A DESCRIPTION OF THE CALIFORNIA CURRENT ECOSYSTEM BY FACTOR ANALYSIS

GEORGE T. HEMINGWAY
Scripps Institution of Oceanography
University of California San Diego
La Jolla, CA 92093

INTRODUCTION

The California Current has been studied extensively since the California Cooperative Oceanic Fisheries Investigations (CalCOFI) were begun in 1949. Monthly or quarterly cruises on a 40-nautical-mile grid pattern from San Francisco to Magdalena Bay have provided an immense (ca. 18,500 stations) data base for understanding the historical physical dynamics, chemistry, and biology of this region. The advent of the high-speed, large-capacity computer and the concurrent development of numerical analytic techniques may facilitate the manipulation and synthesis of large amounts of heavily intercorrelated data of this type.

This study applies factor analysis to the 1969 data, which include the first long-term sampling of chlorophyll, providing a trophic link between the physical-chemical milieu and the fish consumers.

METHODS

Complete data on 21 variables are available from 216 stations from 1969:

Northness (CalCOFI line number);

Temperature (°C), salinity (⁰/oo), and oxygen (ml/liter) at 10 m depth (Scripps Institution of Oceanography [SIO], unpublished data);

Nitrite, nitrate, phosphate, and silicate (mg-atoms/m^3), chlorophyll and phæophytin (mg/m^2; from data used in Thomas and Seibert 1974 and Owen 1974), integrated from the surface to 50 m;

Zooplankton volume (g/1000 m^3), from surface to 150 m (NOAA/Southwest Fisheries Center [SFC], unpublished data);

Anchovy larvae (*Engraulis mordax*) in five size classes, integrated from the surface to 150 m: 1 = 2.0-3.0 mm, 2 = 3.5-5.0 mm, 3 = 5.5-8.0 mm, 4 = 8.5-12.0 mm, 5 = 12.5-ca. 25 mm (NOAA/SFC unpublished data);

Sardine larvae (*Sardinops caerulea*), 150 m to surface (NOAA/SFC unpublished data);

Hake larvae (*Merluccius productus*), 150 m to surface (loc. cit.);

Depth of the mixed layer (SIO unpublished data);

Distance offshore (nautical miles; SIO unpublished data);

Month of the year (SIO unpublished data).

Since oceanic ecosystems are complex and multidimensional and the available variables are numerous, factor analysis was used to reduce the number of variables to a minimum, without excessive loss of information, thus facilitating intelligible summarizations of the data.

Factor analysis is a statistical method that attempts to elicit normal multivariate structure of a universe in which many correlated variables can be sampled (Seal 1964). Factor analysis in research has been discussed at length by Cattell (1965 a, b) and by Rummel (1969) and Poole (1971), and its use in oceanographic work has been discussed by Kelly (1975), Angel and Fasham (1974), and Ebeling et al. (1970a, b).Stevenson et al. (1974) and Poole (1971) have examined the efficacy of combining environmental and species-abundance variables in common factor analysis. Colebrook (1974) has performed a principal-components analysis of major taxa groups in the California Current for the period 1955-59 in an attempt to explain their biomass fluctuations. Goodall (1954), Fisher (1968), Gittens (1968), and Echelle and Schnell (1976) have mapped factor scores and demonstrated the relationships between the generated factors and real environmental features.

The analytical method used was *R*-type factor analysis, wherein the matrix of product-moment coefficients is between variables rather than between units (see Kaiser 1958; Horst 1965). The program is available as part of the Statistical Package for the Social Sciences (SPSS: Nie et al. 1970) on the B-6700 computer at the University of California San Diego.

Station scores for each factor were computed, based on the annual pooled data, then mapped and contoured by hand.

The terms used in the Results and Summary and Conclusions that follow are here defined:

factor, a composite variable in which the relationship of the original variables is unique;

loading, the degree and direction of relationship of a variable to its factor, designated "alpha" (α);

communality, the amount of each variable's variation that is involved in the factors; the difference between communality and unity is the variable's "uniqueness," designated h^2;

correlation coefficient, here used to indicate residual relationship between factors before oblique rotation, designated r;

percent common variance, the amount of regularity accounted for by this factor in this data universe.

RESULTS

Analysis of 21 variables from 216 stations in the California Current in 1969 yielded seven factors (Figure 1):

Factor I, nutrient upwelling
Factor II, young anchovy and hake larvae;
Factor III, mixing;
Factor IV, thermal stratification;
Factor V, older anchovy larvae;
Factor VI, phytoplankton standing stock;
Factor VII, sardine larvae.

This is the minimum number of factors necessary to describe the relationships between the 21 variables without undue loss of information (they have eigen-values greater than 1.0, a criterion suggested by Nie et al 1970). The loadings (α) are the correlations of each variable to each factor. All variables participate in all factors to varying degrees, but those loadings less than .20 have been eliminated in order to simplify the table.

Pooled 1969 Data

Thirty-six percent of the common variance in the California Current in 1969 was due to nutrient upwelling regimes (Factor I), identified by low temperature, high salinity, and a shallow mixed layer, usually nearshore (see Yoshida and Mao 1957). The principal variables in this regime are the plant nutrient chemicals ($\alpha\ NO_3 = .94$; $\alpha\ PO_4 = .89$, $\alpha\ SiO_3 = .77$; $\alpha\ NO_2 = .53$). Zooplankton tends to be associated with this regime ($\alpha = .26$; see Figure 1).

Mixing regimes (Factor III) accounted for 18.0% of the regularity. These were identified by low temperature ($\alpha = -.68$), low salinity ($\alpha = -.98$), and high oxygen concentration ($\alpha = .60$). These regimes tended to be northerly and also had a positive zooplankton association ($\alpha = .34$).

Thermal stratification (Factor IV), which was identified by a very shallow mixed layer depth (α mixed layer depth $= -.69$), and warm surface water (α temperature $= .42$), accounted for 8.7% of the common variance.

Chlorophyll *a* and phæophytin as indices of phytoplankton standing stock (Factor VI) accounted for 6.3% of the common variance.

The larval fish seem to be related to two, and possibly three, different regimes:

1) Young anchovy and hake larvae (Factor II), accounting for 20.6% of the common variance, appear to be related to a separate set of conditions from

2) Older anchovy larvae (Factor V), which account for 7.3% of the variance in the data, and

3) Sardine larvae (Factor VII), which account for 3.0% of the variance in the data. Sardine larvae abundance is correlated to this factor ($\alpha = .43$) in which it is the principal loading.

The nutrient upwelling and mixing regimes are correlated at $r = .30$, whereas phytoplankton standing stock is correlated at $r = .45$ with nutrient upwelling and only at $r = .12$ with mixing.

Month-by-Month Analysis

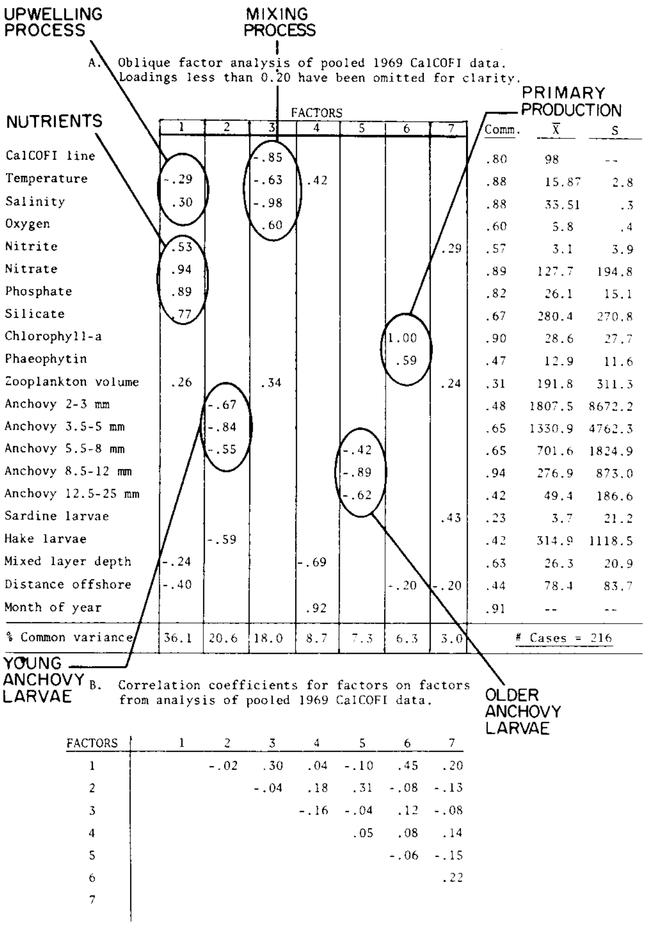
The monthly trend maps are shown in Figures 2-7, their corresponding matrices as Appendix I-VI.

