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BIOLOGY AND FISHERY OF DOLPHINFISH AND RELATED SPECIES. *E. MASSUTÍ and B. MORALES-NIN (eds.)*

Apparent habitat extensions of dolphinfish (*Coryphaena hippurus*) in response to climate transients in the California Current*

JERROLD G. NORTON

NOAA-Fisheries, Southwest Fisheries Science Center/ Pacific Fisheries Environmental Laboratory, Pacific Grove, CA, 93950-2097. E-mail: jnorton@pfeg.noaa.gov

SUMMARY: Dolphinfish, *Coryphaena hippurus*, a globally distributed, fast growing, predatory species has extended its habitat poleward off the west coast of North America in response to atmosphere-ocean climate transients that can be measured throughout the Pacific Ocean basin. Poleward habitat extension is measured by the availability of dolphinfish to southern California Commercial Passenger Fishing Vessel (CPFV) anglers. Before 1972 the annual CPFV dolphinfish catch during the July-October fishing season seldom exceeded a few hundred fish. Thereafter, more than 10^3 dolphinfish were taken in 23 of the next 25 seasons. The next shift was in 1990 when catch exceeded 3.0 x 10^4 fish. More than 2.0 x 10^4 fish were reported in three of the next seven seasons. The apparent habitat extension coincides with increased ocean temperatures, forced by increases in North Pacific cyclogenesis and increases in downwelling coastal-trapped long wave transmission from the equatorial ocean. Interannual analysis shows that habitat expansion is associated with a decrease in upwelling off northern Mexico, which may be locally or remotely forced. Dolphinfish habitat shifts poleward in response to Pacific climate transients, reflecting global environmental trends. If subtropical ocean surface layers continue to warm throughout the world, as observed off southern California and northern Mexico, a global increase in the dolphinfish habitat is expected.

Key words: *Coryphaena hippurus*, dolphinfish, climate transients, California, Mexico, recreational fishery.

INTRODUCTION

Dolphinfish, *Coryphaena hippurus*, are permanent residents of more than 30 percent of the ocean's surface layers and are found seasonally in an additional 15 percent of the world's oceans. Industrial, artisanal and recreational fisheries occur throughout their permanent and seasonal ranges (Palko *et al*., 1982; Hamm *et al*., 1993; Massutí and Morales-Nin, 1997; Lleonart *et al*., 1999; Sakamato and Kojima, 1998). Off southern California, dolphin are caught by Commercial Passenger Fishing Vessel (CPFV) recreational anglers in the warmest months (July-October) of warmer years (Table 1). Sexual maturity and lengths exceeding 90 cm occur in the first year. Successful spawning appears limited in poleward extent by the 23-24°C sea surface isotherm (Palko *et al.,* 1982; Ditty *et al*., 1994). Habitat extension into temperate waters off southern California appears limited by surface isotherms of about 19-20°C (Palko *et al.,* 1982; Goldberg and Aguilar, 1985; Norton and Crooke, 1994).

Throughout the dolphinfish's range, peak catch is seasonal (Oxenford and Hunte, 1986; Patterson and

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TABLE 1. – Annual CPFV catch of dolphinfish, mean temperature, number of CPFV reporting and angler trips per boat per year. Data assembled from State of California Department of Fish and Game Annual Report of Statewide Fish Landings by the CPFV fleet (1948 -1996); Young, 1969; Leet *et al.*, 1992; and California Department of Fish and Game, Long Beach. Symbols: na, not available; { }, estimated.

Year	Number dolphinfish landed by CPFV	Mean annual temp. (6mT) °C	Total boats reporting	angler trips/ boat/ year
48	0	15.6	71	860
49	0	16.1	77	834
50	1	16.0	99	758
51	0	15.9	93	1039
52	2	15.3	98	1105
53	0	15.8	99	1273
54	12	16.5	101	1353
55	0	16.3	92	1394
56	2	15.9	85	1658
57	2805	16.8	75	2483
58	0	17.2	64	2092
59	4	17.7	63	2268
60	1	15.8	70	2150
61	3	15.8	62	2426
62	0	15.7	59	2549
63	139	16.5	61	2495
64	4	16.0	60	2840
65	341	16.1	62	2576
66	45	16.5	83	2553
67	198	16.5	82	2583
68	929	16.5	93	2553
69	170	16.3	108	2175
70	103	16.0	101	2600
71	188	15.7	128	1671
72	206	16.3	116	1985
73	5941	16.1	117	1439
74	1967	15.8	102	2161
75	604	15.2	87	2317
76	6509	17.0	79	2393
77	4300	16.9	86	2481
78	2330	17.1	99	2399
79	9184	16.2	106	2180
80	8840	16.3	105	1876
81	1281	17.1	88	2335
82	1099	16.8	84	2135
83	4992	17.7	91	2237
84	6532	17.6	98	2221
85	1307	16.6	97	2182
86	1866	17.2	91	2147
87	3518	17.4	81	2367
88	3349	16.4	94	2144
89	2341	16.6	92	2218
90	31548	17.3	92	2312
91	1000	16.4	64	2466
92	22727	17.6	72	2339
93	8952	17.9	59	2638
94	5018	17.5	68	2449
95	5022	17.4	75	2199
96	21939	17.5	76	2651
97	28606	{17.9}	na	na

Martinez, 1991; Hamm *et al.,* 1993; Oxenford, 1999; Kraul, 1999). These changes in availability may be due to good localized survival followed by dispersal into seasonally available habitat. Enough adults remain in or return to core areas where initial survival is adequate to reproduce the dispersing population. When reproductive areas are displaced geographically, they will be inhabited by individuals originating in areas of previously successful gamete formation and growth. Annual mortality rate may exceed 90% in the western Atlantic (Mahon and Oxenford, 1999). Dolphinfish are prey for marlin, *Makaira* spp.; epipelagic sharks; swordfish, *Xiphias gladius*; and large tuna, *Thunnus* spp. (Parin, 1970; Brock, 1984; Friedlander, 1995).

The results presented below suggest that when physical habitat boundaries expand, dolphinfish move into the newly available habitat. In captivity, dolphinfish have a high degree of intraspecific aggression and may spawn daily for periods exceeding 40 days. In the ocean these characteristics may augment physical mechanisms of population dispersal.

Norton and Crooke (1994) examined interannual fluctuation in dolphinfish availability to southern California CPFV anglers during the 1978-1992 seasons. Dolphinfish enter California waters under conditions that include elevated ocean temperatures and increased onshore and poleward coastal ocean transport. Southern California CPFV dolphinfish catch is predominately within 200 km of Oceanside and San Diego as shown by the heavy broken line in Figure 1. Overall, the largest percentage of catch is in August, but the maximum may occur in July (as in 1993) or in September (as in 1983). Fishing frequently continues into October (as in 1990 and 1993). Large-scale environmental events that apparently increase dolphinfish abundance off southern California appear related to regional decreases in eastern Pacific subtropical high pressure system (STH) development (Norton and Crooke, 1994). When the STH is less intense, there is less southward wind along the coast. Consequently, California Current southward transport (Chelton *et al.,* 1982) and coastal upwelling are decreased and the inshore counter current brings anomalously warm water into the southern California Bight (Lynn, 1967; Lynn and Simpson, 1990; Norton and Crooke, 1994).

The distribution of CPFV dolphinfish catch and surface layer characteristics of the southern California Bight during the fall of 1992, a year of higher CPFV dolphinfish capture, are shown in Figure 2, which is reproduced from Norton and Crooke (1994). The physical data are from California Cooperative Oceanic Fisheries Investigations (CalCOFI) routine ocean sampling off southern California. Geostrophic flow was calculated from analyses of density in the three-dimensional ocean study area during October 1992 (Anon., 1997). The 21°C, 10m

