

## OCCASIONAL AVAILABILITY OF DOLPHIN, *CORYPHAENA HIPPURUS*, TO SOUTHERN CALIFORNIA COMMERCIAL PASSENGER FISHING VESSEL ANGLERS: OBSERVATIONS AND HYPOTHESES

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### ABSTRACT

Records from California-based commercial passenger fishing vessels (CPFV) show that dolphin, *Coryphaena hippurus*, catch off southern California was more than 8% of the total southern and Baja California CPFV catch in 1983, 1984, 1990, 1992, and 1993. The major portion of the catch is made off northern Baja California. Record catches for southern and Baja California were recorded in 1990 and 1992. Dolphin enter California waters under conditions that include elevated ocean temperatures and increased onshore and poleward coastal ocean transport. Large-scale environmental events, which apparently increase dolphin abundance off southern California, appear related to regional decrease in eastern Pacific high-pressure systems. When the high-pressure system is less intense, there is less southward wind along the coast. Consequently, California Current southward transport and coastal upwelling decrease, and the inshore countercurrent brings anomalously warm water into the Southern California Bight. Local kelp mat cover and local ocean processes are also likely to be important in aggregating dolphin and making them available to CPFV anglers.

### RESUMEN

Los registros de la Flota Comercial de Pesca Deportiva ("FCPD") demuestran que la captura del dorado *Coryphaena hippurus* frente a la costa del sur de California rebasó el 8% de la captura de la FCPD de Baja California (B.C.) y B.C. Sur (México). La mayor parte de la captura se realiza frente al norte de Baja California. En 1990 y 1992 hubo capturas record en B.C. y B.C. Sur. El dorado entra en aguas de California en condiciones que incluyen temperaturas elevadas del océano e incremento del transporte hacia el norte (en la zona costera) y hacia la línea de costa. Los eventos a gran escala que aparentemente produjeron un incremento en la abundancia del dorado frente al sur de California parecen estar relacionados con un decremento regional en el sistema de alta presión del Pacífico oriental. Cuando el sistema de alta presión afloja, también afloja el viento hacia el sur a lo largo de la costa. Y en consecuencia tanto el

transporte hacia el sur debido a la corriente de California como la surgencia costera decremantan, y la contracorriente cercana a la línea de costa acarrea aguas anormalmente cálidas a la Cuenca del sur de California. La disponibilidad local de frondas de algas pardas ("kelp") así como otros procesos oceánicos locales también podrían ser importantes para concentrar dorados y ponerlos a disposición de la FCPD.

### INTRODUCTION

Dolphin (*Coryphaena hippurus*), also known in the United States as dorado and mahimahi, are epipelagic predatory fish found in the world's tropical and subtropical oceans (Palko et al. 1982). Off southern California, dolphin are caught by commercial passenger fishing vessel (CPFV) anglers in the warm months of warmer years (tables 1 and 2).

Dolphin commonly reach sexual maturity and lengths exceeding 100 cm in their first year (Oxenford and Hunte 1986). Individuals may live longer than five years, but in both commercial and sport fisheries fewer than 5% of the fish taken are thought to be older than two years

TABLE 1  
Number of Dolphin Caught by Commercial Passenger  
Fishing Vessels off California and Baja California

Year	Calif.	Total, Calif. and Baja Calif.	% Calif. <sup>a</sup>	Avg. temp. <sup>b</sup>
1979	1	9,184	0	18.9
1980	2	8,840	0	19.0
1981	35	1,281	3	19.8
1982	0	1,099	0	18.1
1983	1,258	4,992	25	18.9
1984	527	6,532	8	20.1
1985	3	1,307	0	19.3
1986	31	1,866	2	19.2
1987	0	3,518	0	18.1
1988	1	3,349	0	18.6
1989	3	2,341	0	18.7
1990	7,216	31,548	23	19.3
1991	0	1,301	0	17.6
1992	1,882	22,727	8	20.1
1993	707	8,574	8	18.8
Total	11,665	108,459	11	

<sup>a</sup>California percentage of total catch.

<sup>b</sup>Average 10 m temperature (°C) of a 3° × 3° area containing the California catch.

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TABLE 2  
 Seasonal Dolphin Catch Expressed as Percentage of  
 Annual Catch by Month

A. Southern California						
Month	1983	1984	1990	1992	1993	Average
Jan.	0	0	0	0	0	0
Feb.	0	0	0	0	0	0
Mar.	0	0	0	0	0	0
Apr.	0	0	0	0	0	0
May	0	0	0.0	0	0	0.0
June	0	0	0.3	0	0	0.1
July	6.3	1.5	1.3	42.8	35.2	17.4
Aug.	69.0	36.2	86.4	40.9	21.4	50.8
Sept.	22.7	62.2	3.1	15.3	21.9	25.0
Oct.	2.0	0	8.8	1.1	21.2	6.6
Nov.	0	0	0	0	0	0
Dec.	0	0	0	0	0	0

No. of fish 1,258 527 7,216 1,882 707 11,590  
 California percentage of total during 1983, 1984, 1990, 1992, 1993 = 15.6%

