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COASTAL UPWELLING OFF WESTERN NORTH AMERICA, 1976

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INTRODUCTION

The nearshore marine environment off western North America is markedly influenced by processes of coastal upwelling and downwelling. Upwelling is widely recognized as a fundamental factor in the formation of nutrient rich surface water favorable to primary production. Wind induced surface layer divergence may also dramatically modify nearshore marine climate, and may act as an important driving mechanism for continental shelf/slope circulation.[2]

Variations in biological communities often occur nearly in phase with the predominant seasonal cycle of coastal upwelling. Major fluctuations in the intensity of coastal upwelling also occur at frequencies corresponding to the diurnal sea breeze, to synoptic "events", and to interyear variations in the location and intensity of the large scale atmospheric circulation system over the northeastern Pacific. Anomalously strong or weak upwelling may be related to major fluctuations in stock recruitment (Parrish 1976) which are likely to have subsequent effects higher in the food chain.

Bakun (1973) computed an index of coastal upwelling based on calculations of surface wind stress derived from analyzed fields of surface atmospheric pressure. These fields are routinely produced by the U.S. Navy Fleet Numerical Weather Central. The "upwelling index" is defined as the offshore directed component of Ekman transport, and is considered to be a gross measure of the amount of upwelling required to replace water transported offshore in the surface layer. Negative values of this index

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[2]Niiler, P. P., and C. N. K. Mooers. 1977. A model shelf dynamics program. A report to the National Science Foundation, Office of the International Decade of Ocean Exploration, January 1977.

Reprinted from: *In* J. R. Goulet, Jr. and E. D. Haynes (editors), Ocean variability in the U.S. Fishery Conservation Zone, 1976, p. 65-75. NOAA Tech. Rep. NMFS Circ. 427, June 1979.

indicate onshore surface transport and downwelling at the coast. Monthly mean upwelling index values for the period 1946-71 were presented for the 15 locations shown in Figure 6.1. These time series have been updated for 1972-74 and 1975 (Bakun 1976, 1978).

Monthly upwelling indices for 1976 are given in Table 6.1. Anomalies from the 20-yr (1946-67) mean monthly values are presented in Table 6.2. Upwelling indices are displayed in percentiles in Figure 6.2. Percentile values were based on the rank of the upwelling index for each month and location within the 31-yr (1946-76) time series.

THE GULF OF ALASKA

Wind driven surface transport in the Gulf of Alaska (60N, 149W to 51N, 171W) tends to be divergent in the interior and convergent at the coast.[3] The annual cycle of coastal convergence is dominated by vigorous downwelling during the winter season, when intense cyclonic storm activity characterizes the atmospheric circulation in the region. During 1976 monthly upwelling indices were negative along both northern and eastern boundaries, except in June and July when small positive values were evident.

In January more intense than normal downwelling was indicated along the eastern boundary, while positive anomalies occurred in the northern Gulf of Alaska. This pattern of anomalies reversed the trends for these two areas begun during the last quarter of 1975 (Bakun 1978). The remainder of the first quarter of 1976 was marked by less intense than normal winter downwelling. Reduced levels of coastal convergence may be associated with less intense than normal surface divergence offshore. A decrease in the strength of the coupled "pumping" between the central Gulf of Alaska and the coast would tend to reduce the baroclinicity established during the previous three months.

More intense than normal coastal convergence was evident during the remaining months of 1976. A general pattern of upwelling indices below the median (Fig. 6.2) was interrupted in June, when small positive values occurred, and in October, when an irregular transition to vigorous winter downwelling was apparent. Anomalies from the long-term monthly means (Table 6.2) were negative from April through September, except during June, at

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[3] Ingraham, W. J., Jr., A. Bakun, and F. Favorite. 1976. Physical Oceanography of the Gulf of Alaska. U.S. Dep. Commer., NOAA, NMFS, Northwest Fish. Cen., Processed Rep., 132 p.

these five locations. Upwelling indices at 54N, 134W and 51N, 131W for May and July were the lowest (largest negative values) calculated in the 31-yr time series. Coastal convergence continued through the summer at approximately one-half the intensity of the preceding winter's downwelling. Under these conditions, the existing baroclinic structure would tend to be maintained. This situation contrasts with more typical relaxed summer conditions, in which the baroclinicity established during a previous winter is dissipated.

A smooth transition to vigorous winter downwelling was replaced by less intense than normal downwelling in October. This period of positive anomalies immediately followed and preceded several months of large negative anomalies. An examination of the monthly mean surface atmospheric pressure field for October (not shown) indicated a westward shift, relative to the long-term mean position, of the center of the low pressure system and a much reduced pressure gradient near the coast. A return to near normal (50th percentile) winter downwelling occurred in December.

