recruitment (Table 1). This result, suggests that the present approach may be appropriate, but it does not necessarily mean that the most important physical terms have been included in the analysis. Future research must be sensitive to other parameters' ability to match patterns of fish stock recruitment and add dimension to descriptions of the fishes' environment.

The simple system used here allows some knowledge of the biological systems to be gained without knowing exactly how the biological systems are affected by the physical environment or even what particular aspect of the physical environment is most important. Also, the assumption that the biological system is reacting in a simple straightforward way need not be abandoned. The assumption that can be avoided in using the multidimensional approach is that the rockfish systems react directly to physical parameters as we happen to measure them, e.g. temperature, sea level, etc.

Species distinction has been shown to be important. If, for instance, recruitment of chilipepper and widow RF were summed, it would be much more difficult to form associations with physical environmental patterns. Another species distinction is that the value a particular physical data set will have in helping to understand recruitment will depend on the species involved. The data presented in table 1 are somewhat more successful in describing the widow RF recruitment data set than in describing the chilipepper recruitment data set. Widow RF recruit best under the Aleutian low, El Nino and downwelling conditions. The only apparent exception is 1971, the year following the most numerous year class in the record. This may not be an exception because 1971 is the year class most likely to have its size overestimated because of the tendency to miss annular rings in aging older fish.

Figure 3 summarizes some of the points made above. It is a scale-less grid or coordinate system with two main axes. The vertical axis represents advective current flow in the CC system. Increased northward flow is toward the top of Figure 3, while increased flow to the south is represented by the space below the horizontal axis. Negative atmospheric pressure anomaly or an intensified Aleutian Low Pressure System is toward the right on the horizontal axis. Positive anomaly representing a less developed Aleutian Low is to the left. The right side of the horizontal axis is further divided into two areas. When the winter-time Aleutian Low extends over the coastal