From January through May 1969, the communalities (h^2) were very low, suggesting that much of the variance could be accounted for by variables not measured, or that the variables tend to be more independent during those months, or that there were insufficient data per month to provide good convergence; the last appears more likely, since the annual pooled data showed good convergence (a rule of thumb for the design of a factor analysis is that the number of variables should not exceed the square root of the number of cases; John Senner, personal communication 1976). Nonetheless, some patterns are revealed by the analysis (Table 1).

January. In January primary and secondary production are low and related to phosphate and silicate concentration and a northern mixing regime. Nitrate concentration is related to upwelling more than to mixing. Nitrite concentration is related to zooplankton and older (8.5-25 mm) anchovy larval abundances. The younger (2-3 mm) anchovies appear to be independent of the older anchovies. Mixing processes account for 46.8% of the regularity in January, whereas upwelling is barely indicated in Factor VI, with 6.7% common variance.

Analysis of the January trend maps shows that mixing is occurring north of Point Conception and that there is some suggestion of a countercurrent south of there. Such a countercurrent has been previously demonstrated by Reid and Schwartzlose (1962) and others.

The stratification trend field is monotonous and negative (from −1.0 to −1.5), reflecting the fact that the current is unstratified at this time of year. The nutrient factor, which contains the upwelling component, is positive in coastal enclaves near San Francisco, off Monterey, south of Point Conception, and south of San Diego to Cape Colnett. The chlorophyll field is positive from San Francisco Bay to Monterey Bay and south of Point



A. Oblique factor analysis of pooled 1969 CalCOFI data. Loadings less than 0.20 have been omitted for clarity.

FACTORS	1	2	3	4	5	6	7	Comm.	$\bar{X}$	S
CalCOFI line			-.85					.80	98	--
Temperature	-.29		-.63	.42				.88	15.87	2.8
Salinity	.30		-.98					.88	33.51	.3
Oxygen			.60					.60	5.8	.4
Nitrite	.53						.29	.57	3.1	3.9
Nitrate	.94							.89	127.7	194.8
Phosphate	.89							.82	26.1	15.1
Silicate	.77							.67	280.4	270.8
Chlorophyll-a						1.00		.90	28.6	27.7
Phaeophytin						.59		.47	12.9	11.6
Zooplankton volume	.26		.34				.24	.31	191.8	311.3
Anchovy 2-3 mm		-.67						.48	1807.5	8672.2
Anchovy 3.5-5 mm		-.84						.65	1330.9	4762.3
Anchovy 5.5-8 mm		-.55			-.42			.65	701.6	1824.9
Anchovy 8.5-12 mm					-.89			.94	276.9	873.0
Anchovy 12.5-25 mm					-.62			.42	49.4	186.6
Sardine larvae							.43	.23	3.7	21.2
Hake larvae		-.59						.42	314.9	1118.5
Mixed layer depth	-.24			-.69				.63	26.3	20.9
Distance offshore	-.40					-.20	-.20	.44	78.4	83.7
Month of year				.92				.91	--	--
% Common variance	36.1	20.6	18.0	8.7	7.3	6.3	3.0	# Cases = 216		

B. Correlation coefficients for factors on factors from analysis of pooled 1969 CalCOFI data.

FACTORS	1	2	3	4	5	6	7
1		-.02	.30	.04	-.10	.45	.20
2			-.04	.18	.31	-.08	-.13
3				-.16	-.04	.12	-.08
4					.05	.08	.14
5						-.06	-.15
6							.22
7							

Figure 1. Descriptive interpretation of a factor analysis: the 1969 pooled data. Analyses for monthly data are given in the Appendix.

Conception. Young anchovy scores were highest in the Santa Barbara Channel. Older anchovy-larvae scores were highest from off Monterey south to Point San Martin, outside the Channel Islands, and in diminished strength from San Diego to Punta Eugenia.

February-March. In February mixing (20.9% common variance) is still responsible for primary production, but new nutrient input is provided by upwelling (37% common variance). The contours for the mixing factor are generally perpendicular to the coast, and the contour of the average mixing factor score has moved northward, suggesting that the net effect of mixing has been reduced. Northward movement of nearshore waters has disappeared. Both the stratification and nutrient (upwelling) factor contours are parallel the coast, and the positive zones are strongly concentrated into coastal pockets. The highest phytoplankton standing stock appears from Punta Descanso to Punta San Antonio, Baja California, included in a general high from Point Conception to Viscaino Bay. Younger and older anchovy larvae again are geographically separated.

TABLE 1

Percent Common Variance (Regularity) Accounted for by Each of Three Physical Regimes in the California Current for 1969.

	Jan.	Feb.	Apr.	May	Jul.	Sep.
Upwelling.......	6.7	37.0	38.7	39.8	37.2	(46.0)
Mixing..........	46.8	20.9	I	I	6.1	22.7
Stratification	(8.5)	(6.8)	12.9	7.3	44.2	8.8

Figures in parentheses indicate that identification is questionable due to low correlation of salinity and temperature to the factor. "I" indicates that the contribution of the regime is indeterminate with the technique used but that it is very low.

April. In April upwelling accounts for 38.7% of the common variance; the standing stock of phytoplankton (chlorophyll *a*) is strongly correlated to the upwelling factor ($\alpha = .37$), as are the principal plant nutrient chemicals (α NO_3 = .48; α PO_4 = .40; α SiO_3 = .36). The younger anchovy larvae occupy nearshore, more stratified waters, whereas distributions of older anchovy larvae seem more strongly influenced by zooplankton abundances.

May-June. In the May-June period, 39.8% of the regularity is accounted for by upwelling, which dominates the physical processes; the southern area is becoming more stratified, and some mixing is seen offshore in the north. The high-value nutrient trend lines hug the coast from San Francisco to Cape San Quintin. Chlorophyll *a* and fish larvae have an affinity for areas with shallow mixed layers. Mixing only accounts for 7.3% of the common variance. The zooplankton have a strong affinity for areas of high phytoplankton standing stock ($\alpha = .59$). The fish larvae picture is confused.

July. In July 44.2% of common variance is contained in a stratification factor, nearshore, which contains the principal primary production (α chl *a* = .84) and anchovy larvae components (α 2-3 mm = .96; α 3.5-5 mm = .67; α 5.5-8 mm = .86; α 8.5-12 mm = .94).

The fourth factor is negatively correlated to the stratification factor ($r = -.42$); if the signs of the loadings are reversed, the sign of the correlation coefficient may be reversed, and the sum of common variance accounted for by stratification processes is 50.3%.

Sardine and hake larvae were absent. Upwelled nutrients account for 32.7% of the common variance. Zooplankton abundance ($\alpha = .77$) and oldest anchovy larvae ($\alpha = .22$) are correlated with this regime. This factor is strongly nearshore (α offshoreness = $-.59$) and has a very shallow mixed-layer depth (α mixed-layer depth = $-.61$) component.