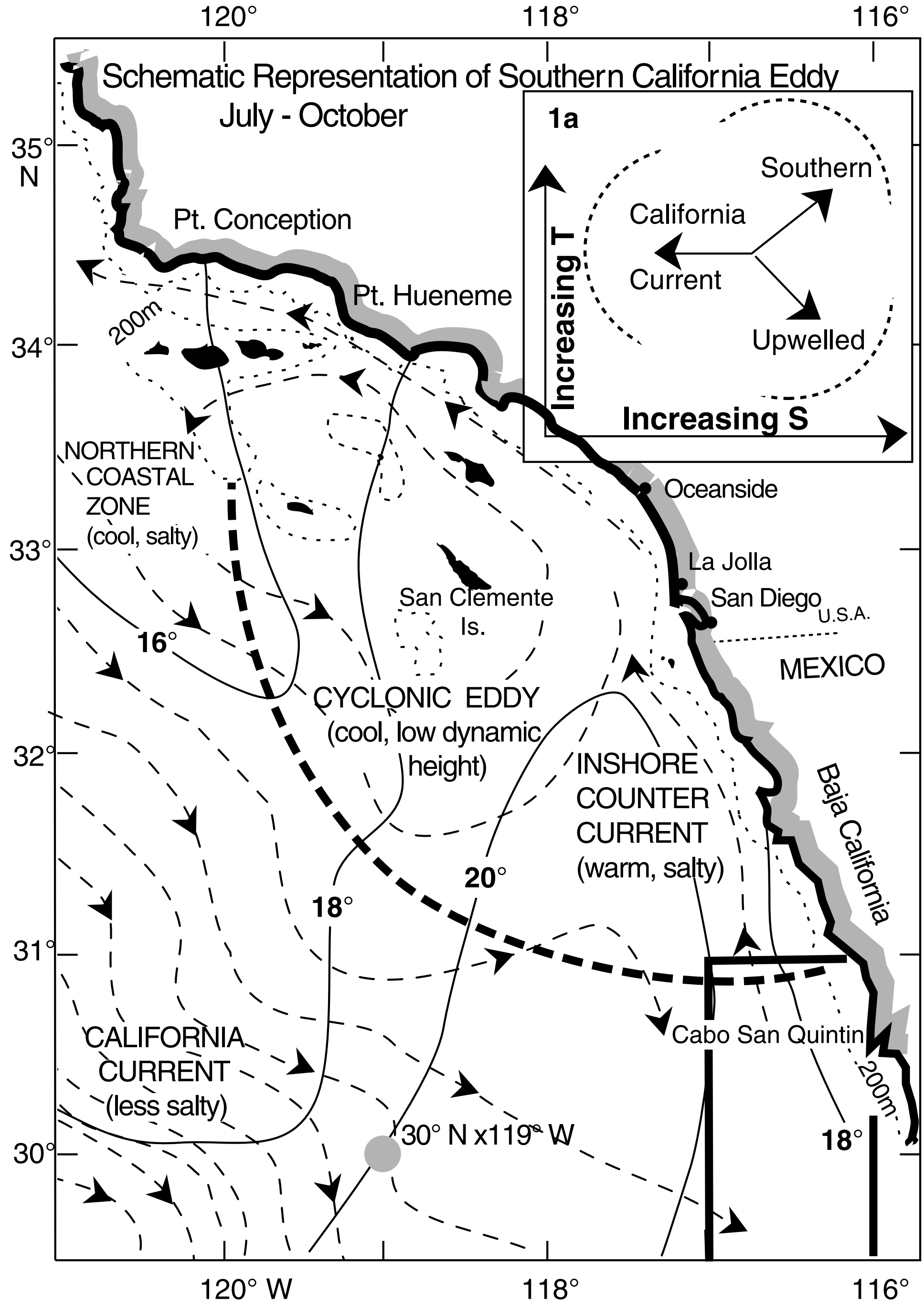

FIG. 1. – Diagram of the typical Southern California Eddy processes. Broken lines show contours of dynamic height (500 m reference level) with average spacing of 0.02-0.04 dynamic meters, arrows show flow direction and contour interval indicates speed. Solid lines show contours of ocean temperature at 10 m depth. The two hundred meter isobath is dotted. Heavy broken line shows average range of CPFV seeking pelagic gamefish. Rectangle at lower right shows ocean area sampled for sea surface temperature. The insert (Fig. 1a) shows trends in ocean temperature and salinity associated with increasing influx of various surface layer water types (see text for additional details). Adapted from Reid *et al.*, 1958; Lynn, 1967; Peláez and McGowan, 1986; Lynn and Simpson, 1987 and Anon.,1997).

isotherm extends into the channel between San Clemente Island and the mainland, well to the north of the main harvest area off northern Mexico. Largest catches off southern California during 1992 were from the offshore area of strongest northward geostrophic flow (Fig. 2).

Seasonal distribution of dolphinfish off the west coast of Mexico, north of 20°N, is given by the CalCOFI ichthyoplankton study, and summarized by Moser *et al.* (1994) in Figure 3. Larval distributions over the period from 1956 to 1984 show that the greatest and farthest northward extent of larvae

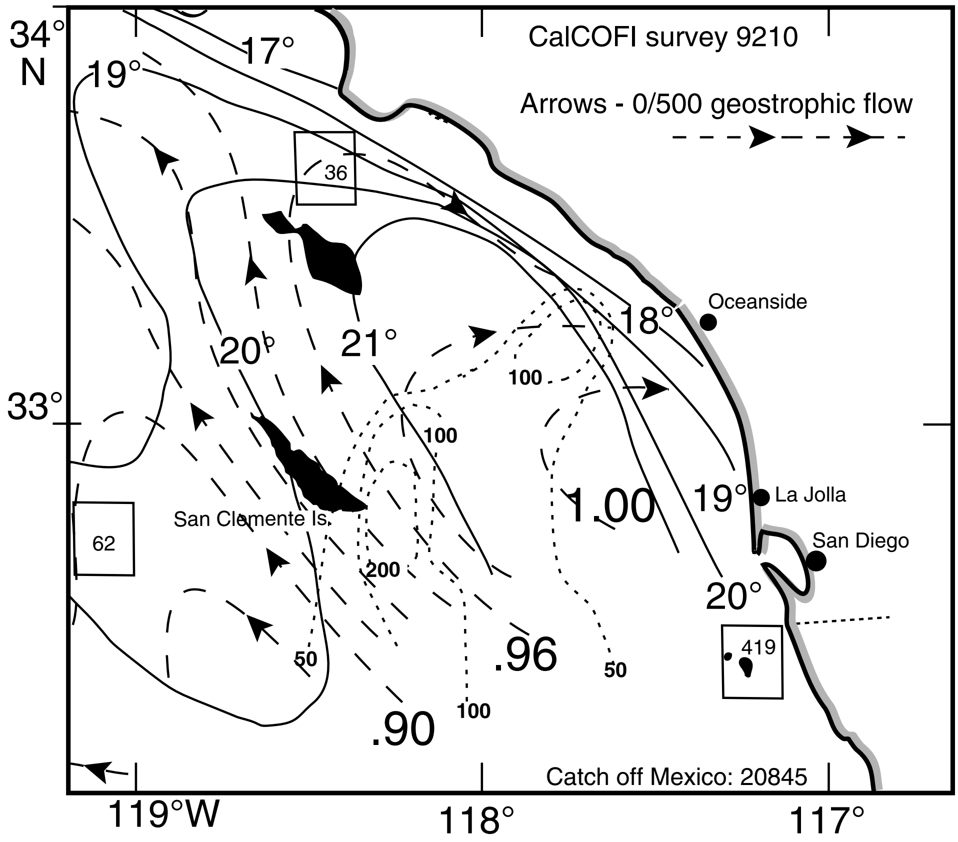

FIG. 2. – Spatial distribution of total CPFV dolphinfish catch in 1992 (dotted, small numbers), ocean temperature at 10m (solid), and geostrophic flow (arrows). Boxes show 0.1° areas with catch greater than 30 fish that were not contoured by standard conventions. Temperature at 10 m and dynamic height anomaly (dashed) are from CalCOFI survey 9210. Maximum velocity (about 22 cm/sec) is shown by more closely spaced contours. Figure from Norton and Crooke, 1994.

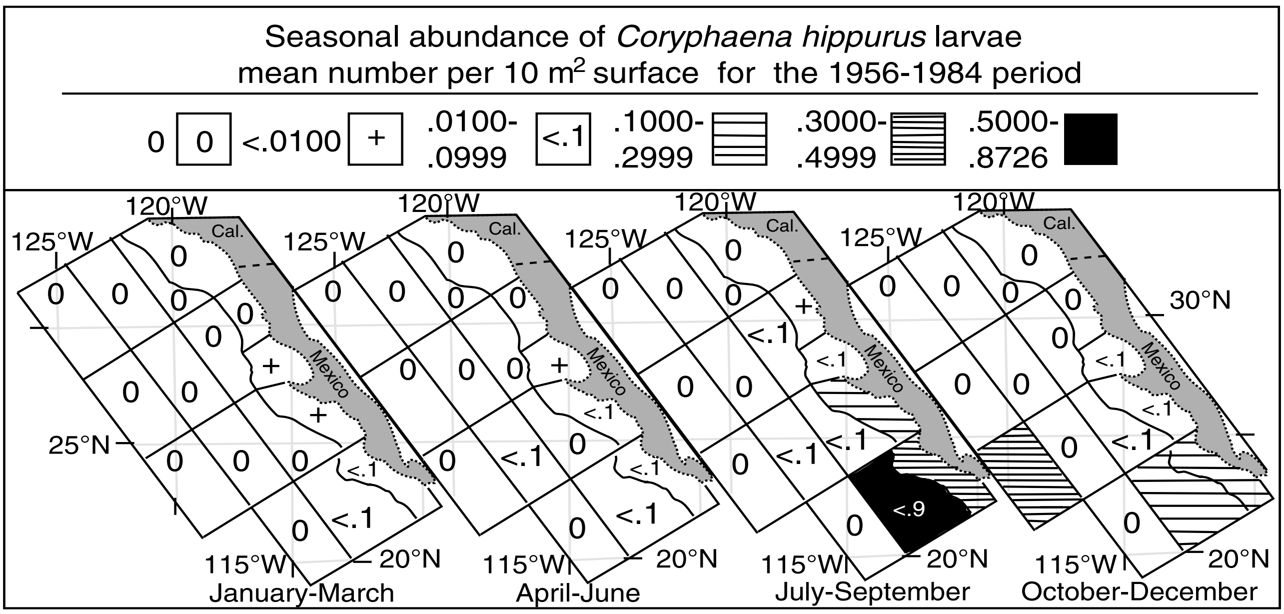

FIG. 3. – California Cooperative Oceanic Fisheries Investigations (CalCOFI) sampling of seasonal distribution of dolphinfish larvae off southern California and northern Mexico. Symbols show abundance (number per 10 m^2) in each area in each season averaged over 29 years. Fewer than 1000 total larvae were found in the 29-year period. Redrawn from Moser *et al*., 1994.

occur during the July-September quarter, when dolphinfish are most available to CPFVs (Moser *et al*., 1994; Norton and Crooke, 1994). During the last half of the year the greatest number of larvae have been found offshore (Fig. 3). Coastal upwelling along the coast of Mexico cools surface waters inshore (Lynn, 1967), apparently making conditions less habitable to dolphinfish. This report expands the study of Norton and Crooke (1994) and examines recent years of high dolphinfish catch by CPFVs in the context of the last 50 years of North Pacific ocean climate.