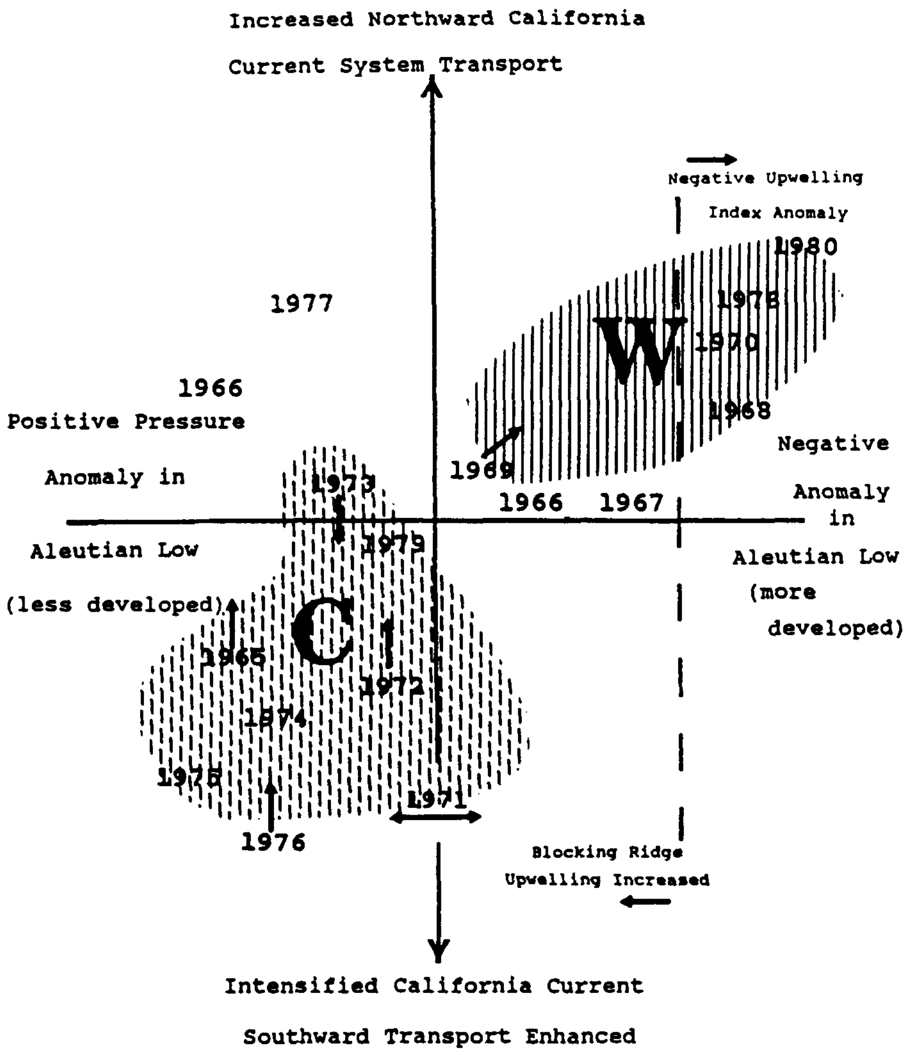

Figure 3. Coordinate system organizing rockfish recruitment data and physical parameter tendencies into four quadrants. The verticle axis represents advective current flow in the CC system. Increased northward flow is toward the top and increased southward flow is represented by the space below the horizontal axis. Negative atmospheric pressure anomaly in an intensified Aleutian Low is to the right. The positioning of the year designations was done on the basis of the combined parameter (table 1, row 12). Arrows associated with the date give inferred direction of change during the year. Years that favor chilipepper rockfish are in the the lower left quadrant (broken hatching) and years that favor widow rockfish recruitment are in the upper right quadrant (solid hatching).

When the winter-time Aleutian Low extends over the coastal California Current System, it frequently results in increased winter downwelling (Figure 3, right of dotted line). The area in the upper right quadrant between the main vertical axis and the dotted vertical ancillary axis would contain years when the Aleutian Low did develop but was blocked from the coast by a high pressure ridge as in the 1976-1977 winter (1977 in Table 1). The 1967 - 1968, 1977 - 1978 and 1979 - 1980 winters (1968,1978 and 1980 respectively in Table 1) would be to the right of dotted line in the upper right quadrant. The upper left quadrant is the area of California El Ninos that occur without Aleutian Low intensification. El Nino years of 1966 and early 1973 would be in this quadrant. Columns 1 and 2 in Table 3 would represent the area above the horizontal axis in the left and right quadrants respectively. If the event types occurred together in a combined event as in 1969 - 1970, the year would be placed in the upper right quadrant. The high downwelling value for 1970 moves the year further to the right past the dotted line. These years are usually warm with elevated coastal sea level and increased onshore transport in the coastal ocean's surface layers (table 3).

The space below the horizontal axis in Figure 3 corresponds to the cool CC years when transport to the south is enhanced. (table 3, col. 3). The lower left quadrant would contain the cool years of the early and mid-1970's. Aleutian Low enhancement is not as frequent or intense during cool periods, so few years will be characteristic of the lower right quadrant. In the 1965-80 series, 1971 is a possible example. The lower left quadrant contains 1965(early), 1972(early), 1973(late), 1974, 1975, 1976(early), and 1979 which were definitely cool and largely devoid of warming event influence as these influences are described in this study.

Years that appear to favor chilipepper recruitment are in the lower left quadrant and those that favor widow rockfish recruitment are in the upper right quadrant of Figure 3. The best widow rockfish years are to the right of the dotted line indicating that the best widow rockfish recruitment years have intense coastal winds which bring warming of the surface layers of the coastal ocean and leading to northward transport. Increased onshore, cross shelf, transport will accompany increased northward transport. This will carry pelagic larvae and weakly swimming early juvenile stages toward shore.

This possible mechanism for increased widow RF recruitment fits the generalities proposed by Parrish et al. (1981) that explain fish species distributions along the Washington, Oregon and California coasts. They state that the California Coast between Cape Mendocino and Point Conception is unfavorable to recruitment of species with pelagic eggs and larvae because of the vigorous surface offshore transport that accompanies the nearly year around upwelling circulation (Parrish et al. 1981, Bakun and Parrish 1980). At present there is no way of knowing if onshore transport is the important environmental factor in widow RF recruitment, but the data suggest an important winter mechanism that has dynamics in common with northward and onshore CC System transport. If widow RF depend on winter onshore transport to maintain early life stages in favorable environments for settling and the onshore transport is wind driven (apparently the more the better, table 1), then it is not surprising that the commercial fishery for widow RF does not extend south of San Francisco, and that the targeted fishery of the early 1970s was centered off Oregon where winter winds from the seasonally intensified Aleutian Low are a conspicuous feature of the mean annual cycle. It may be that the prolonged upwelling season and associated offshore transport, or divergent flow, characteristic of the central California Coast carries planktonic stages of widow RF larvae offshore into environments hostile to survival and growth. If planktonic stages of widow RF are characteristically in the surface layers, then it is probable that this is the mechanism inhibiting population maintenance off central California.