VANCOUVER ISLAND TO POINT CONCEPTION

The stretch of coast from Vancouver Island (48N) to Point Conception (36N) is a transition zone, in which wind driven surface transport changes from predominantly onshore to predominantly offshore. During 1976 this entire coastal region was characterized by a pattern of three periods of more positive than normal upwelling indices separated by two short intervals of more negative than normal indices. These features repeat the general pattern noted in the previous section, and indicate a degree of coherence in the large scale atmospheric circulation on space scales approaching 1,200 km and on time scales of two to four months.

Neah Bay to Central Oregon (48N, 125W to 45N, 125W). Large positive anomalies in January extended a period of relaxed coastal convergence first noted in December 1975 (Bakun 1978). This trend did not continue; near normal downwelling was indicated from February through April along the coasts of Washington and northern Oregon. A prolonged period of relaxed coastal upwelling from May to September was interrupted in June by a return to near normal index values. However, this feature appeared as an anomaly in a pattern of upwelling indices below the median, in a region stretching from the northern Gulf of Alaska to Oregon. Upwelling peaked in June, somewhat earlier than the long-term mean values would indicate (Bakun 1973). Fall and early winter were characterized by a return to negative mean values (coastal convergence), although positive anomalies indicated less intense than normal downwelling.

Cape Blanco to Point Conception (42N, 125W to 36N, 122W). The patterns of positive anomalies during winter and negative anomalies during summer noted above were not repeated exactly along the coasts of southern Oregon and northern California. This stretch of coast encompasses the core of the California Current upwelling region, which is characterized, in the mean, by a maximum in the alongshore component of surface wind stress during July (Nelson in press). In 1976 the timing, duration, and intensity of the indicated upwelling at Cape Blanco (42N), Cape Mendocino (39N), and to a lesser extent Point Conception (36N), were markedly different than the 1946-67 long-term mean conditions.

Positive anomalies occurred in January and February, during a part of the year ordinarily characterized by coastal convergence. Although onshore transport was indicated at 42N, upwelling indices for 39N were positive and were clearly above the 50th percentile. This feature continued a long trend of positive anomalies which began in April 1975 (Bakun 1976).

The onset of anomalous upwelling appeared to occur rather abruptly in March. The timing of this event was coherent at three locations along the coast (Fig. 6.2). Near Cape Mendocino (39N), the March index was nearly a factor of three greater than the long-term mean value for this month and location. A return to near normal conditions occurred in April.

Conditions favorable to strong coastal upwelling reappeared in May, June, and July. Monthly mean indices exceeded the 80th percentile at both 42N and 39N. The values computed for Cape Mendocino (39N) were the second highest in May, and the third largest in June within the 31-yr series. This recurrence of unusually large positive anomalies marked the fourth consecutive year in which stronger than normal coastal divergence has been indicated. Such long-term persistence possibly suggests either a shift in, or intensification of, the large-scale atmospheric circulation influencing the west coast of North America. The timing of the summer upwelling season was also somewhat unusual. Index values peaked in May, two months earlier than the peaks in the long-term mean cycles for these locations.

A rapid transition to below normal upwelling (i.e., negative anomalies) during August was immediately followed by a return to large positive anomalies in September. The period of relaxed upwelling in August was notable, since negative anomalies during this month were evident along the entire stretch of coast from the northern Gulf of Alaska to the Southern California Bight.

The pattern of positive anomalies persisted through the last quarter of 1976. While the upwelling indices at 42N approached the 20-yr mean values (i.e., downwelling), indices exceeding the

80th percentile occurred in September and October at Cape Mendocino. The indices for November and December showed a gradual return to median values; however, upwelling was still indicated for 39N. As Bakun (1978) has already noted, such a prolonged period of upwelling would appear to be favorable for those fish stocks dependent upon upwelling based primary production.

POINT CONCEPTION TO BAJA CALIFORNIA

A secondary California Current upwelling regime along this coast (33N, 119W to 21N, 107W) is characterized by positive values of offshore transport throughout the year (Bakun and Nelson in press). Maximum upwelling index values occur from March to May and coincide, in time, with major peaks in spawning.

Although the upwelling index remained positive during 1976, the most prominent features were the extended periods of large negative anomalies in January and February, and again from August to December. This pattern marked an almost complete reversal of the conditions which prevailed in 1975. During the previous year, below median values occurred in summer, while above median indices were evident in spring and fall.