Pacific basin-scale forcing of the California Current region

Observational and modeling studies indicate that a large percentage of California Current temperature variability is due to remote oceanic forcing from the tropics and from local atmospheric forcing. The terms "local" and "remote" are used in a large-scale sense to describe forcing and response processes that may effect the entire California Current system. Local atmospheric forcing acts on scales exceeding 1000 km and is associated with the semi-permanent subtropical high (STH) and Aleutian low atmospheric pressure systems. Remote forcing is through the ocean and is thought to be the result of coastal-trapped internal (baroclinic) long waves propagating from the south. Each of these large-scale processes force upwelling and downwelling as the ocean thermostructure is elevated or depressed, respectively. Direct, atmosphere-ocean forcing and response processes occurring on scales of less than 1000 km are termed "topical."

Anomalously warm years in the coastal California Current frequently correspond to El Niño conditions in the eastern equatorial Pacific Ocean (Enfield and Allen, 1980; Chelton *et al*., 1982; McLain *et al*., 1985; Rienecker and Mooers, 1986; Enfield, 1987; Chelton and Schlax, 1996; McGowan *et al*., 1998). Ocean model studies show a mechanical link between the coastal California Current and the tropical ocean through coastal-trapped long waves that propagate cyclonically along the eastern ocean boundary. As the coastally trapped long waves traverse the coastal zone, they lose energy to westward propagating Rossby waves that spread warming and cooling signals westward (Rienecker and Mooers, 1986; Chelton and Schlax, 1996; Meyers *et al.,* 1996).

However, much of the supposed El Niño variation in temperature and sea level in the coastal California Current region (Fig. 1) can be associated with the effects of anomalously intense North Pacific Aleutian Low atmospheric cyclogenesis (Emery and Hamilton, 1984; Huyer and Smith, 1985; Simpson, 1984, 1992; Trenberth, 1995), which is frequently augmented during El Niño years (Bjerknes, 1966; Wallace and Gutzler, 1981). The Aleutian Low pressure system may also intensify anomalously when the tropical El Niño is not evident (Douglas *et al.,* 1982; Norton *et al.,* 1985). El Niño events and anomalous warming have received the most attention in scientific and popular literature, but recent work by Norton and McLain (1994) and Meyers *et al*. (1996) shows that in the California Current region many of the relationships apparent in warming cycles are in a reverse sense part of California Current cooling cycles as well. That is, downwelling coastal-trapped long waves will warm the coastal zone's surface layers and upwelling coastal-trapped waves will cool the coastal zone's surface layers (Pares-Sierra and O'Brien, 1989; Norton and McLain, 1994; Meyer *et al*., 1998).

Norton and McLain (1994) showed that vertically coherent regional warming events in the California Current region occurred only during moderate or strong tropical El Niño periods, as defined by Quinn *et al*. (1987). These vertically coherent temperature changes, occurring in surface and subsurface layers, are positively correlated (correlation coefficient squared: $r^2 > 0.48$) with western tropical Pacific sea level atmospheric pressure (SLP). The inference is that this vertically coherent California current warming is the result of downwelling coastal-trapped waves propagating into the coastal California current region from the tropical ocean (Enfield, 1987; Pares-Sierra and O'Brien, 1989; Norton and McLain, 1994; White, 1994; Meyers *et al*., 1996).

Norton and McLain (1994) also found that temperature changes corresponding to local large-scale atmospheric forcing over the northeastern Pacific affect only the upper 100 m of the ocean, consistent with changes expected from seasonal large-scale Ekman transport, vertical mixing and surface heat exchange (Enfield and Allen, 1980; Haney, 1980; Rienecker and Mooers, 1986; Trenberth, 1995; Ramp *et al.,* 1997). Ocean temperature changes below 100 m are not significantly correlated to changes in the local atmosphere. Norton and McLain (1994) found that seasonal change in SLP over the northeastern Pacific is negatively correlated with changes in temperature in the California Current ($r^2 > 0.38$). This surface layer warming is forced by cyclonic winds that blow from the south and southwest transporting warmer water onshore. Isotherm and isopycnal depression next to the coast (downwelling) promotes northward transport and additional warming of the California Current environment (Emery and Hamilton, 1984; Huyer and Smith, 1985; Simpson, 1984, 1992; Norton and McLain, 1994; Meyers *et al*., 1998)

Off southern California and northern Mexico, the subtropical atmospheric high pressure system (STH) dominates atmospheric forcing of ocean processes during the season of dolphinfish availability. In general, a more developed STH will correspond to increased coastal zone upwelling and cooling (Chelton *et al.,* 1982).

Ocean-to-atmosphere heat transfer associated with sea surface temperature anomalies in the equatorial Pacific Ocean lead to increased cyclogenesis over the northeastern Pacific Ocean (Bjerknes, 1966; Horel and Wallace, 1981; Rasmusson and Wallace, 1983; Norton and McLain, 1994). Consequently, time series of surface oceanic and atmospheric variables from the North Pacific and the tropical Pacific may have considerable common variability.

In the Norton and McLain (1994) study, remote (western tropical Pacific) and local (northeastern Pacific) atmospheric forcing patterns were represented by interannual SLP changes at Darwin, Australia (12.4°S x 130.9°E) in the western tropical Pacific and in the northeastern Pacific (45°N x 165°W) respectively. SLP time series from these locations are used in the present study.

The California Current System and the southern California Eddy

The California Current System (CCS) is the eastern limb of the anticyclonic subtropical oceanic gyre. The subarctic water of the CCS is characterized by relatively low salinity and temperature. As the CCS meanders southward, mixing and dilution increase temperature and salinity, but a low salinity core is evident to at least 24°N (Reid *et al.,* 1958). Off southern California, salinity minima mark the core of California Current transport of modified subarctic water southward (Lynn and Simpson, 1987).

The southern California Eddy is a permanent, topical scale feature of the CCS coastal zone between 30° and 35°N (Reid *et al.* 1958; Lynn and Simpson 1987). It is produced by atmospheric and oceanic effects associated with southern California Bight topography. At Pt. Conception, the generally north-south coastline bends abruptly to a nearly east-west orientation, then veers back to a more north-south direction south of Pt. Hueneme, describing the southern California Bight (Fig. 1).

The southern California Eddy (Eddy) is formed as cool coastal zone water, characteristic of central California, separates from the coast at Pt. Conception producing a coastal zone extension seaward of the banks and islands to the south. Persistence of cooler, more saline, upwelled water west of the banks and islands is augmented by the cyclonicity of the Eddy associated with the southward flowing California Current transition zone to the west and the inshore northward flowing counter current to the east, within the Bight (Fig. 1). The southern California Eddy is evident in most physical (Reid *et al.,* 1958; Lynn, 1983; Lynn and Simpson, 1987) and biological (Bernal and McGowan, 1981; Peláez and McGowan, 1986; Brinton and Reid, 1986) measurements made from the surface to depths exceeding 200 m. The cool water plume (e.g. 18°C isotherm in Fig. 1) may extend more than 500 km equatorward under the influence of persistent southward winds associated with strong seasonal development of the STH. However, the Eddy normally extends south to Cabo San Quentin where the CCS transition zone may approach to within 50 km of the coast (Fig. 1). The coastal area from Cabo San Quentin to the U. S. border supports the most productive CPFV dolphinfish harvest. However, if coastal upwelling is persistent in this area, surface layers will be cooled and less suitable as a dolphinfish habitat (Lynn, 1967; Norton and Crooke, 1994).

Inshore of the cool, more saline plume of upwelled water, surface geostrophic flow (computed from a reference level of 500 m *(*0/500) is northward, into the Bight (Lynn and Simpson, 1990). As southward winds and coastal upwelling slacken in summer and fall, the inshore counter current increases and warmer water flows into the Bight from the south and southwest, increasing inshore dynamic height (Lynn and Simpson, 1987, 1990). Late summer and early fall bring the highest sea surface layer temperatures and highest dolphin concentrations toward the Bight, when surface layer temperatures exceed 20°C (Fig. 2). As the Eddy becomes anomalously warm in the summer and fall of warm years, the development of physical conditions associated with the subtropical biogeographical zone may allow southern species to enter the

Bight from the south and southwest (Longhurst, 1967; Brinton and Reid, 1986; Lea, 1998; McGowan *et al.,* 1998).

Two areas of enhanced coastal upwelling provide topical barriers to the expansion of dolphinfish habitat into the range of southern California CPFVs. When southward advection and upwelling around Pt. Conception and the offshore islands are strong, the cool, high salinity, freshly upwelled water is carried southward (Peláez and McGowan, 1986), providing a cool water barrier to dolphinfish entry from the west (Fig. 1). If there is also vigorous upwelling off northern Mexico (Lynn, 1967; Lynn and Simpson, 1987), there will be a cool water barrier to dolphinfish entry from the south. In addition, the tilting of the isotherms and isopycnals upward toward the coast (upwelling) will promote southward current flow (Chelton *et al.,* 1982), carrying dolphinfish habitats southward and offshore.