B. Southern and Baja California						
Month	1983	1984	1990	1992	1993	Average
Jan.	0	0.3	0.1	0.1	0	0.1
Feb.	0	0	0	0	0	0.0
Mar.	0	0	0	0	0	0.0
Apr.	0	0	0	0	0	0.0
May	0	0	1.7	0	0	0.3
June	0	0	0.1	0.5	0	0.1
July	9.8	1.0	9.0	28.5	53.1	20.3
Aug.	52.0	46.5	51.4	41.2	20.1	42.2
Sept.	32.2	31.6	21.7	20.1	6.3	22.4
Oct.	2.7	6.1	14.3	8.3	9.7	8.2
Nov.	1.8	14.1	1.2	0.9	9.1	5.4
Dec.	1.4	0.4	0.4	0.4	2.0	0.9

No. of fish 4,992 6,532 31,548 22,727 8,574 74,373

(Kojima 1964; Beardsley 1967; Palko et al. 1982). About 85% of the dolphin taken by southern California CPFV anglers are less than one year old.

In the northeastern Pacific, the largest concentrations of all dolphin life stages are in the tropical biogeographic zone (Palko et al. 1982), which extends from the equator north to the southern end of the Baja California Peninsula at 22.8° N (Ekman 1953; Parrish et al. 1981; Bakus 1986; McGowan 1986). Poleward migration into the northern subtropical biogeographic zone appears limited by factors associated with the 20°C sea-surface isotherm (Kojima 1964; Palko et al. 1982). Biogeographic zones would be expected to be plastic for wide-ranging nektonic species such as dolphin. It is probable that the migrations of dolphin and other nektonic species reflect changing physical oceanographic conditions (Squire 1987). Throughout the dolphin's range, peak catch is seasonal, suggesting annual migrations (Patterson and Martinez 1991; Hamm et al. 1992).

Since 1979, total annual catch from southern and Baja California waters has varied thirtyfold (table 1). Catch

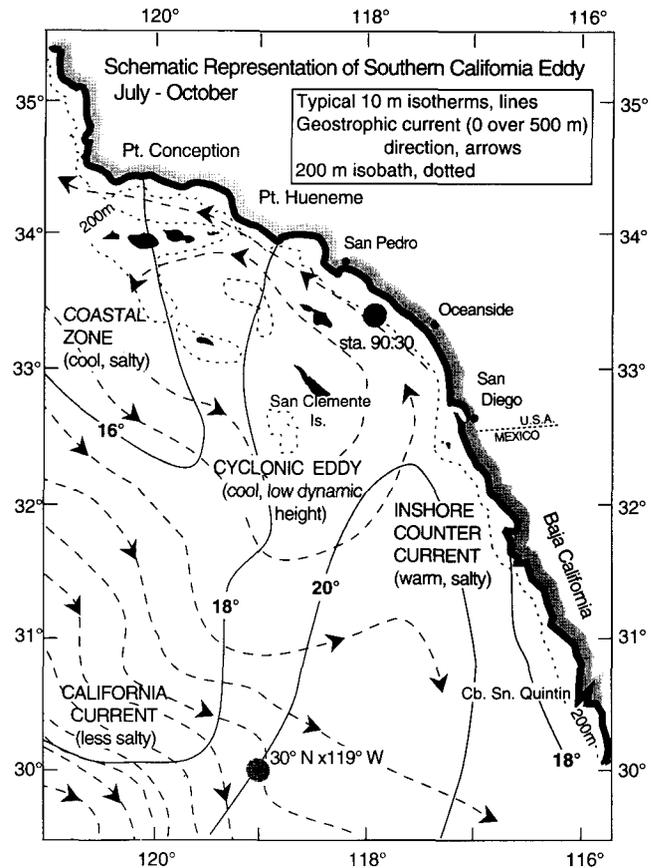


Figure 1. Composite diagram of the Southern California Eddy. Dashed lines show contours of surface dynamic height anomaly at an average spacing of 0.02–0.04 dynamic meters. Shaded circles show locations referred to in the text. Adapted from Reid et al. 1958; Lynn et al. 1982; Peláez and McGowan 1986; and Lynn and Simpson 1987.

off southern California is episodic. Off Baja California catch is more consistent; more than 1,000 dolphin are caught each year. When the total catch exceeds 4,000 fish, 75%–85% of the dolphin are taken north of Cabo San Quintin (figure 1) on 20- to 24-hour CPFV trips from San Diego and Oceanside. Usually CPFVs are pursuing yellowfin tuna (*Thunnus albacares*), skipjack (*Euthynnus pelamis*), or yellowtail (*Seriola lalandi*) on these excursions. Dolphin are a desirable bycatch. If dolphin fishing is successful, the CPFV will not abandon it to search for other species.

Dolphin are most frequently taken from beneath free-floating kelp mats composed of tangled *Macrocystis* sp. stipes and blades (fronds). Locating the fish depends on the CPFV operator's ability to find floating kelp mats.

Many studies have focused on the basin-scale environmental events of seasonal to several-years' duration (Norton et al. 1985; Ebbesmeyer et al. 1991; Norton and McLain 1994) and their possible biological consequences (Uda 1961; Norton 1987; Parker 1989; Lluch-Belda et al. 1992; Hollowed and Wooster 1992). The

best-known environmental events of this scale are the ENSO, or El Niño/Southern Oscillation, and its global teleconnections (Rasmusson and Wallace 1983; Simpson 1992; Norton and McLain 1994).