Positive monthly mean anomalies were evident from March to August (Table 6.2). Much more intense than normal upwelling at locations from Punta Eugenia (27N) to Cabo San Lucas (21N) extended the upwelling season to late summer. This period was immediately followed by a decline to large negative anomalies. This pattern of negative anomalies during fall and early winter encompassed the entire region from Point Conception (36N) to Cabo San Lazaro (24N). Upwelling indices were consistently below the 30th percentile, which suggested extremely relaxed upwelling for this time of year.

The pattern of negative anomalies corresponded in time and in location with a rapid warming of surface water during fall and winter. The intensity of warming was indicated by December sea surface temperature anomalies 2C warmer than the 1946-67 mean, and more than 3C warmer than the temperatures during the 1975 winter season.[4] Relaxed upwelling (i.e., small values of offshore transport) is correlated with northward surface flow

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[4] _Fishing Information_, No. 12, December 1976. Southeast Fisheries Center, NMFS, NOAA, La Jolla, CA 92038.

near the coast.[5] The upwelling conditions during fall and winter 1976 indicated the possibility of a major intrusion of warm southern water which could have extended beyond Point Conception.

RELATION TO FISHERIES

Within the coastal region from Point Conception (33N) to Cabo San Lucas (21N), upwelling and upwelling related processes may be important transport mechanisms for fish stocks which spawn in the area.[6] The five months of below normal indices in this region followed a period of moderate upwelling at 30N, 119W. On the basis of above normal upwelling at this location during peak spawning, recruitment models predicted better than average reproductive success for Pacific mackerel in 1976.[7] Relaxed upwelling during the fall and increased northward flow near the coast would tend to favor northward transport of the southern stock of Pacific mackerel, *Scomber japonicus*, which would increase the estimates of the 1976 year class above those predicted on the basis of spring upwelling alone. Current market evidence indicates that, indeed, the 1976 year class is much stronger than had been anticipated.[8]

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[5]Nelson, C. S. 1976. Seasonal variations in processes related to the California Current. Paper presented at the 23rd Eastern Pacific Oceanographic Conference, September 29-October 1, 1976.

[6]Parrish, R. H., and C. S. Nelson. Fish stocks and the California Current. Paper presented at the Calif. Coop. Oceanic Fish. Invest. Conference, November 16-18, 1976, Palm Springs, CA. Unpubl. manuscr.

[7]R. H. Parrish, Pacific Environmental Group, NMFS, NOAA, Monterey, CA 93940. Pers. commun.

[8]R. A. Klingbeil, California Fish and Game Comm., Long Beach, CA 90802. Pers. commun.

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Table 6.1 - Monthly coastal upwelling indices for 1976. Units are cubic meters per second per 100m length of coast. Negative values indicate onshore transport of surface waters and resultant downwelling.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
60N 149W	-85	-91	-10	-16	-2	4	2	-1	-17	-12	-68	-94
60N 146W	-113	-104	-13	-26	-4	8	2	-2	-33	-22	-123	-146
57N 137W	-201	-50	-35	-54	-35	6	-6	-8	-81	-58	-237	-132
54N 134W	-159	-18	-40	-55	-55	5	-26	-7	-56	-39	-163	-86
51N 131W	-81	1	-16	-33	-21	20	-23	4	-12	-6	-68	-48
48N 125W	-63	-35	-24	-3	6	31	5	9	1	-6	-37	-53
45N 125W	-41	-30	-10	-0	21	56	23	17	14	-0	-31	-47
42N 125W	-10	-4	20	15	132	166	95	44	52	7	-23	-27
39N 125W	9	9	101	59	331	304	249	111	134	79	2	3
36N 122W	22	20	124	115	259	196	224	109	80	49	4	1
33N 119W	-1	34	120	198	304	262	277	212	88	50	4	-6
30N 119W	44	64	139	160	231	199	160	145	70	80	54	28
27N 116W	27	51	127	158	215	214	142	170	57	58	28	17
24N 113W	24	50	127	153	191	172	107	86	57	72	34	32
21N 107W	21	33	122	125	119	36	30	4	1	16	18	35