Surface water from the south will be more saline than offshore water and it will be warmer than recently upwelled water (Lynn, 1967; Lynn and Simpson, 1987; Norton and Crooke, 1994). These relationships are diagrammed in Figure 1 (upper right, Fig. 1a). Perpendicular arrows show increasing temperature and salinity. Radial arrows show changes in temperature and salinity that will indicate transport of different water types into the fishing grounds off southern California. Present use of these temperature-salinity relationships refers to the 5-50 m surface layers. Topical heating can obscure temperature-salinity relationships at the surface during periods of maximum insolation.

In the following sections, climate and dolphinfish availability transients and their possible linkages are examined from decadal to interannual and from basin-wide to topical perspectives. The 50-year series presented below show many of the same features as the time series presented in support of anthropogenic climate change hypotheses (Houghton *et al*., 1996). When considered this way, the present study is also an examination of physical-to-biological coupling expected during population range extensions due to global climate changes.

DATA AND METHODS

Dolphinfish catch records for the 1948 -1996 period from the State of California Department of Fish and Game CPFV log book data base provide numbers of each species caught per 0.1° x 0.1° geographical area off southern California. (Table 1). CPFVs frequently travel into waters off northern Mexico in search of pelagic gamefish (Thomson and Crooke, 1991). The number of boats from San Diego and Oceanside contributing to the California Department of Fish and Game log book data base and the average number of angler trips per boat during each year is shown in the last two columns of Table 1. More than half the angler trips are taken during the July-October period of dolphinfish availability (Thomson and Crooke, 1991). Logbook data for fish taken off Mexico are within areas of 1.0 x 10^4 km^2. Catch data for 1997 were obtained from Steve Crooke of the California Department of Fish and Game, Long Beach.

Total reported CPFV catch per year was used as the measure of dolphinfish abundance for three reasons. First, these values are obtained with minimum calculation and estimation. Second, gross adjustment for unit effort does not change the character of the catch time series. Adjusted and unadjusted catch series are highly correlated, r^2=0.98. Third, Table 1 shows that the 1970-1997 period examined most closely below contains an apparent dolphinfish abundance increase of more than 1000% while apparent effort decreased about 40%. The growth period in numbers of CPFV anglers was from 1948 to 1970, when there was nearly a 500% increase in angler trips (Table 1).

The seasonal edge of the dolphinfish habitat off southern California and northern Mexico may represent a steep environmental gradient that requires little increase in CPFV range and little geographical environmental shift to increase dolphinfish abundance. Table 1 shows that the number of boats has decreased 18% during 1989-1996 as compared to the previous eight years. At the same time, the number of angler-trips on each boat per year has apparently increased 8%. Available information does not show whether CPFVs are carrying more passengers per trip or they are making more trips per season. If the CPFVs are carrying more passengers per trip, it may imply an increase in average CPFV size. Larger CPFVs may have greater range.

Several observations suggest that increased dolphinfish catch since 1970 is not the sole result of CPFVs traveling farther. First, Norton and Crooke (1994) found that more than eight percent of the total catch was taken north of the Mexican border in 1983, 1984, 1990, 1992 and 1993 with more than 20 percent of the total catch taken north of the Mexican border in 1983 and 1990. This indicates that availability is not completely dependent on CPFV traveling farther into Mexican waters. Second, in 1957 almost 3.0 x 10^3 dolphinfish were taken during the initial phases of an intense El Niño warm water period (Sette and Isaacs, 1960). The 1957 catch, which is comparable in magnitude to catches that occurred frequently after 1973, was not dependent on a CPFV fleet with post-1970 characteristics. Third, Norton and Crooke (1994) found that more than 4.0 x 10^3 of the fish taken during the 1990 season were caught within range of a fleet with the characteristics of the 1965 CPFV fleet described by Young (1969). Fourth, economic factors keep practical CPFV range from increasing in proportion to possible range. Greater range increases trip expenses for the boat operator and angler. Greater angler expense may make CPFV excursions less desirable when compared to other recreational options. Shorter excursions are more desirable to operators because revenue is increased when more passengers can be accommodated comfortably on each trip. When these circumstances are considered along with the following environmental analyses, it appears unlikely that the 50-year trend increasing dolphinfish availability (Table 1) is due to changes in the CPFV fleet alone. The non-target status of dolphinfish also reduces the impact of CPFV fleet characteristics on catch (Norton and Crooke, 1994), but the question of range is worth investigation when appropriate information becomes available.

Monthly mean sea surface temperature (SST) off northern Mexico and atmospheric sea level pressure (SLP) data were obtained from the U.S. Navy Fleet Numerical Meteorology and Oceanography Center's (FNMOC) surface observations data set and resulting SLP analyses. Each monthly mean SST (°C) for the area off Mexico (Figure 1, box at lower right) is composed of 10 to 30 observations. Analyzed SLP (millibars or mb) fields are produced every 6 hours by FNMOC from hundreds of northern hemisphere fixed station and transiting ship observations. These were first averaged into monthly means, then five- and 24-month centered running means were derived. Periods of 20 to 30 months are coincident with the dolphinfish life cycle (Oxenford, 1998).

Seasonal mean values for the Southern Oscillation Index (SOI) were obtained from the Climate Analysis Center (NMC/NOAA). SOI values are five-month running means of the difference between the standardized sea level pressure anomalies at Tahiti (17.5°S x 149.6°W) and Darwin, Australia, (12.5°S x 130.9°E). SOI values are well correlated with atmospheric, oceanic and biological anomalies throughout the world (Gill, Chapter 11, 1982; Trenberth and Shea, 1987). Monthly mean SLP values for Darwin were also provided by the Climate Analysis Center. Running means were estimated to the ends of the monthly mean series by using available series values. For five and 24-month running means, the last value is the mean of the last three and the most recent 11 monthly mean values respectively.

Monthly mean values of SLP and an upwelling index (UI) for the northeastern Pacific were derived from the monthly average of available FNMOC analyzed SLP fields (Bakun, 1973; Schwing *et al.*, 1996). The SLP is a general atmospheric parameter that will reflect changes in air-sea heat exchange, wind stress, wind stress curl forcing, and wind-forced mixing. The UI is computed from the on-offshore SLP gradient at three degree increments of latitude along the west coast of North America from 21°N to 60°N. This is a transport index with units $m^3 s^{-1}$ (100m of coastline)$^{-1}$ (Bakun, 1973). Although the interpretation of the UI may be more complex than the terminology would imply, it is more closely related to topical Ekman transport and coastal upwelling than SLP. However, SLP series may be more indicative of combined large-scale forcing (Norton and McLain, 1994).

Temperature (6mT) and salinity (6mS) measurements were taken within a meter of the bottom, 6 m below mean lower low water, at the end of the Scripps Institution of Oceanography (SIO) Pier, 23 km north of San Diego Bay at La Jolla, California (Fig. 1). These data are collected 20 to 31 times a month and archived by the Marine Life Research Group, SIO. The 6mT (°C) and 6mS (practical salinity units or psu) data provide continuous series of monthly means over the intervals examined in this report. Using the elementary T- distribution test for differences between means of intervals exceeding five years, differences in mean SLP and 6mT were found significant ($p < 0.05$) if the difference exceeded 0.2-0.3 mb or °C.

La Jolla shore temperature (6mT) as dolphinfish habitat indicator

To examine the utility of 6mT data in representing dolphinfish habitats off northern Mexico, monthly 6mT was compared to SST monthly means obtained from the rectangle 29-31°N 116-117°W off northern Mexico (Fig. 1). Figure 4 shows contours of r^2 for the positive correlation of these two ocean

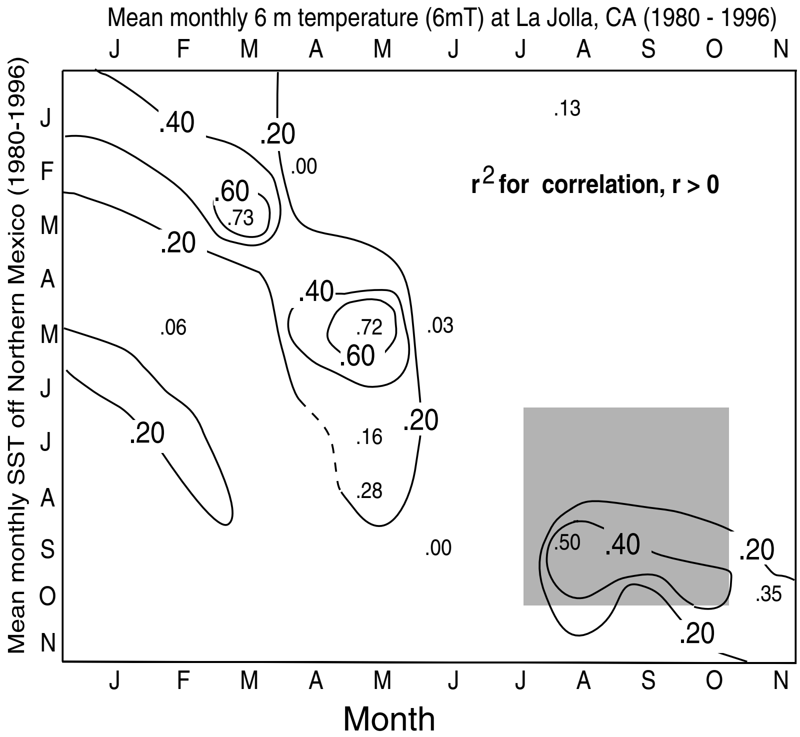

FIG. 4. – Contours of the time-dependent relationship between monthly mean temperature at the La Jolla, California shore station and monthly mean temperature from a rectangle with the 29°N 116°W to 31°N 117°W diagonal for 1980-1996 (Fig. 1). Squared correlation coefficients (r^2) are contoured at 0.20 intervals. r^2 values are used rather than r values to simplify plotting and accentuate gradients. The July-October CPFV fishing season, when more than 80% of the fish are landed, is shaded. Correlation is positive for all $r^2 > 0.02$. For $r^2 > 0.3$, $p < 0.05$.

temperature measurements. The maxima in Figure 4 suggests that from August through May much of the variability in SST off northern Mexico is reasonably represented by 6mT. In general the variability is in phase, as shown by diagonal contours. An exception to the diagonal relationship is the relation between May 6mT and April, May, June and July SST off northern Mexico. Because of greater continuity and timeliness, 6mT data are preferred over northern Mexico SST in the following discussions. The apparent June and July breakdown in the relationship between 6mT and SST off Mexico (Fig. 4) is the result of differences in horizontal and vertical distribution of heat from insolation and coastal upwelling at the two measurement sites.