August-September. In September there is a general moderate nutrient abundance, strongest inshore and to the north of Point Conception. Zooplankton volume ($\alpha = .44$) and the two younger anchovy size classes ($\alpha = .50$ and .25 respectively) are correlated to this nutrient-containing factor. Standing stock of phytoplank-

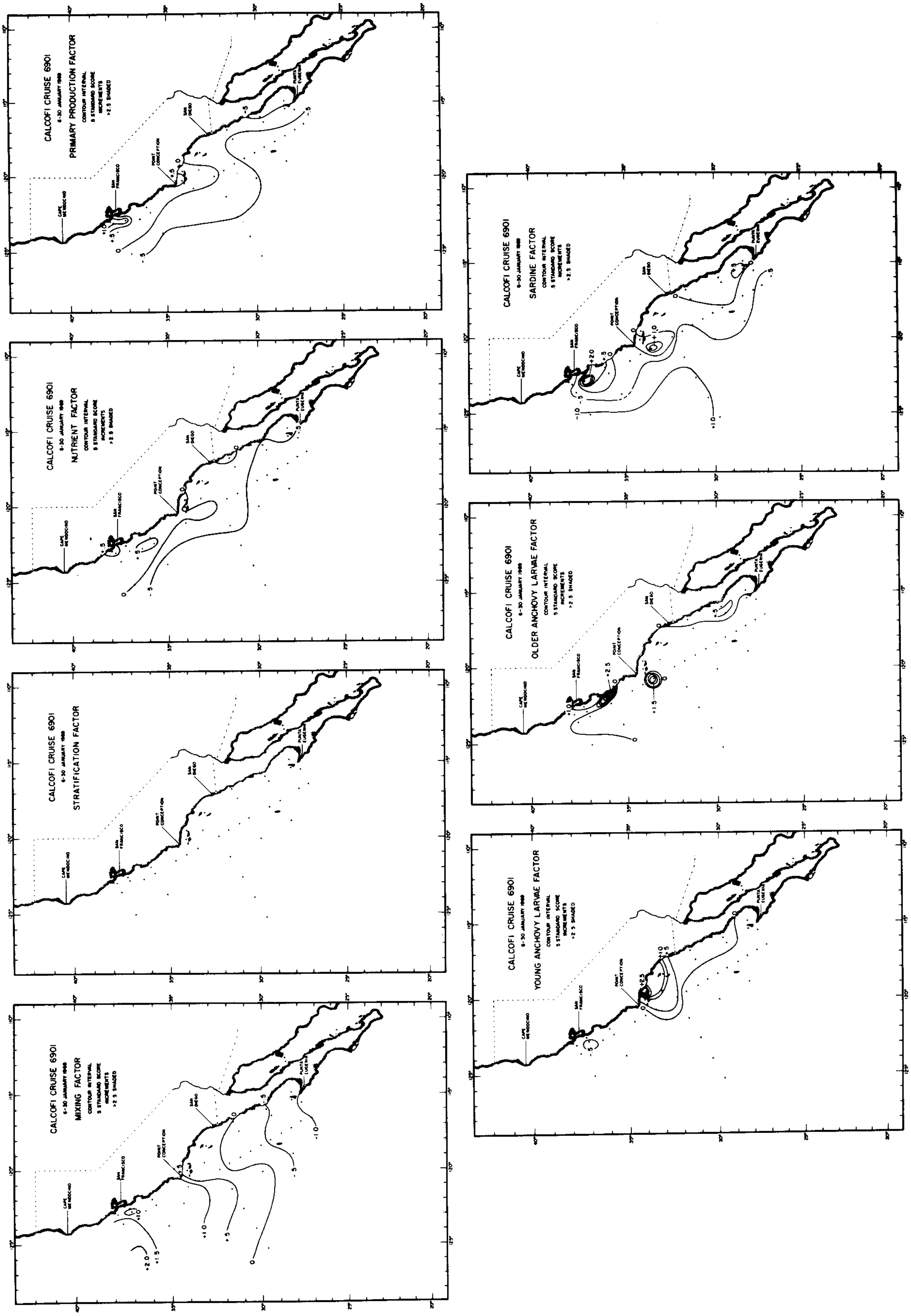


Figure 2. Contour maps of station scores for each of seven factors in the California Current for January 1969.

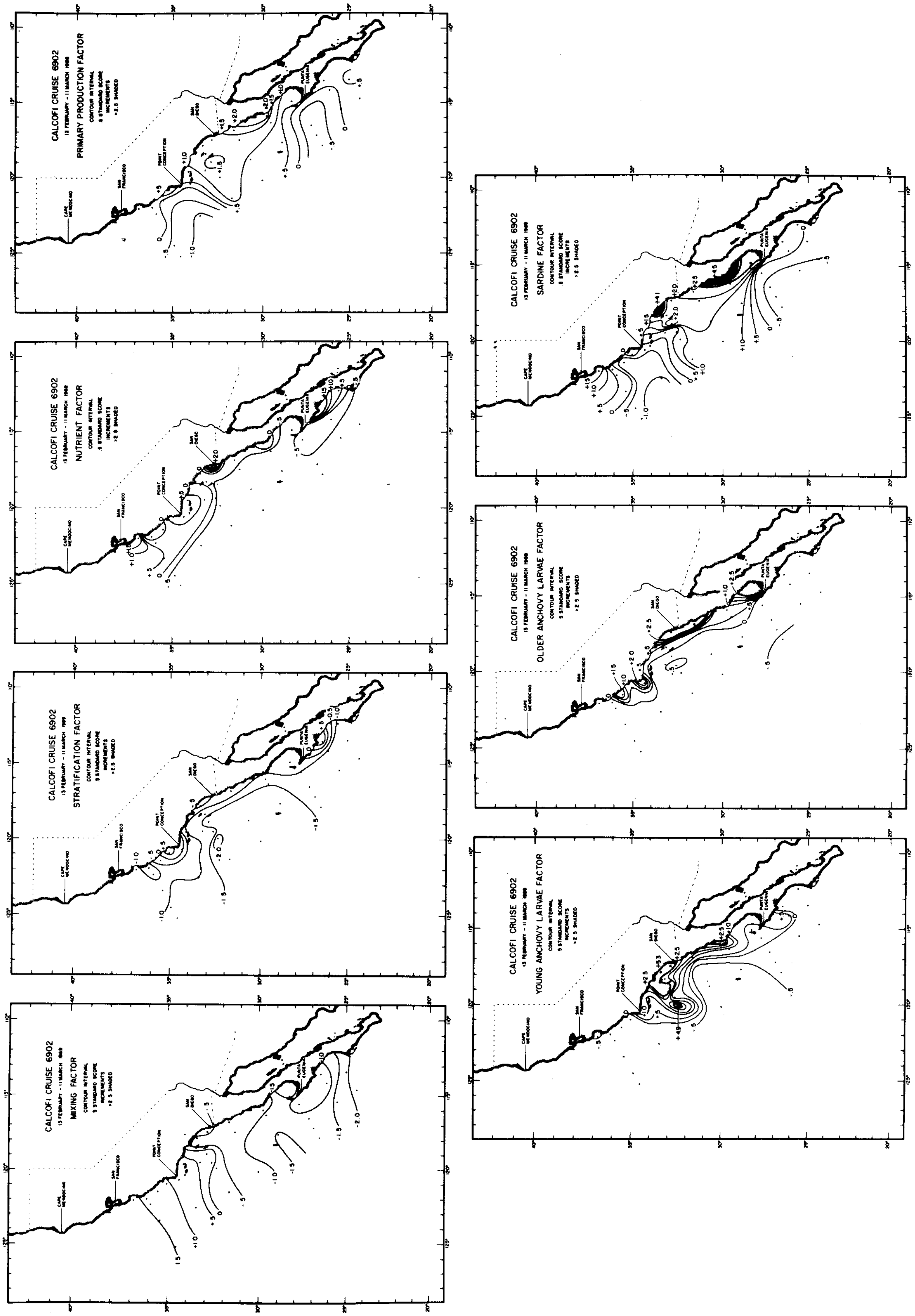


Figure 3. Contour maps of station scores for each of seven factors in the California Current for February-March 1969.