Because global anomalies associated with ENSO appear to be triggered by tropical Pacific events, it may be useful to compare tropical indicators of ENSO activity to physical conditions associated with the subtropical biogeographic zone (Longhurst 1967; Brinton and Reid 1986; Squire 1987) and to dolphin catch by southern California CPFV anglers.

The objective of this paper is to compare variation in CPFV dolphin catch off southern and Baja California to several scales of variation in the physical environment and to use the results of these comparisons to develop scenarios describing conditions that allow dolphin to enter the Southern California Bight. Comparisons begin with processes that may last several years and include the entire north Pacific, then proceed to smaller scales, concluding with seasonal and spatial variation of processes within the Southern California Eddy (figure 1).

## DATA

Dolphin catch records (tables 1 and 2) were obtained from the California Department of Fish and Game database of CPFV logbook information, which provides numbers of each species caught per  $0.1^\circ$  geographical square off southern California. The origin of dolphin catch from Mexican waters is not as specific. When dolphin are available within 40 km of southern California ports, they are heavily fished by private boats (carrying two to six anglers) that may catch as many dolphin as the CPFVs. This suggests that when many fish are caught—as in 1990 and 1992; table 1—the CPFV logbook records underestimate abundance.

Commercial passenger fishing vessels are believed to be thorough as they search the coastal ocean for desirable pelagic species, especially within 70–120 km of their home ports. CPFV operators maintain radio contact with one another, commercial fish-spotting planes, commercial fisherman, and private boat operators. Radar and sonar devices aid the search.

Between San Pedro and San Diego more than 80 CPFVs (more than half from San Diego and Oceanside) search the coastal ocean each day from July through September. Each boat carries about 30 fishermen, so there are more than  $2.0 \times 10^5$  angler days per season. Dolphin catch per angler day was about 0.15 during 1990, the year of greatest abundance (table 1).

The CPFV anglers use labor-intensive methods, unsuitable for commercial exploitation, that involve presenting live anchovies (*Engraulis mordax*) and sardines (*Sardinops sagax*) as bait. Many fish entering the Southern California Bight may not encounter CPFV activities,

but it is unlikely that high concentrations of desirable fish occur within CPFV range without being sampled (caught) by CPFV anglers.

When fishing is good, increased fishing effort may be directed toward catching the more available species. This “target homing” by CPFVs may lead to negative and positive feedback bias in the catch records. That is, total catch values might be relatively deflated during years of low catch, and inflated for years of high catch. For dolphin, these biases are reduced by two related factors: (1) other pelagic species (see above) have been available and pursued during years of high dolphin catch, and (2) dolphin are usually taken as desirable bycatch during excursions for other species. Dolphin are not specifically sought, and they are not specifically rejected. Each factor reduces bias introduced by CPFV target homing.

Monthly mean sea temperature at 10 m depth was interpolated from vertical temperature profiles in the U.S. Navy Fleet Numerical Oceanography Center’s (FNOC) Master Oceanographic Observations Data Set (MOODS5). Temperature profiles were extracted, checked for consistency, and plotted with the programs of McLain et al. (1985).

California Cooperative Oceanic Fisheries Investigations (CalCOFI) temperature–salinity–depth data were obtained from the Scripps Institution of Oceanography, Marine Life Research Group. Historical and mean (1950–78) station data were obtained from the Southwest Fishery Science Center (NMFS/NOAA). CalCOFI data are published in data reports of Scripps Institution of Oceanography (UCSD) along with parameter distribution maps. Maps from CalCOFI cruises of July 1990 (9007) and October 1992 (9210) have been adapted for use in our figures.

Seasonal mean values for the Southern Oscillation Index (SOI) were obtained from the Climate Analysis Center (NMC/NOAA). These are the five-month running mean of the difference between the standardized sea-level-pressure anomalies at Tahiti ( $17.53^\circ$  S,  $149.57^\circ$  W) and Darwin ( $12.47^\circ$  S,  $130.85^\circ$  E).

SOI values correlate well with atmospheric, oceanic, and biological (ENSO) anomalies throughout the world. Tropical atmospheric oscillations as measured by the SOI may be connected with the region of dolphin catch off southern and Baja California via the atmosphere and the ocean (Rasmusson and Wallace 1983; Baumgartner and Christensen 1985; Kope and Botsford 1990; Simpson 1992; Clarke 1992; Norton and McLain 1994).

Monthly mean values of SLP and an upwelling index at  $30^\circ$  N,  $119^\circ$  W were derived from the FNOC  $63 \times 63$  grids of northern hemisphere analyzed fields (Bakun 1975). The SLP is a general atmospheric parameter that reflects changes in air-sea heat exchange, wind stress and wind-curl forcing, and wind-forced mixing. The up-

welling index is computed from SLP gradient at 30° N, 119° W. Although the interpretation of the upwelling index may be more complex than the terminology would imply, it is more closely related to Ekman transport and coastal upwelling than to SLP. However, SLP series are probably more indicative of combined large-scale forcing (Norton and McLain 1994).

## RESULTS

Although the catch record is too short for detailed statistical analysis, some patterns are evident and will help form hypotheses to be tested as additional data become available.