Table 6.2 - Monthly coastal upwelling index anomalies for 1976 relative to the 20-year (1948-67) mean value for each month and location. Units are cubic meters per second per 100 m length of coast.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
60N 149W	54	-5	36	-5	-2	-2	-4	-6	-14	14	5	14
60N 146W	67	-2	35	-14	-2	1	-3	-5	-24	12	-29	-17
57N 137W	11	67	16	-30	-25	6	-8	-2	-52	29	-96	31
54N 134W	-63	49	-12	-35	-46	5	-29	-7	-33	43	-65	5
51N 131W	-17	37	-4	-27	-25	5	-39	-9	-9	34	-10	9
48N 125W	27	12	-3	-3	-11	5	-29	-13	-3	33	51	47
45N 125W	53	18	5	-9	-13	8	-51	-34	-3	20	42	46
42N 125W	57	24	16	-18	53	63	-36	-47	16	7	19	31
39N 125W	21	0	65	-10	207	136	68	-28	71	59	8	16
36N 122W	12	-15	44	-5	56	-43	25	-73	-14	0	-8	-6
33N 119W	-20	-14	-0	20	21	-50	46	-0	-49	-26	-18	-16
30N 119W	-12	-14	23	19	31	-0	17	3	-59	-23	-11	-26
27N 116W	-45	-43	8	10	13	19	28	65	-54	-48	-46	-46
24N 113W	-26	-24	34	36	49	44	59	42	8	3	-19	-8
21N 107W	3	-7	25	25	32	-3	27	-2	15	31	10	26

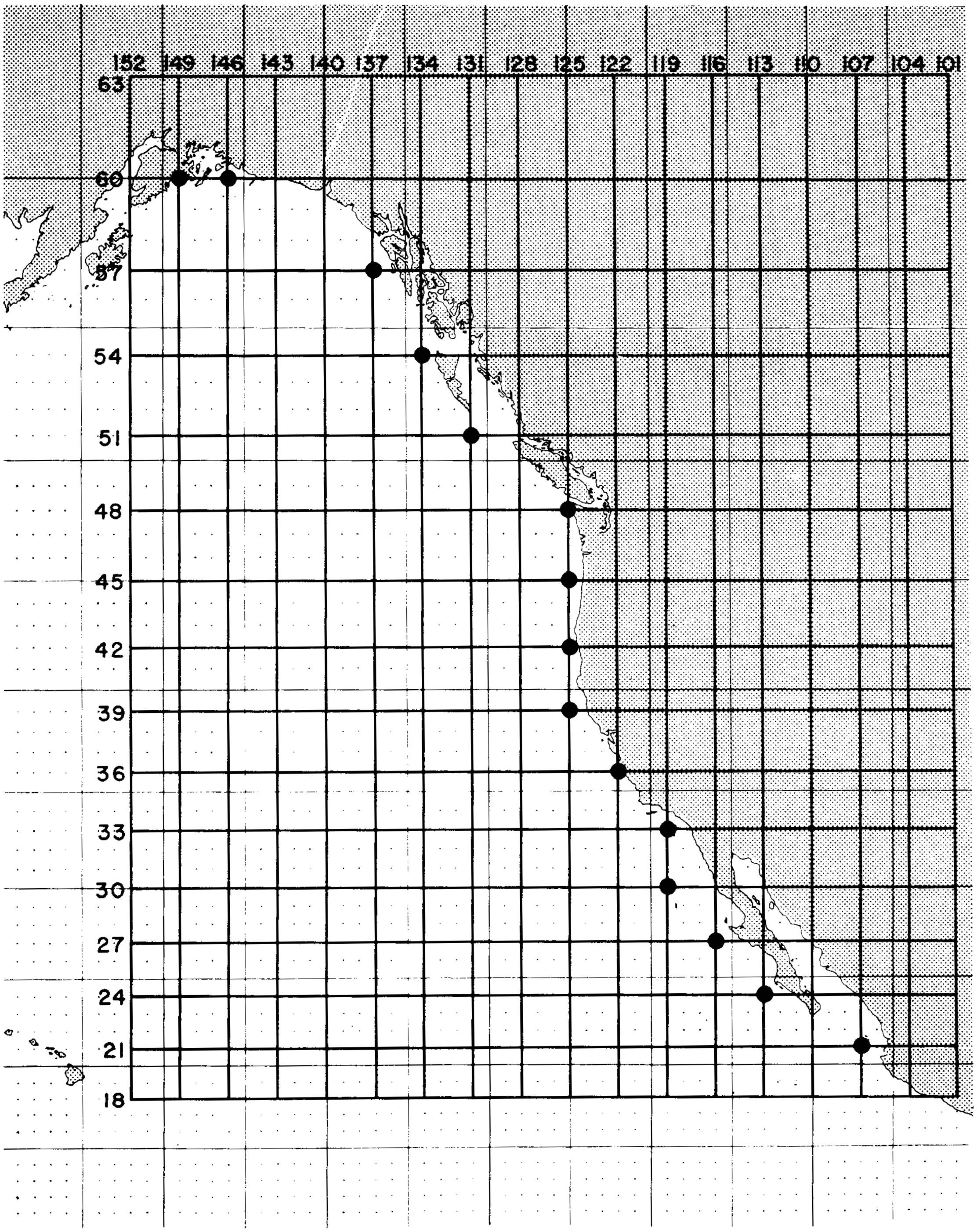

Figure 6.1.—Computation grid. Intersections at which upwelling indices are computed are marked with large dots.