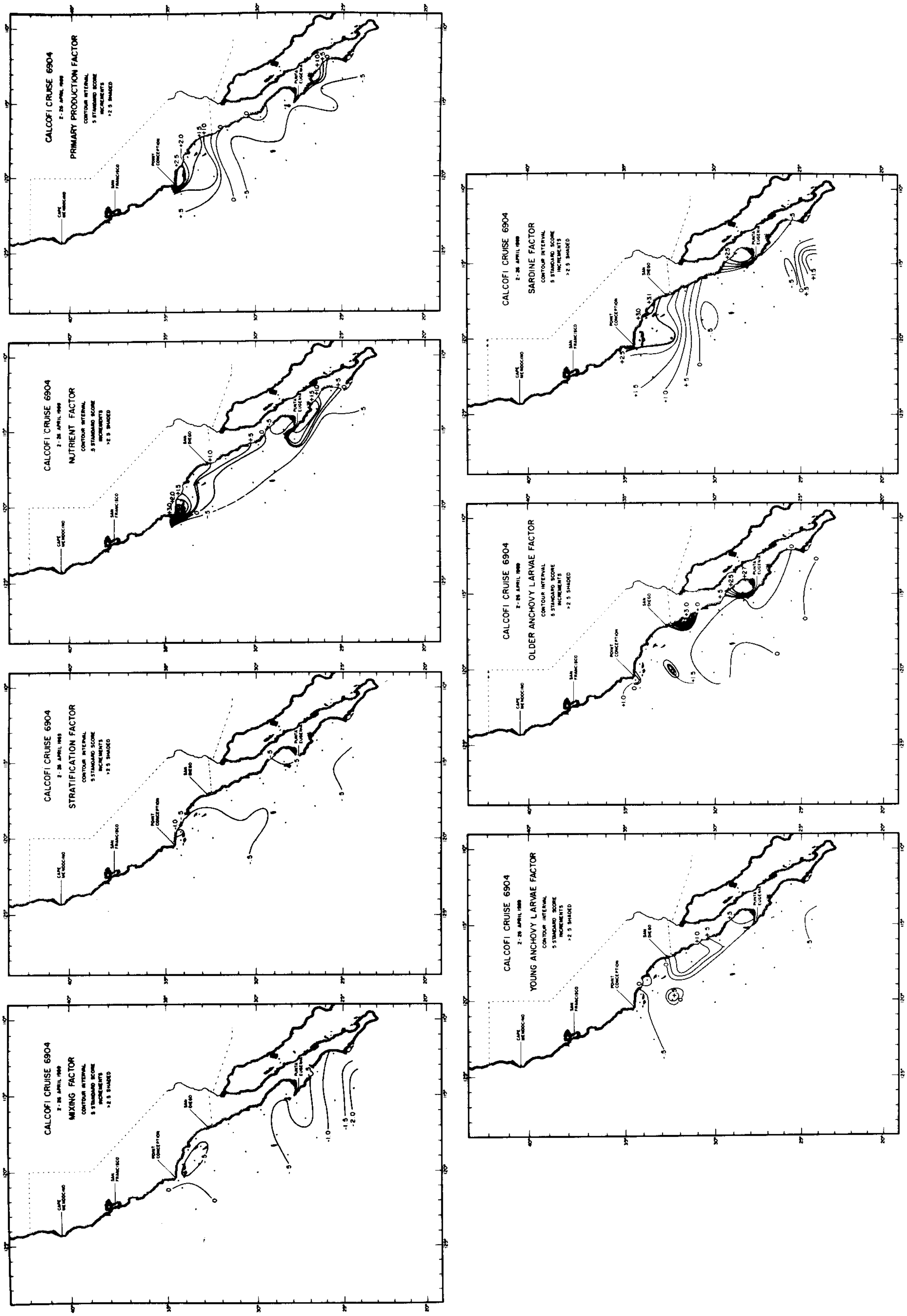


Figure 4. Contour maps of station scores for each of seven factors in the California Current for April 1969.

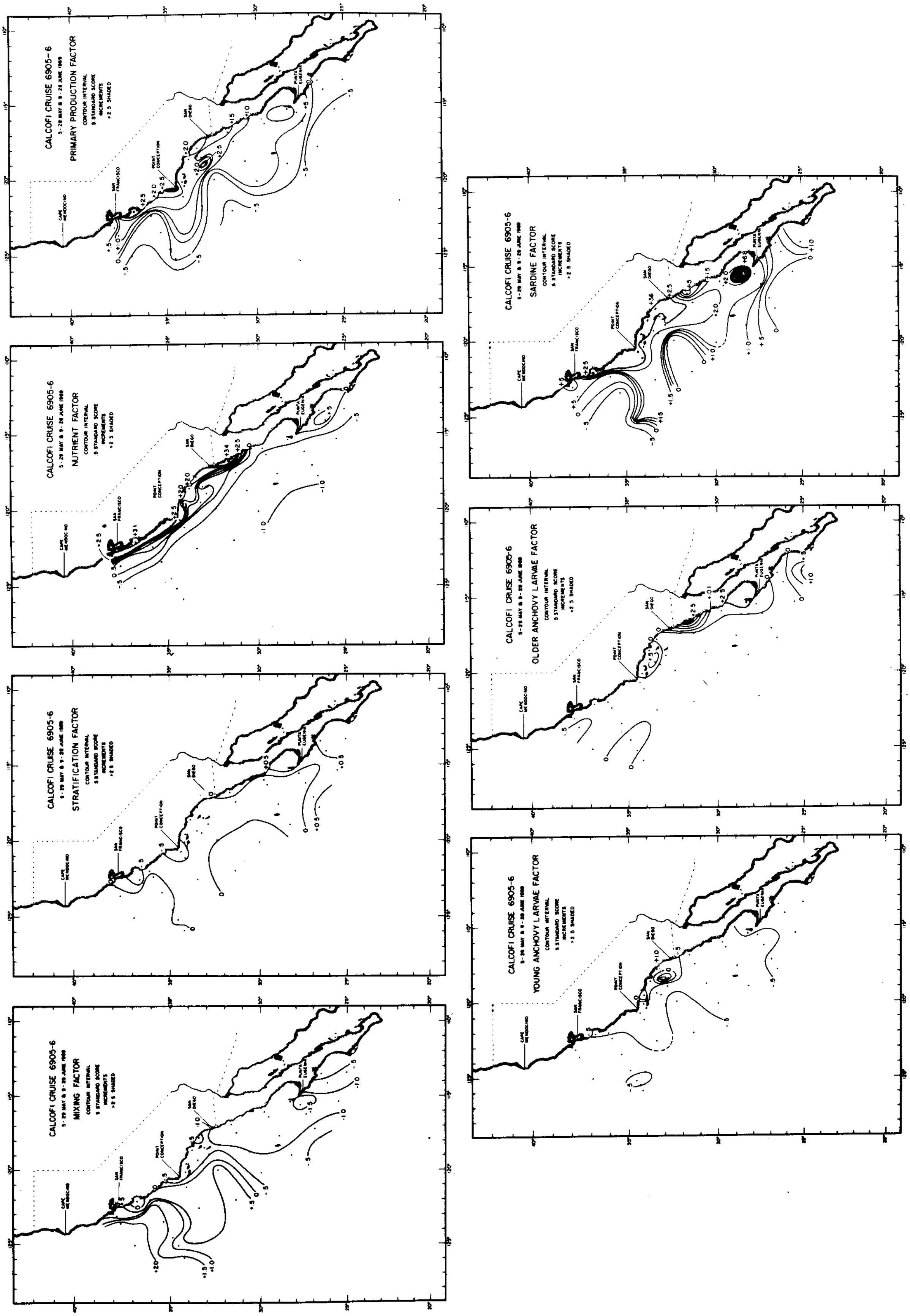


Figure 5. Contour maps of station scores for each of seven factors in the California Current for May-June 1969.