Off southern California, significant dolphin catch ( $\geq 8\%$  of the combined catch) was reported in 1983, 1984, 1990, 1992, and 1993, along with an apparent increase in dolphin availability to southern California CPFV anglers since 1990 (table 1). These observations may represent dolphin response to the environment on two temporal scales. First, there is considerable year-to-year variation ranging over three orders of magnitude in California catch and one order of magnitude in the total catch. Second, a multiyear population response is evident. The high total catch ( $>8,000$ ) recorded in 1979 and 1980 was not observed again for nine years. Then in 1990, 1992, and 1993 high catches were again recorded (table 1).

When the best years for California dolphin catch are compared, the highest percentage of the catch is made in August (table 2). Off California, the catch is limited to July, August, and September. Off Mexico there is frequently good catch in October, with at least some fish being taken during the next three months.

### Large-Scale Events and Dolphin Availability

The occasional availability of dolphin to CPFV anglers may represent an anomalous northward shift of physical conditions characterizing the subtropical biogeographic zone. In this section we use an oceanic indicator series and three atmospheric indicator series to examine how large-scale physical events of seasonal and longer scale relate to a northward subtropical biogeographic zone shift and subsequent dolphin fishing success.

The three atmospheric series are compared to total CPFV catch in figure 2. The period since 1990 (thick dashed lines) is especially striking because there is coincident downward trend in all the atmospheric variables at the same time that dolphin became more available to CPFV anglers.

Dolphin migration into southern California waters is also related to the large-scale events. The extreme 1982–83 perturbation in SOI corresponded to a reduction in SLP annual-cycle amplitude and an unusually high fraction (25%) of the total dolphin catch being made

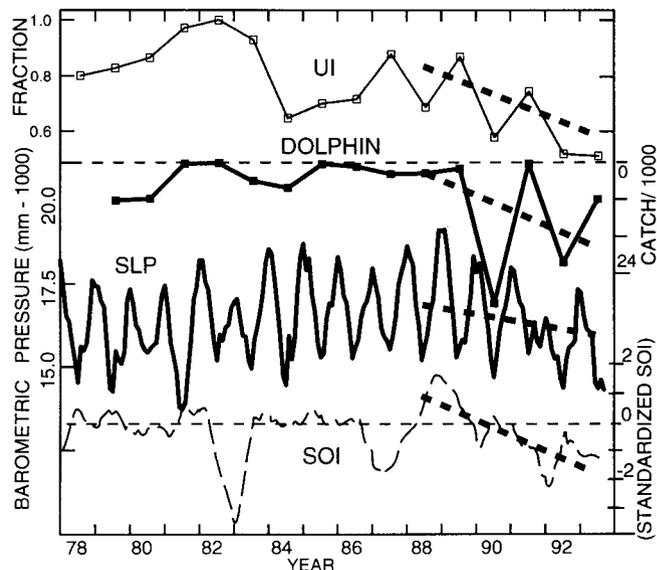


Figure 2. Comparison of atmospheric indices to total dolphin catch (filled squares). The scale giving numbers of dolphin caught per year, upper right, is inverted. Lower dashed line gives the five-month running mean of the standardized Southern Oscillation Index (SOI). Five-month running means of sea-level atmospheric pressure (SLP) at 30° N, 119° W are shown by the lower solid line. The top line gives average July–August upwelling index (UI) at 300° N, 119° W as a fraction of the highest value in the 1978–93 series. The endpoints of the thick dashed lines marking multiyear trend were determined by averaging all available values for 1987–89 and 1990–92.

off southern California in 1983 (table 1). Both total and southern California catch were anomalously large in 1990, a period of conspicuous drop in both the SOI and the average SLP at 30° N, 119° W (figure 2).

Relationships between the SOI and local SLP suggest that large-scale atmospheric adjustments are reflected in both measurements. Downward trends, or generally decreasing values of SOI [ $\delta(\text{SOI})/\delta t < 0$ ], corresponded to shortening of the annual range in SLP fluctuation. That is, the atmosphere off northern Baja California has a more tropical aspect (Gordon 1953) when  $\delta(\text{SOI})/\delta t < 0$ , as shown in 1979–80, 1982–83, and 1990–93 (figure 2). The lower annual maximum SLP during these periods suggests that the anticyclonic subtropical high is locally reduced in magnitude and that southward wind and consequent California Current forcing and coastal upwelling may be reduced (Reid et al. 1958; Parrish et al. 1981).

The upwelling index is more of a local atmospheric indicator than SOI and SLP because of local differencing (Bakun 1975), but some of the same features appear in all three atmospheric series (figure 2). There is a downward trend in upwelling index during 1989–93, coincident with a similar trend in the SLP and SOI series. Also note that two of the three lowest upwelling index values correspond to two of the best years of dolphin fishing. The upwelling index shows an overall drift to lower values, which is not evident in the other series.