Regression relationships

Regression statistics are used in the descriptive or exploratory sense to indicate relationships among available data series rather than as tests of rigid hypotheses (e.g. Velleman and Hoaglin, 1981). Linear regression equations with dolphinfish catch as the dependent variable and two independent physical environmental variables show the relation between dolphinfish catch, 6mT and UI. Regression comparisons are presented as adjusted r^2 values and the variance ratio, F. The contribution of each independent variable in the regression equations is examined using the T-statistic, $T = c_n/SE_n$, where c_n is the variable coefficient and SE_n is the standard error of the coefficient. Variable series may be scaled by dividing all values by the series maximum, which does not change regression relationships.

When time series are compared, r^2 values may be inflated due to shared frequencies and autocorrelated sequences. One method of examining the effects of serial autocorrelation on r^2 is to take the backward difference of each series (Box and Jenkins, 1976) and reform the regression equation. Interannual or backward differences DS_{yr}, for each year (yr) are derived from the series, S_{yr}, by subtracting the value for the previous year, S_{yr-1},

$$DS_{yr} = S_{yr}-S_{yr-1.} \qquad (1)$$

Differencing is effective in reducing series low frequency autocorrelation and assessing the effects of trend on r^2 values. Differencing emphasizes year-to-year changes. These are integrations of processes causing the observed changes. (Norton and McLain, 1994).

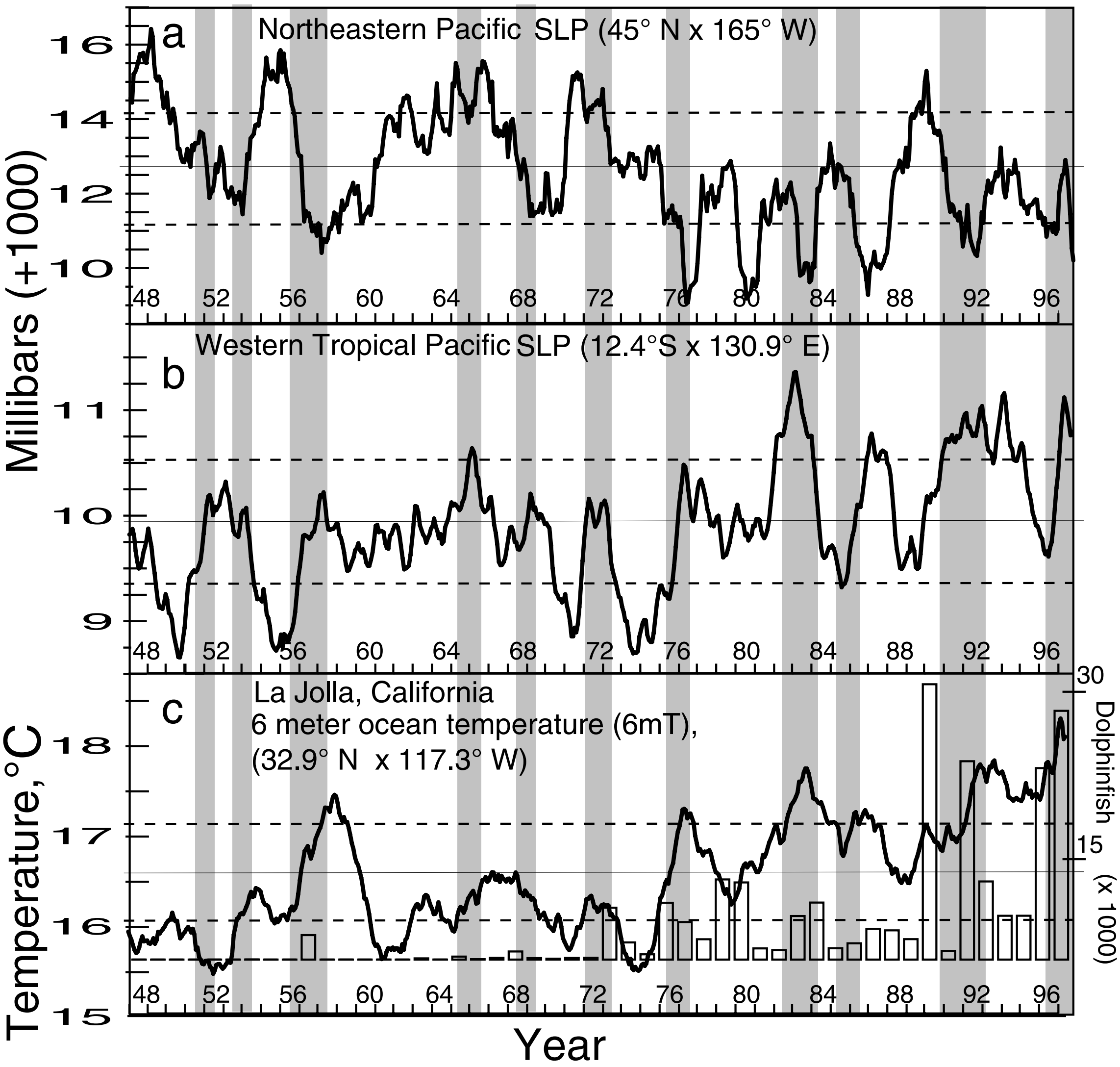

FIG. 5. – Fifty year record of trends and climate transients in sea level pressure (SLP) in the northeastern Pacific and in the western tropical Pacific (a and b respectively). These are compared to six meter temperature from the Scripps Institution of Oceanography, La Jolla shore station in southern California (c). Open bars in panel c show dolphinfish catch (right scale). Each line is a 24-month running mean of available monthly mean values. El Niño periods are shown by vertical shading. Overall mean values are shown by solid horizontal lines. One standard deviation envelopes about the mean are shown by horizontal broken lines. The mean for the recent end of each series was estimated using available values. See text for additional details.

RESULTS

The dolphinfish catch series has a clear 50-year trend (Table 1). Average reported catch over the period from 1948 to 1956 was less than 10 fish/year. During the 1962-1971 period average catch had increased to 212 fish/year. By the 1988-1996 interval average catch was more 1.1 x 10^3 fish/year (Table 1). Corresponding trends are found in environmental time series representative of the western tropical Pacific atmosphere, the northeastern Pacific atmosphere and the ocean temperature in the dolphinfish habitat off southern California and northern Mexico. The variation of the 24-month running mean of these three environmental indices is shown in Figure 5. Overall means are indicated by solid horizontal lines. Ranges of one standard deviation (sd) above and below the mean are shown by broken lines.

Sea level pressure (SLP) in the northeastern Pacific (Fig. 5a) shows an overall trend to lower pressures. The SLP of the 1948 to 1957 period is generally above overall average (solid line) and well above the -1.0 sd level (broken line). During 1988-1997 northeastern Pacific SLP mean values are below the overall mean, with excursions below-1.0 sd.

The 50-year trend in the western tropical Pacific SLP is to higher values (Fig. 5b). In the 1948-1957 period, the mean has many values below -1.0 sd and no values above the 1.0 sd level. The opposite is the case for the 1988-1997 period, when there are many values above the 1.0 sd level and no values below the -1.0 sd level (Fig. 5b).

Both the SLP trends (Fig. 5a,b) represent changes in large-scale processes that will bring warming to the California Current region (Emery and Hamilton, 1984; Enfield, 1987; Shriver *et al.*, 1991; Simpson, 1992; Norton and McLain, 1994; Meyers *et al.*, 1996). This is observed at the La Jolla, California shore station. During 1948-1957, few 6mT values are above the overall mean. In the last decade of the series, few values are below the overall mean. The correspondence of the 50-year trend between dolphinfish catch and temperature is also shown in Figure 5c.

1972-1976 transient

Before 1973, annual CPFV catch seldom exceeded a few hundred fish. Then in 1973 more than 5.0 x 10^3 dolphinfish were taken in the July-October season and more than 10^3 were caught in 23 of the next 25 seasons (Table 1). The generally higher California Current temperatures after about 1976, relative to the decade before, are shown by the southern California 6mT and other studies (Norton *et al.*, 1985; McLain *et al.*, 1985; Miller *et al.*, 1994; McGowan *et al.*, 1998). Increased temperature off northern Mexico (as monitored by 6mT) apparently allowed dolphinfish populations to extend their ranges northward into newly available habitat.