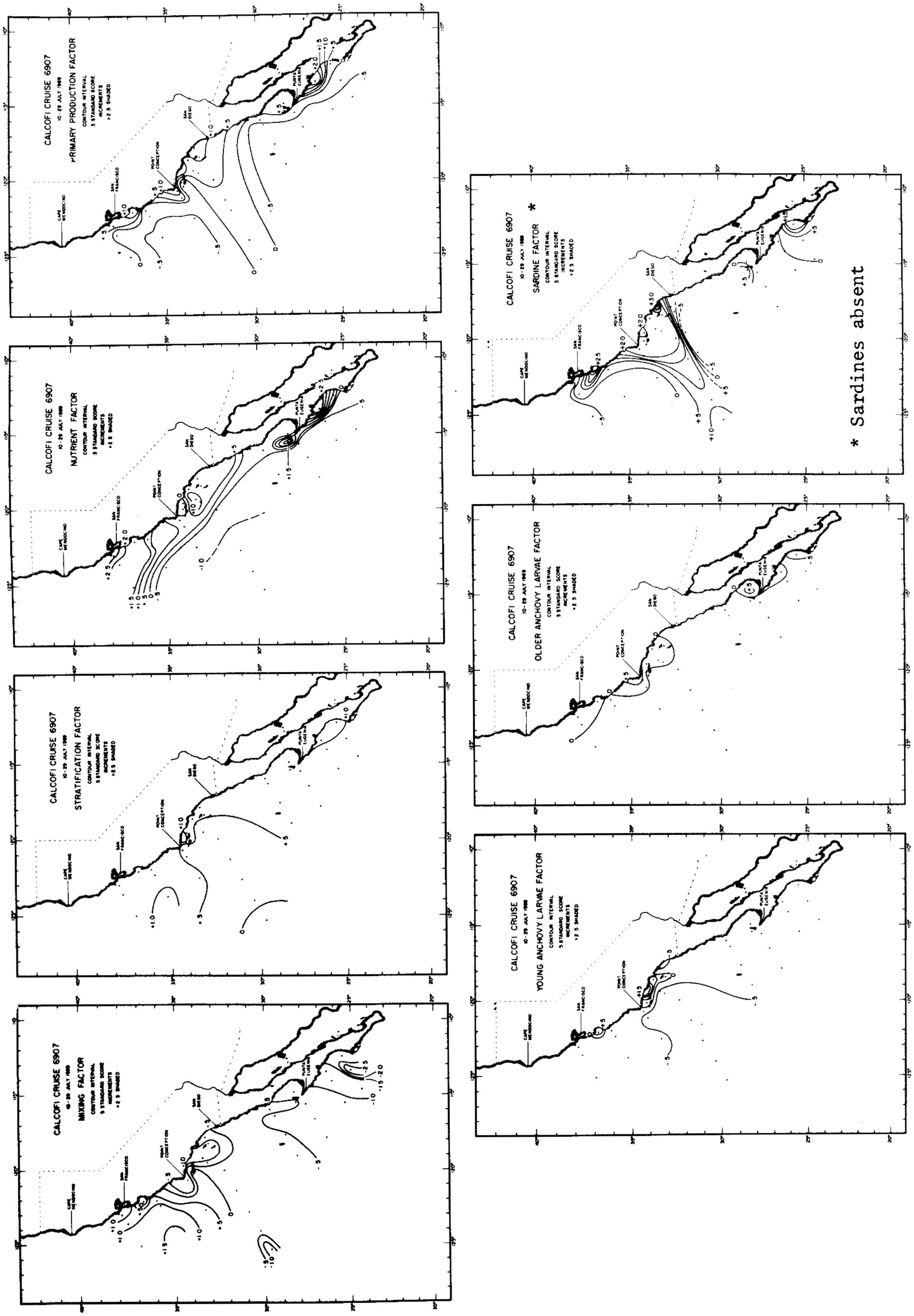
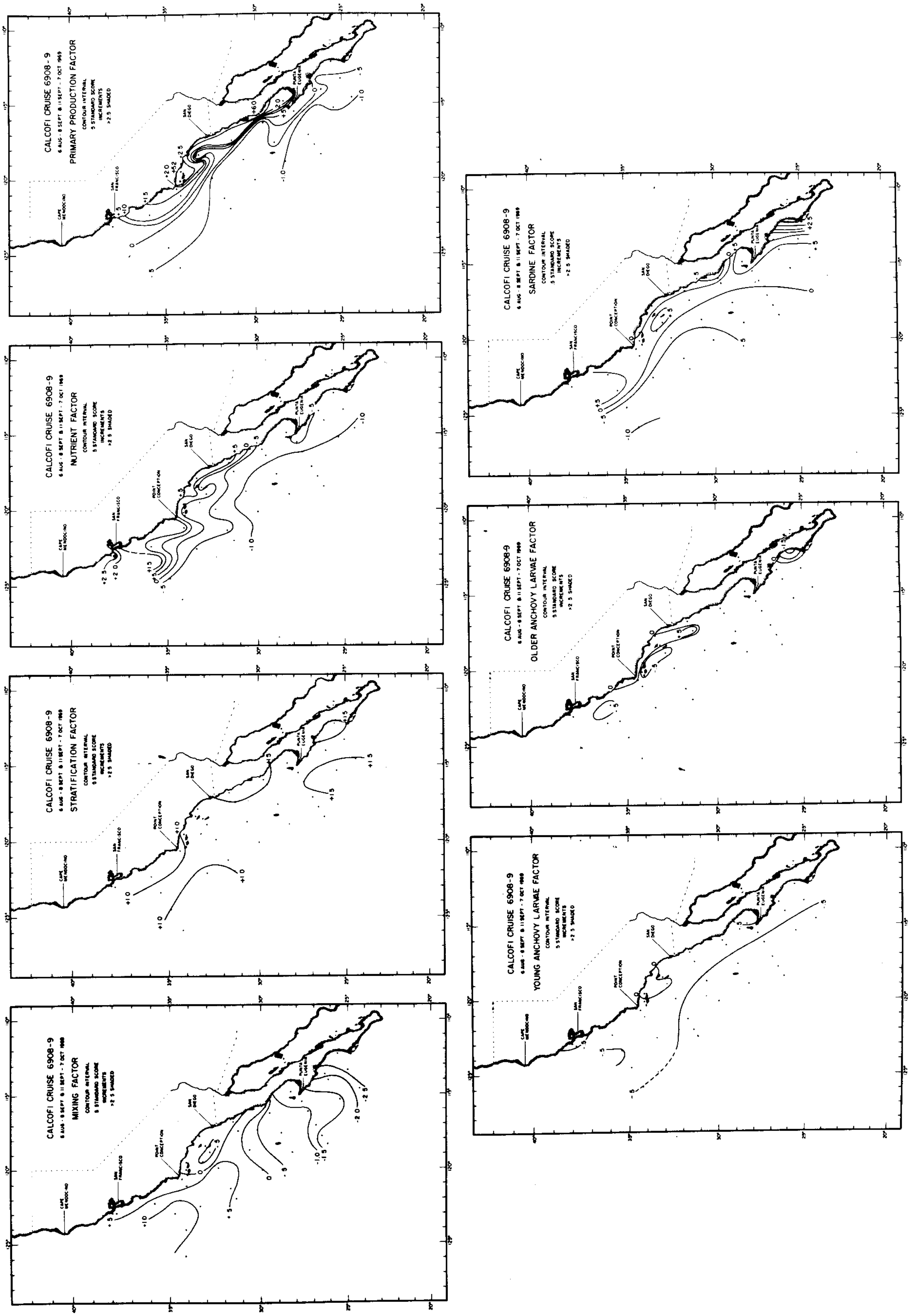


Figure 6. Contour maps of station scores for each of seven factors in the California Current for July 1969.


CALCOFI CRUISE 6908-9
6 AUG - 8 SEPT & 11 SEPT - 7 OCT 1969
PRIMARY PRODUCTION FACTOR
CONTOUR INTERVAL
.5 STANDARD SCORE
INCREMENTS
>2.5 SHADED

CALCOFI CRUISE 6908-9
6 AUG - 8 SEPT & 11 SEPT - 7 OCT 1969
NUTRIENT FACTOR
CONTOUR INTERVAL
.5 STANDARD SCORE
INCREMENTS
>2.5 SHADED

CALCOFI CRUISE 6908-9
6 AUG - 8 SEPT & 11 SEPT - 7 OCT 1969
STRATIFICATION FACTOR
CONTOUR INTERVAL
.5 STANDARD SCORE
INCREMENTS
>2.5 SHADED

CALCOFI CRUISE 6908-9
6 AUG - 8 SEPT & 11 SEPT - 7 OCT 1969
MIXING FACTOR
CONTOUR INTERVAL
.5 STANDARD SCORE
INCREMENTS
>2.5 SHADED

CALCOFI CRUISE 6908-9
6 AUG - 8 SEPT & 11 SEPT - 7 OCT 1969
SARDINE FACTOR
CONTOUR INTERVAL
.5 STANDARD SCORE
INCREMENTS
>2.5 SHADED

CALCOFI CRUISE 6908-9
6 AUG - 8 SEPT & 11 SEPT - 7 OCT 1969
OLDER ANCHOVY LARVAE FACTOR
CONTOUR INTERVAL
.5 STANDARD SCORE
INCREMENTS
>2.5 SHADED

CALCOFI CRUISE 6908-9
6 AUG - 8 SEPT & 11 SEPT - 7 OCT 1969
YOUNG ANCHOVY LARVAE FACTOR
CONTOUR INTERVAL
.5 STANDARD SCORE
INCREMENTS
>2.5 SHADED

Figure 7. Contour maps of station scores for each of seven factors in the California Current for August-September 1969.

ton (α chl *a* = −.22) is negatively correlated with this factor but is positively correlated to two other factors: a mixing factor ($\alpha = .20$) and a nearshore, shallow mixed-layer factor ($\alpha = .56$). The nutrient factor, the mixing factor, and the shallow-mixed-layer factor account for 46%, 22.7%, and 8.8%, respectively, of the common variance.