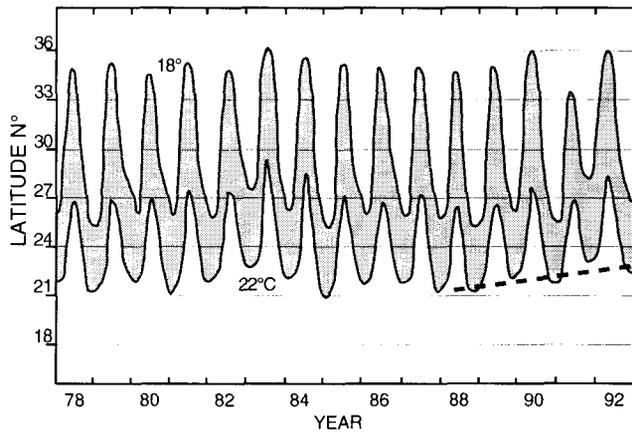


Figure 3. Smoothed envelope bounded by the 18°–22° isotherms at 10 m depth. Available temperature values from coastal areas extending up to 300 km offshore were smoothed with a five-point median filter (McLain et al. 1985). The dashed line marks an apparent multiyear trend beginning in 1988.

Regional oceanic effects of the oceanic and atmospheric connections from the equatorial atmosphere to the California coast are indicated in figure 3, which shows annual excursions of the 18°–22°C temperature envelope at 10 m depth. The latitude spanned by this envelope includes the 20°C isotherm and the northernmost edge of dolphin availability (Palko et al. 1982). The envelope may also be a good indicator of the fluctuating northern boundary of the subtropical biogeographic zone. Spatial scales up to three times the size of the Southern California Eddy are represented in figure 3.

Note that the three years when late-summer extension of the 18°C isotherm reached 36° N were the three years of the greatest California dolphin catch (compare figure 3 and table 1). In addition, the apparently decreasing southern excursion of the 22°C isotherm suggests the same multiyear event shown in figure 2. This trend is probably related to decreased California Current transport and coastal upwelling forced by the regional atmosphere and possibly an increase in downwelling, coastally trapped, wave energy emanating from the tropics (Clarke 1992; Norton and McLain 1994).

The anomalous features shown in figure 2 are reflected in figure 3. Statistical relationships among similar sets of parameters are given by Norton and McLain (1994).

### Ocean Temperature and Salinity (T-S) Relationships in the Southern California Bight during Dolphin Presence

When temperature and salinity values from hydrocasts are graphed with salinity as a function of temperature, the position and shape of the resulting curve—developed by connecting the points representing discrete depths—often identifies water sources. Temperature is on the vertical axis increasing upward

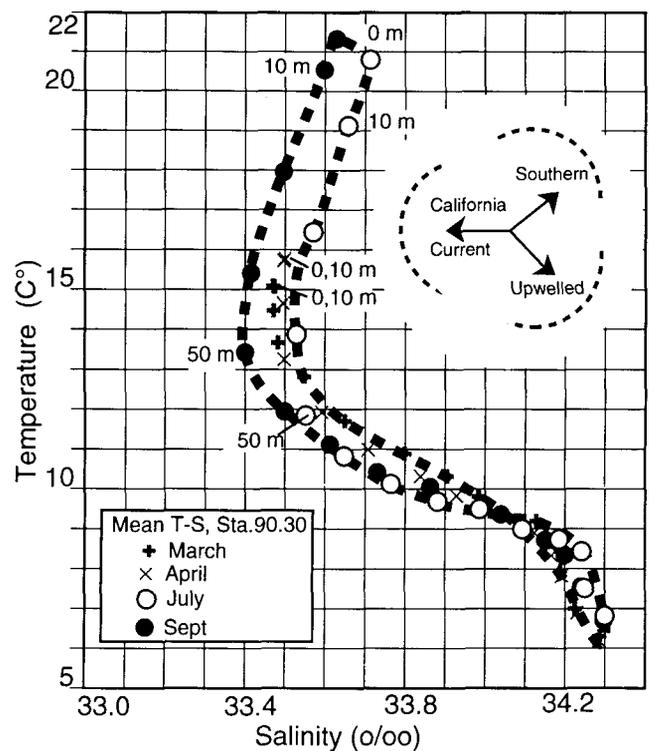


Figure 4. Mean temperature-salinity (T-S) curves at CalCOFI station 90.30. The dotted line encloses a mean seasonal T-S reference range. Selected depths are given in meters. The depths plotted, starting from highest temperature, are 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500 meters.

so that the shallowest depths are plotted toward the top (figure 4).

In this section we discuss T-S curves at station 90.30 (figure 1) during seasons of high dolphin catch, to see how local T-S characteristics relate to availability off southern and Baja California. Average (1950–78) T-S plots for March, April, July, and September are shown in figure 4. Selected depths are labeled. The dotted line enclosing all four curves gives a reference T-S range of monthly means. Note that above 14°C on the temperature scale, July has the highest salinity and is the right boundary of the mean T-S space. September has the lowest salinity and is the left boundary of the mean T-S space.