It is clear the chilipepper rockfish which have maximum abundance on the central California coast are dependent on different conditions than those favoring excellent widow rockfish recruitment. Chilipepper rockfish recruitment is favored by cool years, but the fact that there was good recruitment in 1973 suggests that the cool conditions of the later part of 1973 were more important to young-of-the-year survival than that year's warm initial months. That is, the later part of 1973 appears to fit the pattern that would favor chilipepper RF recruitment. It may be that the character of the winter months at the beginning of the chilipepper rockfishes' first year is less important in determining chilipepper RF survival than they appear to be in determining widow RF survival. The fact that chilipepper rockfish are most successful on the central California coast suggests that they have specific adaptations in their early life history that allow them to avoid being swept offshore in larval and planktonic juvenile stages by the surface offshore transport that accompanies the characteristic upwelling circulation.

Other rockfish species. Preliminary studies of the kind described above are being conducted on yellowtail (*S. favadus*) and canary (*S. pinniger*) rockfish. Data from the 1960-70 period, suggest that yellowtail rockfish recruit better during El Nino years. Years with and without intensified Aleutian Low development may be equally favorable. This would place yellowtail RF in the upper two quadrants of Figure 3 indicating that their recruitment is enhanced by any event forcing northward CC flow. Canary rockfish appear to have better recruitment when there is more southward transport. So, the years favoring canary rockfish recruitment would fall below the horizontal axis in Figure 3. More definite conclusions regarding these species will have to await more complete and accurate recruitment time series.

<u>Fisheries management and investment planning</u>. Understanding the probabilistic nature of recruitment periodicity is essential to resource managers as well as investors looking for maximum return on their investment. Knowing the climatic regime that favors or inhibits recruitment in a targeted species, could lead to better knowledge of how sustainable a fishery might be and what limitations on exploitation may be necessary to maintain a sufficient stock of adults to take advantage of good recruitment conditions when they occur.

Since several time series of physical parameters exist of five to ten decades length, it may be possible to treat these as proxi-variables of recruitment and get quantitative information on expected variability in recruitment.

<u>Widow rockfish boom and bust</u>. The knowledge of the spectacularly good widow rockfish recruitment of 1968 and 1970 followed by very poor recruitment from 1972 through 1976 suggests an explanation for the boom and bust history of the targeted widow RF fishery (Gunderson 1984). It is possible that the discovery of the midwater widow RF fishery in the late 70's was the result of the excellent recruitment conditions of 1968 and 1970. Suddenly, eight years later, there was a large exploitable biomass of widow rockfish which had not been noticed before because it was not there. After the abundant widow rockfish resource was discovered, the fishery increased twentyfold in two years based on the unusually good 1968 and 1970 year classes. The decline in the fishery that began in 1982 was the result of depletion of the two strong year classes. The cool, strong CC years that followed 1970 inhibited widow rockfish recruitment, providing no additional input to the fishery resource in the early 1980's. It will be interesting to note how successful the 1980 widow rockfish year class will be. According to the data presented in table 1, 1980 should be a very good year and initial catch-age composition data suggest that it is a numerous cohort (Figure 1). Data at full recruitment are not presently available.

The combined physical and biological data presented in this report suggest that the bio-economic boom to bust event chronicled by Gunderson (1984) for widow rockfish is perfectly natural considering the pulsed recruitment common in this species and the climatological background of the event. When more is known of the physical conditions favoring the 1968 and 1970 year classes, it will be possible to analyse the historical records and determine expected frequency of proper conditions for exceptionally good recruitment.

Acknowledgements

The author would like to thank Bill Lenarz of the Southwest Fisheries Center's Tiburon Laboratory(NMFS) and Frank Henry of the California Department of Fish and Game for their patience and instruction concerning the rockfish data used in this report. This manuscript would not have been completed without the help of Rosemary Troian, Marlene Hughes and the many hours of consultation and encouragement received from other members of the Pacific Fisheries Environmental Group.

REFERENCES

ADAMS, P., 1980. Morphology and distribution patterns of several important species of rockfish (Genus Sebastes) Mar. Fish. Rev., 42(3-4): 80-82

Anonymous 1981. SIO Reference 81-30
Surface water temperatures at shore stations - United States west coast. Marine Life Research Committee and Marine Life Research Group, University of California, Scripps Institution of Oceanography, La Jolla, CA, 92037, 45pp.