Increases in dolphinfish availability that occurred in the early 1970s appear related to the large-scale changes that occurred throughout the Pacific basin. The three time series shown in Figure 5 initiate transients in the early to mid-1970s with transitions to different levels of mean variability completed by the end of 1976. The overall means are 1012.6 mb, 1009.9 mb and 16.6°C for northeastern Pacific, tropical SLPs and southern California 6mT respectively. For 1976-1997 the corresponding values are 1011.8 mb, 1010.1 mb and 17.0°C. In southern California 6mT, the 1970s transient is seen as an uninterrupted trend to higher values from 1974, when temperatures were anomalously low, through the 1976-1977 El Niño period. From early 1976 through 1997 the mean 6mT has remained above the -1.0 sd level (Fig. 5c). Increased dolphinfish availability appears to be one of the biological results of these large-scale environmental changes.

1990 transient

Dolphinfish CPFV catch exceeded 3.0x10^4 in 1990. This large increase in catch was followed in 1992, 1996 and 1997 by catches of more than 2.0x10^4 fish and in 1993 by almost 9.0 x10^3 fish. Catches in 1990, 1992, 1996 and 1997 were ten times greater than the annual catch in the 1950-1970 period (excepting the 1957 El Niño year) and more than twice the number caught in any year during the 1971-1989 period (Table 1). This increase in dolphinfish availability might be expected from observed increases in ocean temperatures in the California Current region. The means for 6mT are 16.6, 17.0 and 17.3°C for the 1948-1997, 1976-1997 and 1989-1997 periods respectively (Fig. 5c).

In the western tropical Pacific, there are corresponding trends to higher SLP (Fig. 5b). The mean SLP for the 1989-1997 period was 1010.5 mb, 0.4 mb above the mean for the 1976-1997 interval. The 1989-1997 mean exceeds the overall mean by 0.5 mb. Changes in 6mT and western tropical Pacific SLP are consistent with increasing temperature in the coastal region off northern Mexico and an increasing abundance of dolphinfish (Fig. 5, Table 1).

In the northeastern Pacific, the trend to lower SLP is partially reversed during the 1988-1991 period (Fig. 5a). Northeastern Pacific SLP averages 1012.1 mb during the 1989-1997 period, 0.3 mb higher than the 1976-1997 period mean, but below the 1948-1997 average (1012.6 mb). Since the dolphinfish habitat expanded farther northward during the 1990s while northeastern Pacific mean SLP increased (corresponding to cooling CCS tendencies), the forces represented by the northeastern Pacific index were apparently countered by other processes because sea temperature continued to increase and dolphinfish became more abundant (Fig. 5). Large-scale forcing appears to be increasing SST and dolphinfish abundance off southern California and northern Mexico in a 50-year pattern consistent with the global warming hypothesis (Folland, 1990; Houghton *et al.,* 1996; Cane *et al.*, 1997).

Environmental relationships, 1970-1997

Norton and Crooke (1994) found multiyear trends in an index of wind-forced upwelling (Bakun, 1973), sea level pressure and the southern oscillation index (SOI) corresponding to increases in CPFV dolphinfish catch during the 1978-1993 period. The SLP and upwelling index (UI) are comput-

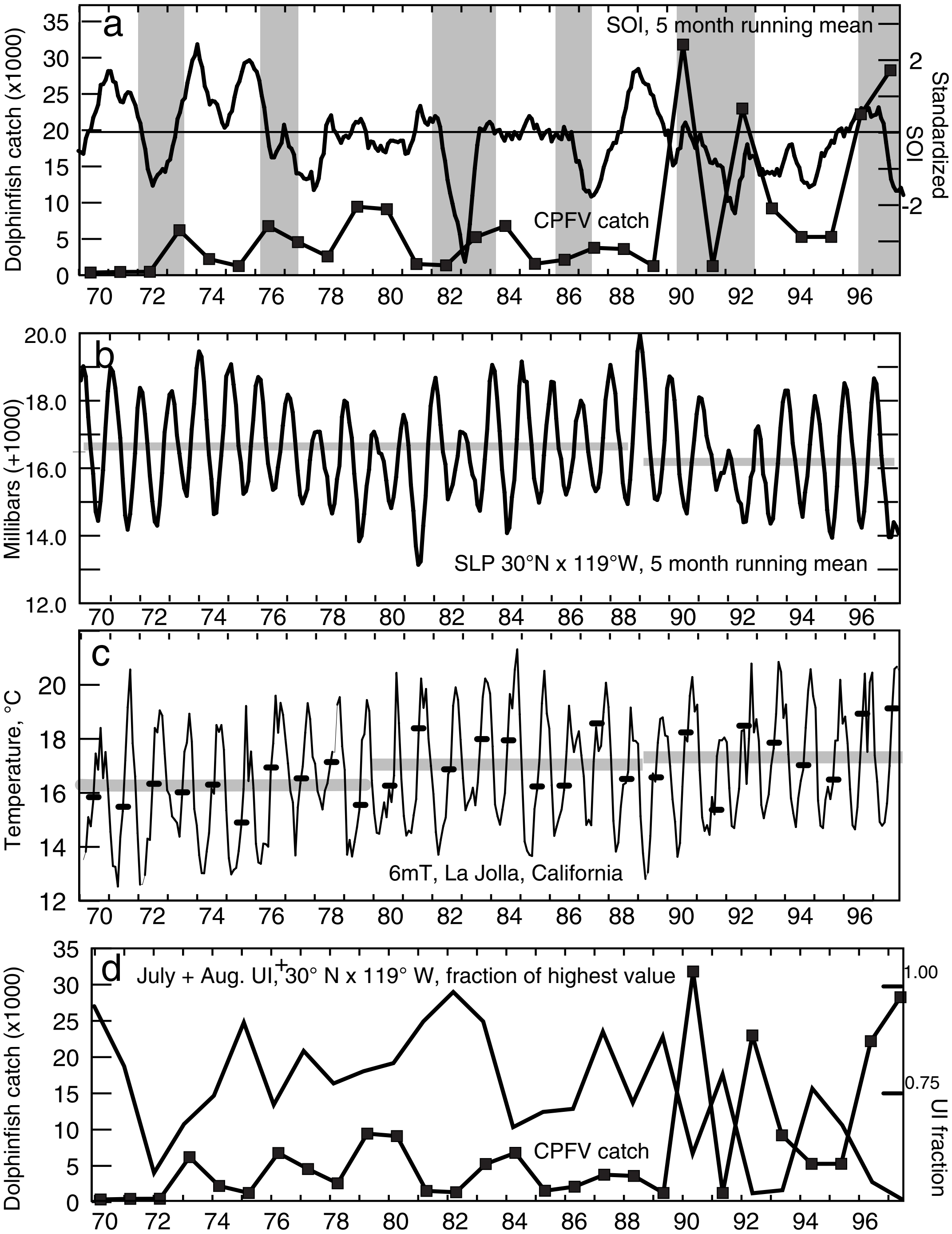

FIG. 6. – Commercial passenger fishing vessel (CPFV) dolphinfish catch compared to four climate and seasonal indicators: a. Five month running mean of Southern Oscillation Index (SOI) is compared to total annual CPFV catch. SOI scale is in standardized units, right. b. Five-month running mean of sea level pressure (SLP) near the dolphinfish habitat off northern Mexico (U. S. Navy Fleet Numerical Oceanography and Meteorology Center in Monterey, California). c. Ocean temperature taken at 6 m depth at the La Jolla shore station (6mT). Horizontal marks show May 6mT. d. Comparison of upwelling index sum for July and August (UI$^+$) calculated for a point off northern Mexico and annual CPFV catch. UI$^+$ is given as a percentage of the highest value in the series (right scale) and is computed from monthly mean values provided by the Pacific Fisheries Environmental Laboratory /SWFSC/NMFS, Pacific Grove, California.

ed for 30°N x 119°, a location within the dolphinfish habitat (Fig. 1, shaded circle). The following sections re-examine these relationships during the 1970-1997 interval (Fig. 6).

Southern Oscillation Index

Relationships between the SOI, El Niño and dolphinfish catch are shown in Figure 6a. The well known relationship between decrease in SOI (corresponding to increase in SLP at Darwin), and El Niño (shaded) is apparent (Fig. 5). El Niño events include periods of increasing SOI [$\delta(SOI)/\delta t > 0$] immediately following periods of decreasing SOI [$\delta(SOI)/\delta t < 0$]. Dolphinfish availability increases in the years following the decrease in SOI. This association is frequent, but not absolute (Fig. 6a). The relatively high catches in 1979 and 1980 are associated with only small drops in SOI and do not appear associated with El Niño events. In addition, low dolphinfish availability in 1991 is associated with a downward trend in SOI. Apparently, El Niño processes are not the only ones allowing dolphinfish to extend their range northward.

Sea level pressure over dolphinfish habitat

A five-month running mean of SLP over the dolphinfish summer habitat (Fig. 1) is shown in Figure 6b. Period means are 1016.6 for the 1970-1979 and 1980-1988 intervals (shaded). The trend to lower SLPs noted by Norton and Crooke (1994) is seen to continue during the 1989-1997 period, when the mean is 1016.2. The subtropical high atmospheric pressure (STH) which dominates climatic conditions off southern California and northern Mexico has apparently become weaker in the 1989-1997 period compared to 1970-1988. Lower SLPs over the seasonal dolphinfish habitat lead to increased atmospheric cyclonicity, which decreases California Current forcing of cooler water transport from the north (Reid *et al.*, 1958; Chelton *et al.*, 1982). In addition, upwelling is decreased and more southern water intrudes from the south as isopycnals lose onshore upward slope (Lynn and Simpson, 1987, 1990).

Decreasing annual range in SLP, an indication of a more tropical atmosphere, is found when mean maxima and mean minima are examined over the 1970-1997 period. Annual range was 3.8 mb for the 1970-1988 period and 3.2 mb (16% decrease) for the 1989-1997 period. A lower annual forcing range may allow dolphinfish habitat to extend northward throughout the year. More northerly winter and spring spawning will produce yearling fish (more than 90% of catch) closer to the CPFV range.