DISCUSSION

Physical Relationships

The three major physical regimes identified in this work were upwelling, mixing (advective + local), and stratification. These accounted for 36%, 18%, and 8.7% respectively, of the common variance in the year's pooled data. The contribution of each on a seasonal basis to the common variance (regularity) in this data universe is shown in Table 1, which suggests that mixing processes dominate the early months, that upwelling processes dominate from February through about May, that stratification processes dominate in midsummer, and that upwelling is again dominant in September. Mixing and stratification tend to be uncorrelated or inversely correlated.

A comparison of a chart of dynamic height anomalies for January of 1969 (Scripps Institution of Oceanography 1976) with a Primary Production Factor Score chart will suggest that higher production levels occur where the nearshore contours of dynamic height anomaly run south-to-north and that negative scores nearshore occur where the contours run north-to-south. This is in accord with the findings of Yoshida and Mao (1957) that the subsurface, poleward component of the nearshore current is associated with ascending motion, i.e. upwelling. Nutrient-factor score maps for 1969 suggest that there is a tendency toward coastal upwelling all year but that greater intensities occur in later spring and early summer. Bakun (1973, p. 10, Figure 6) demonstrates that there is always a positive upwelling index along the coast of the Californias and that this intensity peaks during May, June, and July.

Chemical-Primary Production Relationships

Taken for 1969 as a whole, the four nutrient chemicals studied are correlated to a factor that is related to upwelling processes, but each of the separate cruises has a somewhat different distribution of relationships. In January phosphate and silicate contribute to the mixing factor, whereas nitrate is negatively correlated and nitrite is uncorrelated. Both nitrite and nitrate are positively is uncorrelated. Both nitrite and nitrate are positively correlated to an upwelling factor. Nitrite is also positively correlated to zooplankton and older anchovy larval abundance. This suggests that the mixed water is nitrogen-depleted and perhaps that primary production in such water is nitrogen-limited. The nearshore water, where upwelling is occurring, is not nitrogen-depleted, and the highest standing stock of phytoplankton is in these coastal pockets. The correlation of nitrite to abundances of secondary producers suggests that this nitrogen is a metabolic byproduct or excretory product.

In February, all four nutrients contribute to the upwelling factor. Nitrite remains, however, also correlated to abundances of fish larvae. The only significant phytoplankton standing stock is also correlated to this factor.

The correlation of nitrite and nitrate concentration to phytoplankton standing stock suggests that primary production at this time of year in the California Current system is nitrogen-regulated and that the species comprising this stock may be especially adapted to use excreted nitrite precursors or nitrite (cf. Grenney et al. 1973; Caperon and Meter 1972a, b; Newell et al. 1972; Strickland et al. 1969), as well as nitrate. *Biddulphia aurita*, a cosmopolitan centric diatom, when cultured with nitrate-nitrogen, excreted nitrite-nitrogen, which it was then able to utilize (Liu and Roels 1972).

One may view this winter production as a nitrogen feed-back system, whose effect is extended both temporally and spatially by zooplankton and phytoplankton excretion of nitrite precursors.

By April the effect of upwelling on primary production is great; chlorophyll *a* distribution and concentration are correlated to upwelled water containing the three more conservative nutrients. Nitrite remains uncorrelated to the other nutrients but is highly correlated to the factor containing strong loadings for phæophytin, a photosynthetically inactive degradation product of chlorophyll, and for zooplankton abundance. This tends to reinforce the thought that nitrite, as perceived at the resolving power of this numerical analysis, and when not correlated to the other nutrients, is an excretion product.

In May chlorophyll *a*, phæophytin, and zooplankton are strongly intercorrelated, probably in this way: chlorophyll *a* represents standing stock of the first trophic level; the zooplankton, the grazers; and phæophytin, the product and evidence of zooplankton feeding (in fecal pellets, particles of dead cells; Lorenzen 1965). That primary production is in another factor, separate from that containing the nutrients, suggests that chlorophyll *a*, phæophytin, and zooplankton have more intercorrelation and interdependence for abundance and distribution than they have with the nutrients. There is a hint of correlation between the two factors, but so much variance in this small number of cases (22) has been accounted for within factors that there is little resolution to the matrix of correlation between factors. This is a problem throughout the month-by-month analyses.

Sufficient of the nitrite in the system is now accounted for by direct upwelling that a portion of it is correlated to the factor containing the other nutrients, but a portion of it remains correlated to a factor containing heavy loadings for some fish and may be assumed to be an excretion product.

In July stratification, upwelling, and mixing processes account for 44.2%, 37.2%, and 6.1%, respectively, of the common variance. Stratification and mixing are negatively correlated ($r = -.42$). The phytoplankton standing stock is strongly correlated to the stratification factor ($\alpha = .84$) and uncorrelated to either upwelling or mixing. Since the season of maximum upwelling has just ended, the coastal waters could be considered to be generally enriched. Zooplankton abundance is high, so their excretion products are abundant. I suggest that in summer, coastal waters continue to be enriched by moderate upwelling, which provides a cooler habitat for zooplankton ($\alpha = .77$ on upwelling), whereas the really tremendous numbers and concentrations of phytoplankters occur in stratified, recently enriched waters. The fact that the trend maps of the pooled annual data factor scores for stratification and for the nutrient factor (which contains the upwelling component) overlap positively suggest that there is little gross geographic separation of these two influences at this time of year; in other words, that upwelled water quickly becomes stratified and that the upwelling is concentrated in small localized plumes and domes.

By September, the coastal waters have become generally destratified (stratification = 8.8% common variance), and mixing processes have become much more dominant (22.7% common variance). Nonetheless, phytoplankton standing stock remains highly correlated to stratification ($\alpha = .56$), although slightly correlated to mixing ($\alpha = .20$) and negatively correlated to upwelling ($\alpha = -.22$). New nutrient input (PO_4, SiO_3, NO_3) remains correlated to upwelling processes. Although there is evidence of change toward the winter mixing regime, the base of primary production seems to remain that of the midsummer; i.e. dependent on recently enriched but stratified water.

The Fish Larvae

Anchovies

Analysis of the annual pooled data factors reveals that distributions of the younger anchovy larvae are related to different parameters than are those of older fish and that this separation occurs somewhere between 5.5 and 8 mm length.

Lasker et al. (1970) have shown that first-feeding anchovy larvae (to age 8 days = ca. 5 mm; see Kramer and Zweifel 1970) can survive on a diet of the dinoflagellate, *Gymnodinium splendens*, but their growth on this diet falls off rapidly after ten days (Hunter 1976). During this same period they are intermittent swimmers (Hunter 1972) and require high densities of particles, upward of 40 *Gymnodinium*/ml, in order to ensure successful feeding and survival (Lasker 1975). To aid in this, yolk sac larvae (prior to first-feeding) are actively attracted to *Gymnodinium* swarms (Hunter and Thomas 1973).

Anchovy larvae begin to take small copepod nauplii at about 5 mm (Theilacker, personal communication 1977), but their success rate is below 40% at this stage (Hunter 1972). In Lasker's et al. (1970) experiments, larvae were capable of taking *Artemia salina* (brine shrimp) nauplii at about 8 mm (20 days).

One must assume that these larvae change their feeding tactics at about this age in order to obtain sufficient energy. If they were to continue taking dinoflagellates, they might be assured of successful feeding strikes, but insufficient nutrition, as they grow larger; however, the change to a diet of nauplii would likely involved wider ranging search patterns for a much less concentrated prey. Large concentrations of dinoflagellates must depend on rather calm, stratified, or very slowly upwelling water. Hence, one would not expect to find significant numbers of first-feeders surviving in wind-whipped or rapidly upwelling waters. The older larval stages, however, would not be expected to be so dependent on calm conditions.

Therefore, one may postulate a real difference in habitat requirements occurring at about the 5.5-8 mm size class as predicted by this analysis.

Given that larvae in general have a unique existence and need to survive, as well as a double task to accomplish—both to distribute the species and to grow up to become reproductive adults (Garstang 1928)—we can predict not only this change in habitat but also a series of changes in habitat requirement during the course of maturation. These may be rather drastic, as in the present situation, or gradual; the more gradual the change in requirements, the less amenable to numerical analysis will they become. Kramer and Zweifel (1970) have shown that the food requirements change gradually up to metamorphosis. So it appears that the most drastic, and therefore most likely to be confounded, change in habitat requirement is that from yolk sac to independence from the stratified conditions.