The diagram in the upper right of figure 4 shows the expected displacement of T-S curves when southern water, upwelled water, or water from the core of the California Current is brought into the vicinity of station 90.30 (compare to figure 1). The dashed arcs suggest considerable variation and even overlapping of T-S characteristics in water from the three sources. This diagram indicates that between April and July there is normally an influx of southern water at the surface, as shown by upward, to-the-right movement of the 0 and 10 m points. As fall approaches, this water is mixed with modified California Current water of lower salinity and higher

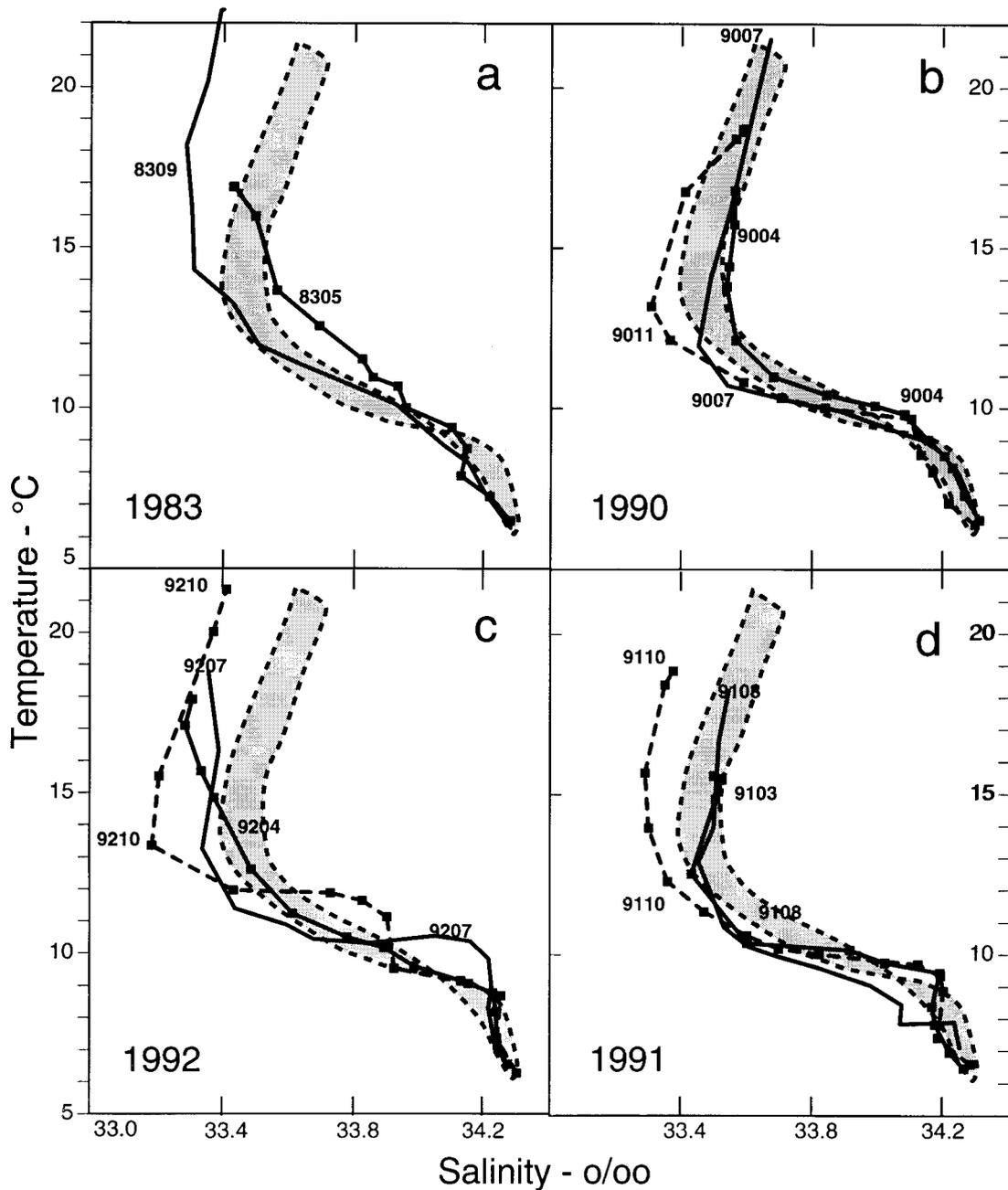


Figure 5. Temperature-salinity relationships derived from available CalCOFI data for station 90.30. Each curve is labeled with the CalCOFI cruise number (year and month). The dotted line encloses the mean T-S reference range shown in figure 4.

temperature, shifting the upper portion of the curve up and to the left. Local and regional insolation and evaporation are also important in the upper 10 m during summer and fall (Nelson and Husby 1983).

Temperature-salinity curves for 1983, 1990, and 1992—the best years for CPFV dolphin catch in southern California—are shown in figure 5.

In each year of good catch, the T-S curve shifts out of the top of the reference envelope during the July–September season. Part of this change is due to local heat

gain by water resident in the eddy, but the large-scale analysis shown in figures 2 and 3 suggests that other processes may be involved.

In 1983 and 1992 lower-salinity California Current water was transported to station 90.30 in the late summer. Summer and fall transport from the south is also indicated during years of high catch, as shown in the movement of the T-S curves (above 15°) from April to July in 1990 and 1992.