Southern California six meter temperature

The annual cycle in monthly mean 6mT at La Jolla is variable (Fig. 6c). Progressive increase in mean temperature from 16.2° to 17.0° to 17.3° is seen for the 1970-1979, 1980-1988 and 1989-1997 periods respectively (shaded). Corresponding maximum/minimum temperatures are 19.5/13.5°C, 20.4/14.5°C, and 20.4/14.5°C. The increase in temperature from 1970 -1979 to 1980-1988 is seen in both minimum and maximum temperatures, but the increase in temperature from 1980-1988 to 1989-1997 occurs in months that are generally neither maxima nor minima.

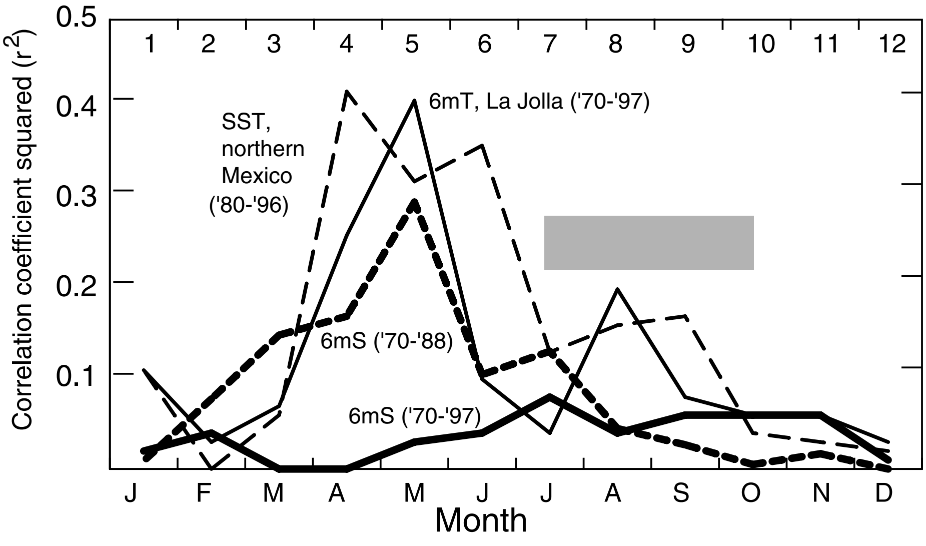

FIG. 7. – Correlation (r^2) of temperature and salinity indices with CPFV dolphinfish catch. Positive correlations of annual dolphinfish catch to monthly average sea surface temperature (SST) off northern Mexico (light, broken) and 6 meter temperature (6mT) at the La Jolla shore station (light, solid). The heavy lines show r^2 for negative associations of salinity (bmS) with CPFV catch. Correlation intervals are shown in parentheses (1970-1988, broken and 1970-1997, solid). Period of dolphinfish availability to southern California CPFV anglers is shaded. For $r^2 > 0.3$, $p < 0.05$.

To examine possible seasonal dependence of dolphinfish availability on regional surface layer temperatures, monthly mean 6mT values were compared to CPFV annual catch values and resulting r^2 values were plotted for the annual cycle (Fig. 7). May 6mT appears to have the closest relationship to dolphinfish abundance in the following July-October CPFV fishing season (shaded). The curve computed from the 1980-1996 time series of SST from the dolphinfish habitat (within rectangle in Fig. 1) shows that the SST off northern Mexico in spring reflects important environmental processes that may contribute to extension of the dolphinfish habitat northward into the CPFV range.

The May 6mT (M6mT) is shown in Figure 6c. M6mT is not always high during years of relatively high catches. In 1979 and 1980 when catches were relatively high, M6mTs were well below the mean. However, in the recent years of very high catches the M6mT has been well above the mean. May 1996 and May 1997 are the warmest M6mTs of the series. The lowest M6mTs were in 1975 and 1991, years of minimum dolphinfish availability. M6mT is used as an independent variable in regression equations discussed below because it appears to reflect important processes that extend the dolphinfish habitat northward (Fig. 7).

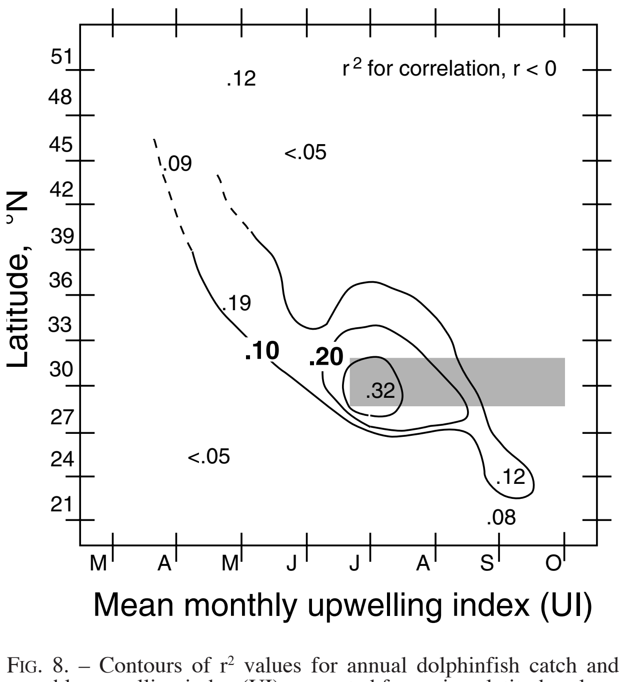

FIG. 8. – Contours of r^2 values for annual dolphinfish catch and monthly upwelling index (UI) computed for various latitudes along the coast of North America for the 1970-1997 period. The relationship is negative with dolphinfish being more available to CPFV anglers when the UI is smaller. Contour interval is 0.10. Shaded area shows time and latitude of CPFV dolphinfish catch by southern California CPFV. For $r^2 > 0.2$, $p < 0.05$.

A two dimensional analysis (time x location) of the relationship of UI at 11 points along the coast of North America to CPFV dolphinfish catch is shown in Figure 8. Values of r^2 are contoured over 30° of latitude for May through October. The relation between dolphinfish catch and upwelling index is negative ($r < 0$) for all r^2 values greater than 0.02. The strongest relationship is at 30°N, off northern Mexico (Fig. 1), during July. This suggests that more intense upwelling in July, at the beginning of the CPFV fishing season, is associated with decreased dolphinfish availability. Diagonal contours suggest upstream effects: anomalous upwelling or downwelling to the north, earlier in the year, may influence dolphinfish availability to CPFVs. July and August monthly upwelling index values at 30° N are partially additive in explaining dolphinfish availability and are combined in the UI^+ variable. The relation of UI^+ , as an indicator of atmospheric wind-forced upwelling, to dolphinfish availability is explored below.

Inspection of Figure 6d shows a negative correlation between combined July and August UI computed for 30°N x 119°W (UI^+) and dolphinfish availability ($r^2 = 0.41$). High values in UI^+ (indicating more local wind-forced upwelling and southward flow) correspond to lower seasonal catches. The downward trend in UI^+ noted here and by Norton and Crook (1994) has continued through the successful 1997 fishing season.

Correlations and regression equations

Correlation and regression techniques are used along with other data and previous studies to gain insight into the following questions. First, does the apparent value of UI^+ and M6mT in explaining dolphinfish catch variability depend on the trend or the year-to-year variability, or both? Second, are M6mT and UI^+ additive in regression equations? Third, is it possible that UI^+ and M6mT have variability representing different forcing factors? Fourth, does the physical forcing that makes dolphinfish available to CPFV change during the 1970-1997 interval?

Correlation of the variables found most effective in describing interannual variations in dolphinfish availability are summarized for three periods and shown as r^2 in Table 2. Dolphinfish catch (DF) is correlated with UI^+, M6mT, May monthly mean salinity at 6 m depth for the La Jolla shore station (M6mS) and a sequence of consecutive integers (nos.). Correlation with nos. shows the

TABLE 2. – Squared correlation coefficients (r^2) for variable combinations during three recent intervals. Differenced variables (Equation 1) are above the diagonal (bold). Squares show negative correlation. Symbols: nos., sequence of integers (same above and below diagonal); DF, dolphinfish catch in number per season and difference; UI^+, combined July and August upwelling index and difference; M6mT and M6mS, May six meter temperature and salinity, respectively, from the La Jolla shore station.

1970 - 1997

	nos.	DF	UI^+	M6mT	M6mS
nos.	--	.01	.00	.00	.02
DF	.29	***.50***	$\boxed{.34}$	.36	$\boxed{.01}$
UI^+	$\boxed{.21}$	$\boxed{.41}$	***.30***	$\boxed{.25}$	.00
M6mT	.36	.41	$\boxed{.23}$	***.47***	.01
M6mS	$\boxed{.20}$	$\boxed{.03}$	.00	$\boxed{.03}$	***.20***

1986 - 1997

	nos.	DF	UI^+	M6mT	M6mS
nos.	--	.01	$\boxed{.02}$	.00	.17
DF	.23	***.58***	$\boxed{.54}$	68.	.00
UI^+	$\boxed{.39}$	$\boxed{.58}$	***.49***	$\boxed{.26}$	.01
M6mT	.05	.52	$\boxed{.32}$	***.62***	$\boxed{.09}$
M6mS	$\boxed{.01}$	.05	.02	.00	***.21***

1989 - 1997

	nos.	DF	UI^+	M6mT	M6mS
nos.	--	.00	$\boxed{.01}$	.01	.22
DF	.07	***.67***	$\boxed{.67}$	.84	.00
UI^+	$\boxed{.31}$	$\boxed{.58}$	***.52***	$\boxed{.65}$	.05
M6mT	.22	.77	$\boxed{.70}$	***.62***	$\boxed{.02}$
M6mS	.00	.11	.02	.01	***.23***

fraction of variability that can be associated with a linear trend. Salinity relationships are discussed in the next section.