BAKUN, A., and R. PARRISH, 1980. Environmental inputs to fishery population models for eastern boundary current regions. In Workshop on the effects of environmental variation on the survival of larval pelagic fishes. Ed. by G. Sharp. Intergovernmental Oceanographic Commission, UNESCO, Paris. IOC Workshop Rep., 28:67-104.

BAKUN, A., 1973. Coastal upwelling indices, west coast of North America 1946-1971. NOAA Tech. Rept. NMFS SSRF 671, 103p.

BIRD, A. , R. KOOB, J. WICKHAM and C. MOOERS, 1984. Hydrographic data from the slope waters off central California. 26 November 1978 - 26 June 1980., Dep. of Oceanography, Tech. Rep NPS 68-84-010, Naval Postgraduate School, Monterey, CA 93943.

BOEHLERT, G. AND M. YOKLAVICH, 1984. Variability in age estimates in Sebastes as a function of methodology, different readers and different laboratories, Calif. Fish and Game, 70(4): 210-224.

BREAKER, L. AND C. MOOERS, 1987. Oceanic variability off the central California coast, Prog. Oceanog. (in press)

BRODEUR, R. AND W. PEARCY, 1984. Food habits and dietary overlap of some shelf rockfishes (genus Sebastes) from the northeastern Pacific Ocean. Fish. Bull., U.S., 82(2): 269-293.

CANE, M., 1983. Oceanographic events during El Nino. Science, 222:1189-1194.

CHELTON, D. , P. BERNAL and J. McGOWAN, 1982. Large-scale interannual physical and biological interaction in the California current., J. Mar. Res., 40(4):1095-1125.

CHELTON, D. and R. DAVIS, 1982. Monthly mean sea-level variability along the west coast of North America. J. Phys. Oceanog., 12:757-784.

COLEMAN, B., 1986. The 1980 Pacific West Coast Bottom Trawl Survey of groundfish resources: Estimates of distribution, abundance,length and age composition NOAA Technical Memorandum NMFS F/NWC-100. Northwest and Alaska Fisheries Center NMFS/NOAA 7600 Sand Point Way NE, Seattle, WA 98115.

CUSHING, D., 1973. Recruitment and parent stock in fishes. WSG 73-1. Washington Sea Grant, University of Washington, Seattle WA 98195.

DARWIN, C. and A. WALLACE, 1858. On the tendency of species to form varieties; and on the perpetuation of varieties and species by natural means of selection. Jour. Proc. Linnean Soc., Zoo., Vol 3. Communicated by C. Lyell and J. Hooker July 1, 1858.

DERISO, R., T. QUINN, P. NEAL, 1985. Catch-age analysis with auxiliary information. Can. J. Aquat. Sci., 42: 815-824.

DOUGLAS, A., D. CAYAN and J. NAMIAS, 1982. Large-scale changes in North Pacific and North American weather patterns in recent decades. Mon. Wea. Rev., 110:1851-1862.

ENFIELD, D., and J. ALLEN, 1980. On the structure and dynamics of monthly mean sea level anomalies along the Pacific coast of North and South America. J. Phys. Oceanog., 10(4): 557-578.

GUNDERSON, D., 1984. The great widow rockfish hunt of 1980-1982. N. Amer. Jour. of Fish. Management, 4: 465-468.

HENRY, F., 1986. Status of the coastwide chilipepper (Sebastes goodei) fishery. (Document submitted to the Pacific Fisheries Management Council, Portland, Oregon, October 1986). California Department of Fish and Game, 411 Burgess Drive, Menlo Park, CA 94025.

HENRY, F., 1987. California Department of Fish and Game, 411 Burgess Drive, Menlo Park, CA 94025.(Personal communication)

HICKEY, B., 1979. The California current system - hypotheses and facts. Prog. Oceanog., 8:191-279.

HIGHTOWER, J.E. and W. H. LENARZ, 1986. Status of the widow rockfish fishery. (Document submitted to the Pacific Fisheries Management Council, Portland, Oregon, October 1986). Southwest Fisheries Center, National Marine Fisheries Service, NOAA, 3150 Paradise Drive, Tiburon, CA 94920.

HJORT, J. 1914. Fluctuations in the great fisheries of northern Europe viewed in the light of biological research Rapp. P. v. Reun. Cons. Perm. int. Explor. Mer, 20:1-228

HUNTER, J. 1982. Feeding ecology and predation on marine fish larvae, In Marine Fish Larvae Ed. by R. Lasker, Washington Sea Grant program, University of Washington, Seattle.