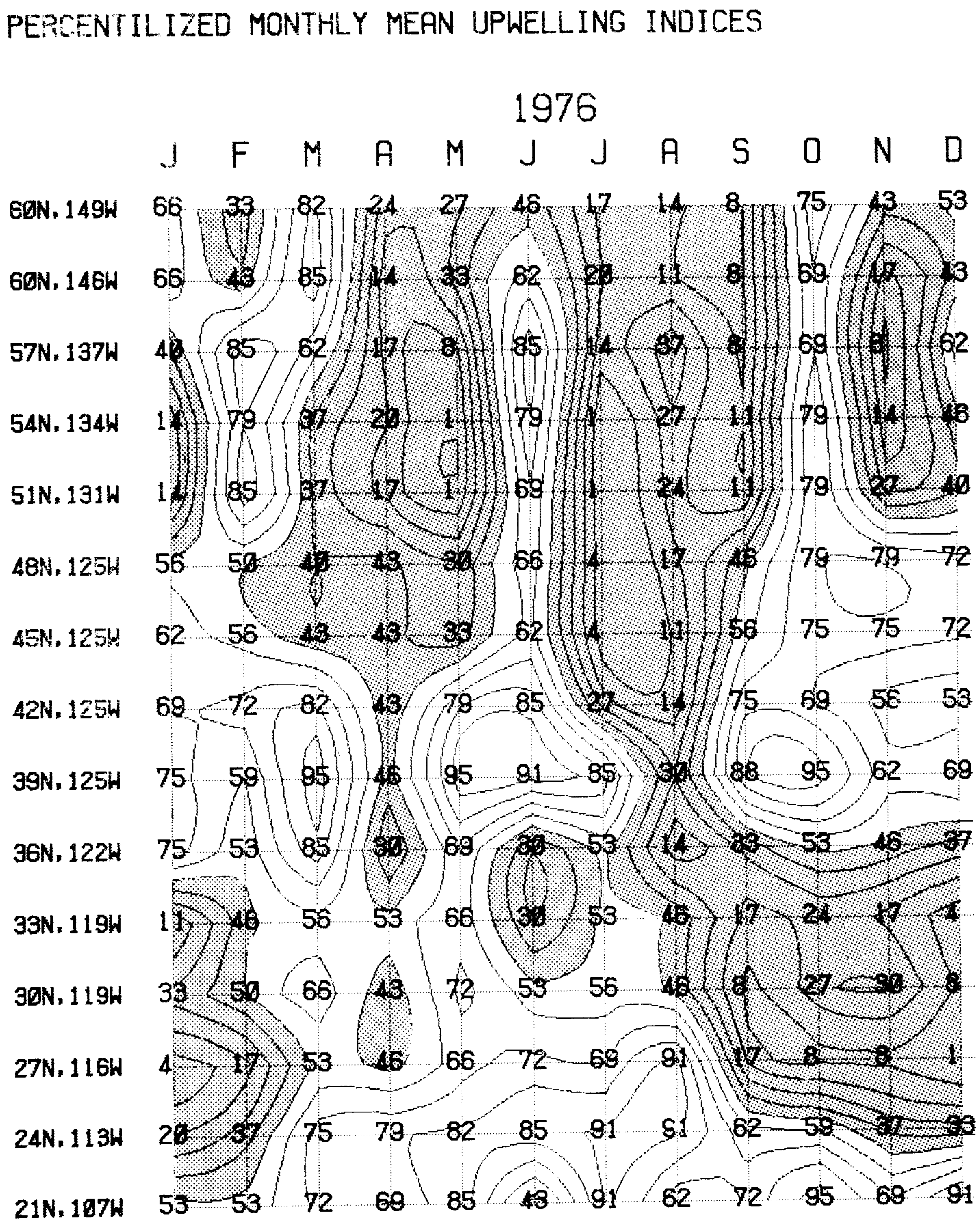

Figure 6.2.—Percentalized upwelling index values for 1976. Percentiles indicate relative ranking within the 31-yr data set for each month and location. The contour interval is 10 percentile units. Values below the median (50th percentile) are shaded.