Figure 5d is representative of T-S curves at station

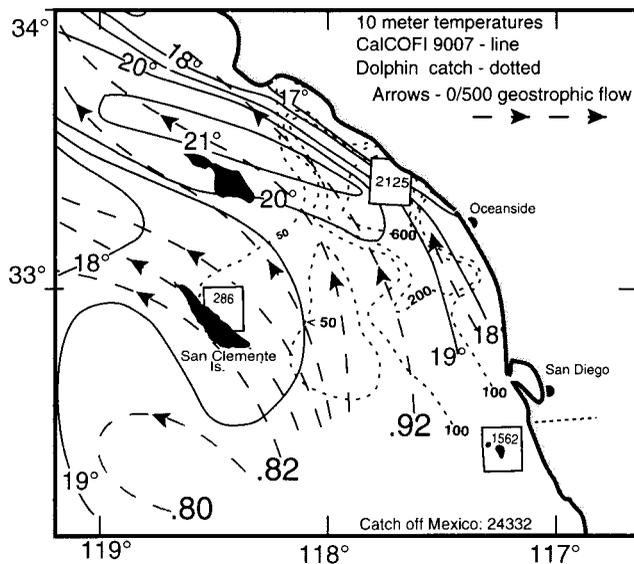


Figure 6. Spatial distribution of CPFV dolphin catch in 1990 (dotted lines), ocean temperature at 10 m (solid lines), and geostrophic flow (arrows) in the southern California catch area. Boxes show 0.1° areas with catch greater than 30 fish that were not contoured by standard conventions. Temperature at 10 m and dynamic height anomaly (dashed) are from CalCOFI survey 9007. The dynamic height anomaly contours are at 0.02 dynamic-meter intervals. Maximum geostrophic velocity was about 20 cm/sec.

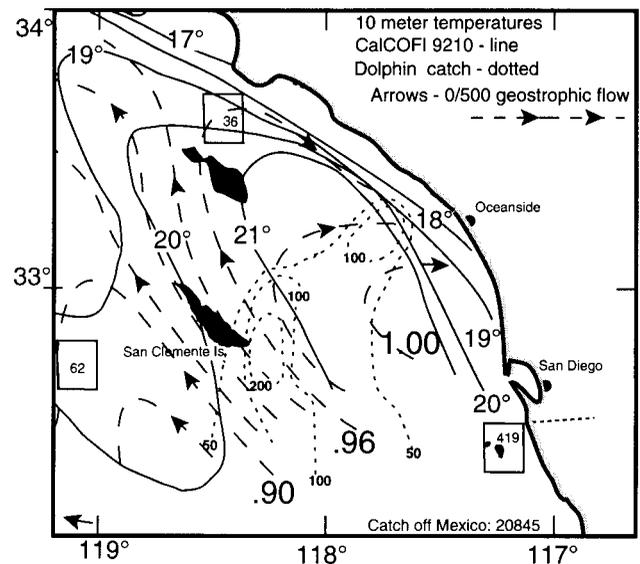


Figure 7. Spatial distribution of CPFV dolphin catch in 1992 (dotted lines), ocean temperature at 10 m (solid lines), and geostrophic flow (arrows) in the southern California catch area. Boxes show 0.1° areas with catch greater than 30 fish that were not contoured by standard conventions. Temperature at 10 m and dynamic height anomaly (dashed) are from CalCOFI survey 9210. Maximum velocity was about 22 cm/sec.

90.30 during a year of low dolphin availability (1991). There was little influx of low-salinity California Current water at mid-depths until late in the season and no evidence of southern water in the surface layers from March through August. All near-surface points were well below the average temperature.

### Distribution of Catch and Physical Processes within the Southern California Bight

During 1990 the greatest catch of dolphin off southern California was along the coast near Oceanside. It appears that water of high temperature (20°–22°C) and high dolphin concentration was maintained in the bight by advection from the south (figure 6).

California dolphin catch in 1992 was less than one-third the catch in 1990. Fish that were caught came from the vicinity of San Clemente Island. The catch area during 1992 coincided with maximum northward geostrophic flow at the surface (computed over 500 m reference level: 0/500) around San Clemente Island (figure 7). Geostrophic flow (0/500) in the channel between the islands and the mainland was greater in 1990. This may be related to dolphins' being closer to the mainland in 1990.

In 1990 and 1992 there were pools of 21°C water thicker than 10 m in the bight. In 1990 the 20° and 21° isotherms were closed on the south, which suggests that cooler water from the west side of the eddy was intermittently transported toward the coast, concentrating the dolphin near shore. Dolphin were apparently less concentrated in 1992, when the isotherms were open

to the south and the 19°C isotherm was removed to the northwest (compare figures 6 and 7). During 1992, there may have been higher concentrations of dolphin in less-well-searched areas offshore.

The T-S data from station 90.30 are consistent with figures 6 and 7 in showing different hydrographic patterns during 1990 and 1992. Low-salinity California Current water was available to the bight in 1992, but the higher salinity of 1990 shows that the California Current was then less directly available to the bight.

The data are less complete for 1983 and 1993, but certain conditions of the fishery and hydrography are worth noting. The catch pattern for 1983 was similar to that of 1990. Channel and mainland fishing areas appeared most important. From mid-July 1983 through the first week in August, the 10 m sea temperature at station 90.30 increased from 18.2° to 21.7°C. During 1993, geostrophic flow (0/500) into the channel between San Clemente Island and the mainland from the south was weak (~7 cm/sec), and the 21°C isotherm intruded to about 33° N. In August 1993, eastward geostrophic flow (0/500) was pronounced; T-S curves from April through October were 0.4‰ salinity to the left of the mean reference space; and the most dolphin were caught early in the fishing season (table 2).