HUYER, A., R. SMITH and E. SOBEY, 1978. Seasonal differences in low-frequency current fluctuations over the Oregon continental shelf. J. Geophys. Res., 83: 5077-5089.

HUYER, A. and R. SMITH, 1985. The signature of El Nino off Oregon in 1982-83, J. Geophys. Res., 90: 7133-7142.

KETCHEN, K., 1956. Factors influencing the survival of lemon sole (Parophrys vetulus) in Hecate Strait, British Columbia. J. Fish. Res. Board Can., 13(5): 647-694.

LOVE, M., 1981. Evidence of movements of some deepwater rockfishes (Scorpaenidae: genus Sebastes) off southern California. Calif. Fish and Game, 67(4): 246-249.

MOOERS, C. and A. ROBINSON, 1984. Turbulent jets and eddies in the California current and inferred cross-shore transports. Science, 223: 51-51.

MYSAK, L., 1986. El Nino, interannual varibility and fisheries in the northeast Pacific Ocean. Can. J. Fish. Aquat. Sci., 43:464-497.

McLAIN, D., 1983. Coastal ocean warming in the northeast Pacific, 1976-83. In The influence of ocean conditions on the production of salmonids in the North Pacific, a workshop, Ed. by W. Pearcy, Sea Grant College Program. Rep. ORESU-W-83-001. Oregon State Univ. Newport, P.61-86.

McLAIN, D. and D. THOMAS, 1983. Year-to-year fluctuations of the California countercurrent and effects on marine organisms. Cal. Coop. Fish Inv. (CalCOFI) Rep., 23:165-181.

NORTON, J., D. McLAIN, R. BRAINARD, and D. HUSBY, 1985. The 1982-83 El Nino event off Baja and Alta California and its ocean climate context. In El Nino North, Ed. by W. Wooster and D. Fluharty, pp 44-72, Washington Sea Grant Program, University of Washington, Seattle.

NORTON, J.,D. McLAIN, D. HUSBY and R. BRAINARD, 1987. Evidence for downward propagation of coastally trapped wave energy found in analysis of California current warming event. Pacific Fisheries Environmental Group, Southwest Fisheries Center, NMFS/NOAA P.O. Box 831, Monterey, CA 93942 (in prep).

PARRISH, R., C. Nelson and A. Bakun, 1981. Transport mechanisms and reproductive success of fishes in the California current. Biol. Oceanog., 1(2): 175-203.

PICAUT, J., 1983. Propagation of the seasonal upwelling in the eastern equatorial Atlantic. J. Phys. Oceanog., 13(1):18-37.

PICAUT, J. 1985. Major dynamics affecting the eastern tropical Atlantic and Pacific Oceans. Cal. Coop. Ocean. Fish. Inv.(CalCOFI) Rep., 26: 41-50.

QUINN, W., D. ZOPF, K. SHORT and R. KUO YANG, 1978. Historical trends and statistics of the southern oscillation, El Nino, and Indonesian droughts. Fish. Bull., U.S., 76(3): 663-678.

REINECKER, M. AND C. MOOERS, 1986. The 1982-1983 El Nino signal of northern California. J. Geophys. Res., 91(C5): 6597-6608.

TABATA, S., 1985 El Nino effects along and off the Pacific coast of Canada during 1982-83, In El Nino North, Ed. by W. Wooster and D. Fluharty, pp. 85-96, Washington Sea Grant Program, University of Washington, Seattle.

TEMPLEMAN, W., 1972. Year-class success in some north Atlantic stocks of cod and haddock. Int. Comm. Northw. Atlant. Fish. Spec. Pub. No. 8, pp.223-238.

UDA, M., 1962. Cyclic correlated occurrence of world-wide anomalous oceanographic phenomena and fisheries condition. J. Oceanogr. Soc. Jpn. 20th Anniv. Vol:368-375.

WALLACE, J. and D. GUTZLER, 1981. Teleconnections in the geopotential height field during the northern hemisphere winter. Mon. Wea. Rev., 109:784-812.

WILKINS, M. 1986. Development and evaluation of methodologies for assessing and monitoring the abundance of widow rockfish, *Sebastes entomelas*. Fish. Bull., U.S. (84) 2: 287-310

WICKHAM, J., 1975. Observations of the California Counter Current. J. Mar. Res., 33:325-340.