It appears that the sustaining nurseries for the northern anchovy are the Catalina Eddy and Viscaino Bay. In the spring of the year, the belt of water from San Francisco Bay to Point Conception is a large contributor, and at various times of the year the waters from Punta Engenia to Cabo San Lucas are a refuge (Kramer and Ahlstrom 1968). Both the Catalina Eddy and Viscaino Bay can be considered semi-closed gyral systems (Wyllie 1961; Schwartzlose 1962; Reid et al. 1958; Groves and Reid 1958; Fleming 1939). These eddies and the longshore currents that connect them may serve to keep the majority of the young larvae from being swept out of their habitat and lost through dispersal. Kramer and Ahlstrom (1968) show a presence of anchovy larvae in these two eddies throughout the year, even when more offshore waters are essentially devoid of larvae. This fact is also demonstrated in the two anchovy larvae factor score maps for each month of 1969 in this study. Although the factor analytical tables are inconclusive, the factor score maps also show that areal distributions of higher factor scores for Factors II and V (young anchovy and hake larvae and older anchovy larvae) are coincident with higher scores for nutrient upwelling and stratification throughout the year.

Sardines

Higher sardine larvae factor scores throughout the year are also associated with the two eddies and the longshore currents that connect them. Sardines were absent during July, so the sardine factor chart for July primarily reflects the abundance of nitrite, the second highest correlate to that factor.

Although the low correlation to any factor might suggest depression due to species interaction (i.e. anchovy versus sardine), the low communality suggests that the sardine larvae were simply not sampled in sufficient numbers to indicate their relationship to other variables. The implications of this are important in future sampling tactics, as well as in the use of existing data, for understanding larval sardine ecology.

The total lack of sardine larvae in the July collection is not surprising since population levels were depressed and larval abundances are typically low in the summer (Kramer 1970).

Hake Larvae

Hake larvae data also suffered from persistently low communalities and frequent zero capture rates, although they seemed to bear some general positive relationship to the distributions and abundances of some classes of anchovy larvae. The absence of hake larave in July and September and the lower abundance in May have been documented previously by MacGregor (1971). The persistent relationship with young anchovies may be due to a need for a common prey or to predation by hake larvae on anchovy larvae (DeWitt 1952).

Other Biological Relationships

Colebrook (1974) performed a principal components analysis on 17 taxonomic assemblages, without reference to environmental variables. There is little doubt that the pattern of distribution in Colebrook's first component is very similar to that of Factor III (mixing) and that that of his second component is strikingly similar to that of Factor I (nutrient-upwelling). This set of results suggests that there are at least two principal axes to zoogeographic distributions and abundances in the California Current area: the upstream-downstream (north-south, cold-warm, rich-depleted) axis and the onshore-offshore (shallow-deep, coastal-oceanic, rich-depleted) axis.

A third physical factor (thermal stratitifaction, Factor IV) may be a partial inverse of Factor III (mixing; $r = -.16$). This stratification factor has a distribution pattern similar to that of some species of zooplankters found in the California Current (see various CalCOFI Atlases), as do mixing and nutrient-upwelling. Zome zooplankton distributions suggest that a fourth physical factor, the partial inverse of nutrient upwelling (Factor I), may exist. That hypothetical factor should represent the influence of the Central Pacific Water mass and may appear in future work involving a large data universe. Some zooplankters having distributions similar to that of Factor I are larval *Engraulis mordax* (northern anchovy), larval *Sardinops caerulea* (Pacific sardine), and the copepod *Calanus pacificus* (shared with Factor III). The larvae of the hake, *Merluccius productus,* have an inverse distribution to the factor, since they are spawned off Baja California and are carried northward (Alverson and Larkins 1969; Nelson and Larkins 1970). *Limacina helicina* (Mollusca; Thecosomata), *Calanus cristatus, C. plumchrus,* and *Candacia columbiae* (all Copepoda) are examples of some zooplankters having distributions similar to Factor III. *Calanus robustior, C. gracilis, C. minor,* and *Limacina inflata* are examples of some zooplankters with distributions similar to Factor IV (see Fleminger (1964) and McGowan (1967) for distributions of copepods and molluscs, respectively).

SUMMARY AND CONCLUSIONS

The use of factor-analysis and factor-score mapping has revealed identifiable characteristics of the California Current. These characteristics are understandable within the context of classical concepts of physical, chemical, and biological dynamics and distributions.

Three physical regimes have been described numerically: mixing processes (low temperature, low salinity, high oxygen); upwelling processes (low temperature, high salinity); and thermal stratification processes (high temperature, high salinity, shallow mixed layer). Phytoplankton nutrient chemicals (PO_4, NO_3, SiO_3) tend to co-occur with mixing and upwelling processes. Nitrite tends to be associated with thermally stratified waters during the summer. High chlorophyll abundances are associated with mixing and upwelling regimes, but first-feeding and very young anchovy larvae are associated with upwelled and stratified waters. The 2-to-5 mm and the 8-to-25-mm size classes of anchovy larvae tend to have mutually exclusive distributions.

The annual cycle for 1969 began in winter with domination by mixing processes, was later (March-June) dominated up upwelling processes, became stratified in late summer, and began mixing again in the autumn.

Factor analysis is amenable to the study of other interrelationships between a much larger number of biological variables. To diminish the number of redundant variables, composite variables of the chemical and physical features of the environment could be formed. These process or concept variables, such as mixing index, upwelling index, stratification index, plant-nutrient index, and productivity index, could be entered with the biological variables. Better definition of the ecosystem may result as other untapped sources of historic data become available.

Analysis of the latent roots of the factor matrices may provide predictive capacity for fishery stock management once basic relationships between age classes of species and ambiental variables have been better defined numerically.

ACKNOWLEDGMENTS

This work was supported by the Marine Life Research Group of Scripps Institution of Oceanography, University of California San Diego. I wish to thank Drs. Elizabeth Venrick, Dan Goodman, and John Senner, as well as anonymous reviewers, for their suggestions and comments. However, I take full responsibility for any errors or deficiencies in this work.

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APPENDIX
I - January

A. Oblique factor analysis of January 1969 CalCOFI Data. Loadings less than 0.20 have been omitted for clarity.

	FACTORS									
	1	2	3	4	5	6	7	Comm.	$\bar{X}$	S
CalCOFI line	−.37							.15	91	–
Temperature	−.35							.14	14.74	1.76
Salinity	−.33							.14	33.44	.29
Oxygen				−.57				.36	5.91	.20
Nitrite			−.30			.26		.20	3.27	3.07
Nitrate	−.26					.21		.16	56.08	69.34
Phosphate	.25							.12	20.54	7.93
Silicate	.35							.16	270.45	266.80
Chlorophyll-a	.39							.18	21.57	10.31
Phaeophytin	.33							.15	12.26	6.90
Zooplankton volume	.20		−.25					.16	97.29	78.41
Anchovy 2-3 mm		.23			.83			.72	1574.23	7230.64
Anchovy 3.5-5 mm		−.34			.48			.36	1389.97	4246.30
Anchovy 5.5-8 mm		−.59						.34	529.50	1559.30
Anchovy 8.5-12 mm			−.63					.40	225.29	718.46
Anchovy 12.5-25 mm			−.64					.42	34.47	186.76
Sardine larvae				−.77				.60	.84	5.19
Hake larvae		−.62						.38	164.50	436.75
Mixed layer depth						−.67		.49	43.7	12.18
Distance offshore						−.58		.37	95.2	–
Month of year										
% Common Variance	46.8	17.8	13.0	8.5	7.1	6.7			# Cases = 38	

B. Correlation coefficients for factors on factors, factor analysis of January 1969 CalCOFI data.

FACTORS	1	2	3	4	5	6	7
1		.03	−.04	−.03	−.02	.06	
2			−.02	−.05	−.06	.05	
3				.01	.04	−.11	
4					−.04	.06	
5						−.11	
6							
7							