### DISCUSSION

The years preceding and following 1991 were good catch years, but in 1991 only 1,301 dolphin were caught (table 1). Because the capacity of the fishing fleet was

comparable in these three years (1990, 1991, and 1992), it is of interest to examine physical variability during 1991. The atmospheric indices (figure 3) do not suggest a cool period of anomalously strong high-pressure systems, which would extend the cool eddy plume southward and push the subtropical biogeographic zone to the south. However, the cool 1991 period is clearly shown in figure 3 and in the T-S curves for 1991 (figure 5d). We might speculate that poleward-propagating, upwelling, coastally trapped waves were important in maintaining this cool period.

Upwelled water appeared to characterize the inshore limb of the eddy during the 1991 dolphin fishing season (figure 5d), leading to flatter dynamic topography. Maximum northward geostrophic flow at the surface was about a fourth of the maximum velocity shown in figures 6 and 7. Consequently, neither temperature nor northward current strength were conducive to dolphin entry into California waters.

Since more than 85% of the CPFV catch comprises dolphin less than one year old, it can be proposed that year-class success of the locally sampled population contributes significantly to CPFV dolphin catch. Thus 1983 is listed as a good catch year because of the relatively high catch in California waters (1,258), but the total catch during 1983 was relatively low (4,992). Certainly, many conditions of the subtropical biogeographic zone were shifted to the north during 1983 (Fiedler 1984; Brinton and Reid 1986; Squire 1987). The low overall dolphin availability during the 1983 season may have resulted from local reproductive failure during the previous year. Note that the southern excursion of the temperature envelope shown in figure 3 is reduced during winters preceding good dolphin catch (1980, 1983, 1984, 1990, and 1992), but it is also reduced for 1986 and 1987, which were not particularly good catch seasons. The atmospheric indicator series (figure 2) also suggest that 1986 and 1987 might have been good dolphin fishing seasons if the fish had been available to migrate northward. It is possible that the low availability of dolphin during 1986 and 1987 also resulted from reproductive failure in the locally sampled population.

The local importance of the 20°C sea-surface layer is verified by this study (figures 6 and 7). However, July–September mean surface temperatures at station 90.30 exceed 20°C (figure 4). From this it might be expected that dolphin would be more frequently found off southern California. The source and path of the warm water appears to be important. To import large numbers of dolphin, the continuity of the advective path from the region of dolphin presence to the waters off southern California must be continuous and temporally uninterrupted by periods (areas) of cooler water. In the eddy system, cool water (<19°C) during the dolphin

fishing season may result from a more intense California Current on the large scale and increased coastal upwelling on the local scale. Both processes are intensified by increased development of high-pressure systems in the eastern Pacific, and resulting southward winds along the coast (Reid et al. 1958; Hickey 1979).

The most productive CPFV dolphin fishing tactic is to cast live bait around floating objects, mainly kelp mats. Concentration and distribution of mats throughout the bight may be important in making dolphin available to CPFV anglers. During warm-water years (e.g., 1990) free-floating kelp fronds may be more abundant because of grazing by kelp bed invertebrates as the thermocline and nutricline are displaced deeper than the holdfasts, thus reducing the overall productivity of the kelp bed (Zimmerman and Robertson 1985; Tegner and Dayton 1991). Aggregations of drifting fronds (mats) will be found in areas of hydrographic convergence, which may be important in aggregating dolphin (Uda 1961) and bringing drifting kelp and feeding fish together.

Increased generation of eastern Pacific tropical cyclones is associated with the waning ENSO (Chan 1985). Increased tropical cyclone activity causes more frequent periods of swell (long gravity waves) that dislodge holdfasts and generate floating mats at kelp beds near the mainland and Channel Islands. These mats concentrate dolphin and may be a factor in the apparent greater abundance during ENSO periods.

## CONCLUSION

Dolphin availability to southern California CPFV anglers will depend on near (small-scale,  $<2 \times 10^2$  km) and distant (large-scale,  $>1.0 \times 10^3$  km) effects. Pacific basinwide perturbations, which weaken or displace the eastern Pacific high-pressure system and lead to less-intense California Current forcing and coastal upwelling, appear important in allowing dolphin to enter California waters from the south and west. Less-intense southward advection of California Current water will allow the subtropical biogeographic boundary to shift northward, opening the Southern California Bight to dolphin migration. Seasonal accumulation of warm water near shore and resulting increased northward geostrophic flow facilitates dolphin migration into the bight. Once dolphin enter the bight, upwelling conditions around the seaward banks and islands may be important in producing a cool plume that will limit the dolphins' westward movement and concentrate them in warm water near the mainland. An alternate but not exclusive scenario involves partial breakdown of the cool central portion of the eddy, which allows warmer, less-saline California Current water to enter from the west. When dolphin are found in this water, they may be less concentrated. Coastally trapped long waves emanating from the south

may be important in forcing local ocean processes and displacing biogeographic boundaries. Local factors affecting the production and distribution of free-floating kelp mats may also be important in making dolphin available to CPFV exploitation.

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