II - February

A. Oblique factor analysis of February 1969 CalCOFI data. Loadings less than 0.20 have been omitted for clarity.

	FACTORS									
	1	2	3	4	5	6	7	Comm.	$\overline{X}$	S
CalCOFI line			−.47					.22	99	–
Temperature			−.41					.19	14.52	1.79
Salinity			−.45					.21	33.52	.35
Oxygen			.39	.44				.36	5.90	.32
Nitrite	.33			.22				.21	3.22	3.27
Nitrate	.47							.22	79.92	113.13
Phosphate	.47							.22	22.82	9.07
Silicate	.47							.22	188.95	131.82
Chlorophyll-a			−.26	.25				.17	26.82	11.06
Phaeophytin			−.35					.17	10.84	6.71
Zooplankton volume	.28							.11	200.82	534.34
Anchovy 2-3 mm					−.49			.27	5900.21	17985.6
Anchovy 3.5-5 mm					−.69			.49	4146.47	9683.03
Anchovy 5.5-8 mm		.42			−.24			.24	1679.55	2989.32
Anchovy 8.5-12 mm		.53						.29	570.68	1073.85
Anchovy 12.5-25 mm		.54						.33	119.11	304.82
Sardine larvae				.66				.44	2.66	12.13
Hake larvae				.44	−.32			.32	1259.97	2271.98
Mixed layer depth	−.20							.12	48.16	2.30
Distance offshore	−.22	−.34						.19	68.68	–
Month of year										
% Common Variance	37.0	23.8	20.9	11.4	6.8					# Cases = 38

B. Correlation coefficients for factors on factors, February 1969 CalCOFI data.

FACTORS	1	2	3	4	5	6	7
1		.02	.03	.06	.02		
2			−.03	.07	−.01		
3				−.04	.02		
4					−.00		
5							
6							
7							

III – April

A. Oblique factor analysis of April 1969 CalCOFI data. Loadings less than 0.20 have been omitted for clarity.

	FACTORS 1	2	3	4	5	6	7	Comm.	$\overline{X}$	S
CalCOFI line				.54				.30	106	–
Temperature	−.22			.34				.20	14.96	1.71
Salinity				.54				.33	33.57	.23
Oxygen	−.29				.71			.56	5.68	.29
Nitrite					.53			.32	2.87	5.47
Nitrate	.48							.24	184.21	233.76
Phosphate	.40							.22	31.55	18.16
Silicate	.36							.16	345.17	294.98
Chlorophyll-a	.37							.16	26.54	18.39
Phaeophytin				−.24	.25			.17	11.41	8.81
Zooplankton volume		−.27			.23			.18	149.79	151.60
Anchovy 2-3 mm			−.62			−.30		.47	1316.48	2896.49
Anchovy 3.5-5 mm			−.56					.36	811.03	1331.57
Anchovy 5.5-8 mm		−.32				.42		.33	1020.79	2194.70
Anchovy 8.5-12.5 mm		−.64						.42	539.17	1437.44
Anchovy 12.5-25 mm		−.56						.33	64.59	138.90
Sardine larvae						.81		.67	1.07	5.76
Hake larvae				−.31				.15	466.17	938.81
Mixed layer depth			.41					.24	2.66	1.17
Distance offshore	−.27		.29					.19	5.72	
Month of year										
% Common Variance	38.7	17.8	13.5	12.9	10.4	6.7			*# Cases = 29*	

B. Correlation coefficients for factors on factors, April 1969 CalCOFI data.

FACTORS	1	2	3	4	5	6	7
1		−.04	−.03	.03	.09	−.01	
2			.03	.08	−.02	−.06	
3				−.06	−.03	−.06	
4					−.01	.00	
5						−.06	
6							
7							

IV – May

A. Oblique factor analysis of May CalCOFI data. Loadings less than 0.20 have been omitted. 12.5-25 mm anchovies were completely absent, and omitted from the matrix.

	FACTORS 1	2	3	4	5	6	7	*Comm.*	X̅	*S*
CalCOFI line					.54			.33	77	–
Temperature	–.20	–.29			.24			.21	13.46	1.35
Salinity	.44			–.21	.25			.33	33.28	.35
Oxygen			.41	.30	–.44			.45	6.31	.27
Nitrite	.26			.20				.15	5.56	5.00
Nitrate	.44							.19	273.86	275.10
Phosphate	.42							.19	34.74	19.11
Silicate	.44							.20	389.91	286.01
Chlorophyll-a						–.54		.33	35.80	29.32
Phaeophytin						–.50		.29	25.88	18.20
Zooplankton volume	–.22				–.27	–.59		.47	420.14	406.08
Anchovy 2-3 mm		–.55	–.23	.25				.43	510.95	1378.26
Anchovy 3.5-5 mm			.60					.39	509.86	1222.69
Anchovy 5.5-8 mm			.57					.35	623.05	1780.25
Anchovy 8.5-12 mm		–.55			–.25			.38	49.68	132.79
Sardine larvae				.77				.60	3.95	18.54
Hake larvae		–.47						.27	13.68	26.75
Mixed layer depth				–.31	–.39	.20		.30	9.5	8.4
Distance offshore	–.24							.13	70.0	–
Month of year										
% Common Variance	39.8	22.5	14.1	10.4	7.3	5.9				*# Cases = 22*

B. Correlation coefficients for factors on factors, May 1969 CalCOFI data.

FACTORS	1	2	3	4	5	6	7
1		–.02	.01	.04	–.05	–.08	
2			–.04	.01	.01	.03	
3				–.09	.01	–.00	
4					–.04	–.07	
5						.01	
6							
7							

V – July

A. Oblique factor analysis of July 1969 CalCOFI data. Sardine and hake larvae have been omitted from the matrix since they were compeletely absent. Loadings less than 0.20 have been omitted for clarity.

	FACTORS									
	1	2	3	4	5	6	7	*Comm.*	$\overline{X}$	*S*
CalCOFI line		−.53		−.65				.72	80	–
Temperature	.26	−.66		−.50				.83	16.05	2.18
Salinity	.30	.64		−.41				.80	33.42	.27
Oxygen	.24		−.67					.55	5.81	.47
Nitrite		.81						.68	3.95	4.27
Nitrate		.76	−.30					.71	162.00	204.18
Phosphate		.80						.65	34.94	12.05
Silicate		.96	.29					.97	338.13	342.99
Chlorophyll-a	.84		−.21					.85	53.82	53.11
Phaeophytin	.44	.24	.20	−.48				.70	23.45	21.93
Zooplankton volume		.77						.63	253.00	201.49
Anchovy 2-3 mm	.96		.28					.90	189	494
Anchovy 3.5- mm	.67		.38	−.34				.85	451	1005
Anchovy 5.5-8 mm	.86							.90	268	440
Anchovy 8.5-12 mm	.94		−.28					.88	102	195
Anchovy 12.5-25 mm		.22	−.67	−.20				.53	12	28
Mixed layer depth	−.22	−.61	.23	.24				.62	16.2	13.1
Distance offshore	−.38	−.59	.26	.23				.75	83.7	–
Month of year										
% Common Variance	44.2	37.2	12.5	6.1						*# Cases = 16*

B. Correlation coefficients for factors on factors, July 1969 CalCOFI data.

FACTORS	1	2	3	4	5	6	7
1		.06	−.09	−.42			
2			−.06	−.01			
3				−.00			
4							
5							
6							
7							

VI – September

A. Oblique factor analysis of September 1969 CalCOFI data. Loadings less than 0.20 have been omitted for clarity. Hake larvae were completely absent and have been omitted from the matrix.

	FACTORS									
	1	2	3	4	5	6	7	*Comm.*	$\overline{X}$	*S*
CalCOFI lines		−.43						.20	118	–
Temperature		−.45						.22	20.99	2.51
Salinity		−.47						.23	33.75	.33
Oxygen		.40						.21	5.29	.38
Nitrite		−.22			−.72			.58	2.18	3.46
Nitrate	.46							.22	16.45	51.97
Phosphate	.37							.15	12.31	7.25
Silicate	.23				−.36			.20	122.00	116.92
Chlorophyll-a	−.22	.20		.56				.40	37.37	54.40
Phaeophytin				.44				.23	10.02	5.67
Zooplankton volume	.44							.20	58.80	36.76
Anchovy 2-3 mm	.50							.25	22	69
Anchovy 3.5-5 mm	.25	−.25						.16	8	19
Anchovy 5.5-8 mm			−.54					.30	29	89
Anchovy 8.5-12.5 mm			−.57					.33	46	205
Anchovy 12.5-25 mm			−.57					.33	10	43
Sardine larvae				.26	.44			.31	11	49
Mixed layer depth				−.37	−.29			.27	16.5	12.7
Distance offshore				−.42				.23	86.5	–
Month of year										
% Common Variance	46.0	22.7	15.5	8.8	6.9					# *Cases* = 20

B. Correlation coefficients for factors on factors, September 1969 CalCOFI data.

FACTORS	1	2	3	4	5	6	7
1		−.01	−.03	.06	−.00		
2			.01	−.03	−.05		
3				−.04	−.03		
4					.03		
5							
6							
7							