Correlation indicators (r^2) below the diagonal bold numbers are for the measured (undifferenced) variables and the r^2 values above the diagonal are for variables differenced according to Equation 1. Differencing accentuates year-to-year variability and reduces trend and other forms of low frequency autocorrelation (Box and Jenkins, 1976; Norton and McLain, 1994). The removal of trend is seen in comparison of the first columns to the first rows in Table 2. The trend shown in the first columns of the three panels of Table 2 is important in understanding the transients to increased dolphinfish availability. There is a conspicuous trend in the dolphinfish catch series and in the environmental variables (Table 2). However, series trend reduces the effective degrees of freedom in correlations, thereby reducing the value of correlation in indicating causal covariability. Measured and differenced correlation tests can be used together to detect possible physical to biological connections while using variables that have considerable trend. Bold numbers in diagonals compare correlation of measured and differenced variables (Table 2). Apparent dependence of DF on UI^+ and M6mT, as measured by r^2, is about the same for measured and differenced variables during each of the three periods (Table 2). Since r^2 values are not uniformly increased or decreased when measured and differenced systems of variables are compared, it can be concluded that the variability of DF explained by UI^+ and M6mT is not entirely the result of a common trend of variable series.

For the 1970-1997 and 1986-1997 series UI^+ and M6mT appear equally effective in describing variability in DF. However, when the series are shortened to the very productive 1989-1997 interval (Table 2, lower), it appears that M6mT is more effective in accounting for DF variance. Apparently, the environmental dynamics extending the dolphinfish habitat northward changes during the 1970-1997 period, with processes other than wind-forced upwelling becoming increasingly important during the latter part of the 1970-1997 interval.

The relation between the upwelling index and sea temperature variables may be clarified by forming regression equations using UI^+ and M6mT as independent variables, then looking at the significance of the variable coefficients in explaining variance in the dependent variable. Regression equations for the 1970-1997 series for measured and differenced systems are shown in Figure 9 with year-to-year comparisons of modeled (broken line) and measured (solid line) values. The T-values for the coefficients of the independent variables are shown in the left columns of Table 3. For the 1970-1997 period, both UI^+ and M6mT appear to make significant contributions to the measured and differenced regression equations, since $T > 2.1$ ($p < 0.05$) for the two measured and two differenced cases. Each

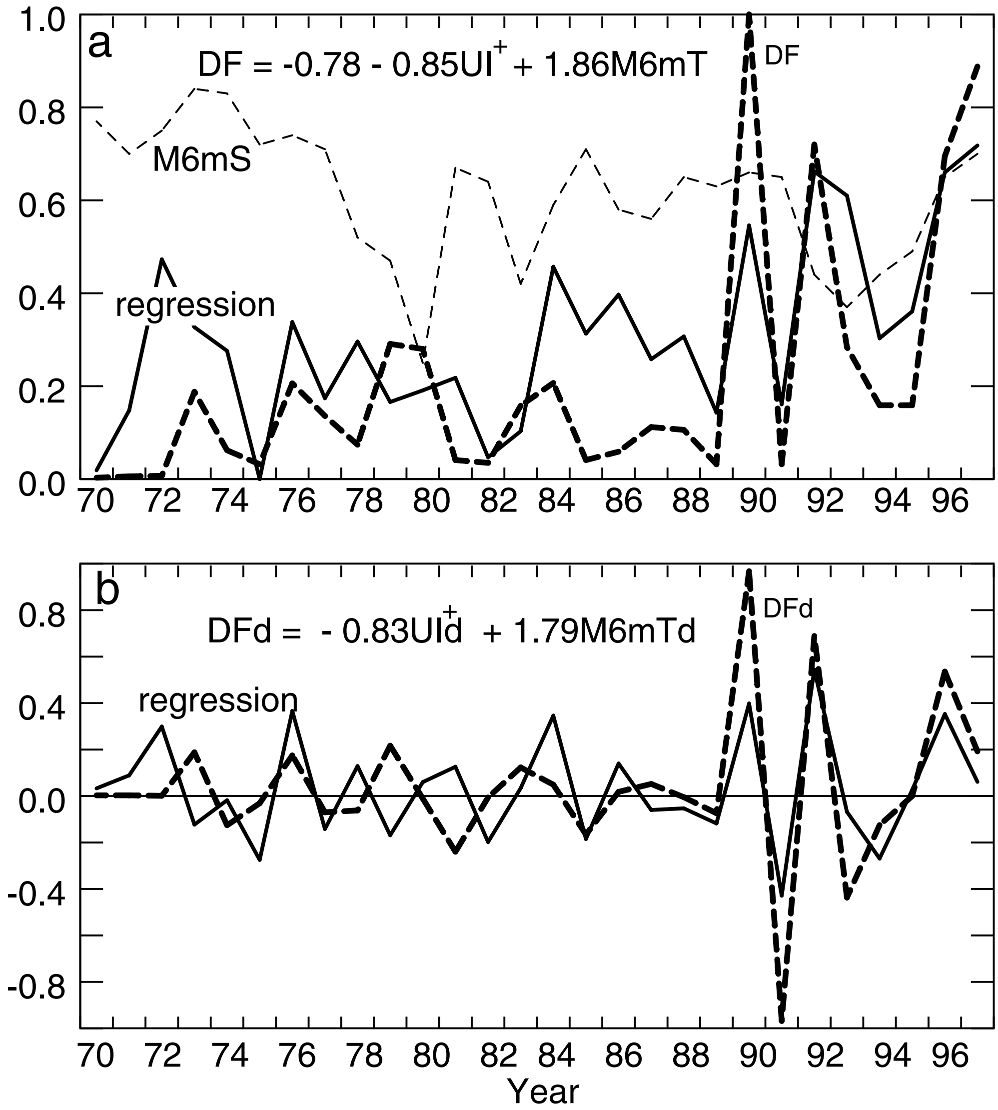

FIG. 9. – Year-by-year comparison of regression equation (solid) and dolphinfish catch (heavy broken) values for measured (a) and differenced (b) variables. Regression equations are at the top of each panel. Dolphinfish catch (DF) is the dependent variable and 6 meter La Jolla shore station monthly mean temperature for May (M6mT) and combined July and August upwelling index (UI^+) are the independent variables. For graphical presentation and regression, all values are percent of maximum. In panel b, all measured variables are differenced according to Equation 1. Additional regression information is given in Table 3. The lighter broken line in panel a gives variation in May monthly average La Jolla salinity (M6mS), which is discussed in the text, but not used in either regression equation. M6mS is plotted on a linear scale with maximum/minimum values = 33.85/33.25.

equation represents more than 40% of the variance in DF and the F-value is well above the $p > 0.05$ level (Table 3). In addition, the magnitude of the DF series fluctuation is matched by the regression equation model with higher values occurring after 1989 (Fig. 9a). The overall trend which is not removed from the regressions using undifferenced variables (UI^+, M6mT) is an important part of the overall increase in dolphinfish availability (see above), but year-to-year variability represented by the differenced system is also well explained by the regression equations. It appears that UI^+ and M6mT have common and unique DF explanatory variability during the entire 1970-1997 period. To the extent that the variability in UI^+ and M6mT is unique, UI^+ and M6mT represent different processes altering the available dolphinfish habitat.

The influence of trend in the equation using measured variables is clearly evident during the 1986-1997 period because consistently low catch values occur during 1986-1989 and the years of very high catch occur during the 1990-1997 period. The 1986-1997 series maximizes the trend of UI^+ and minimizes the trend of M6mT (Table 2, middle panel, left column). The larger T for M6mTd when differenced variables are used in regression equations

TABLE 3. – Regression equations: UI^+, M6mT and DF are differenced (Equation 1) to give UId^+, M6mTd and DFd; T for coefficients of independent variables (coefficient/standard error); r^2 corrected for the number of variables and variance ratio, F. $T_{.05}$ and $F_{.05}$ give p<0.05 (Velleman and Hoaglin, 1981). Other symbols as in Table 2.

Independent variables	1970 - 1997 T	1970 - 1997 r^2/ F	1986 - 1997 T	1986 - 1997 r^2/ F	1989 - 1997 T	1989 - 1997 r^2/ F
dependent variable: reported catch (DF)						
UI^+	-2.9	0.52/15.7	-2.4	0.64/10.9	-0.3	0.69/10.0
M6mT	2.8		2.1		2.2	
dependent variable: reported catch difference (DFd)						
UId^+	-2.2	0.43/11.1	-2.6	0.78/20.5	-0.9	0.82/18.8
M6mTd	2.5		3.8		2.9	
$T_{.05}$ / $F_{.05}$		2.1 /3.4		2.2/4.0		2.3/4.5

show that when the trend is removed, the sea temperature variable is more important than the atmospheric variable (Table 3, lower right).

The results of forming the regression equation for the short 1989-1997 series are shown in the right panel of Table 3. The T-values suggest that all the variability in the DF series explained by UI^+ and M6mT is explained equally well by M6mT. The T-value for UI^+ coefficient is not significant in either the undifferenced or the differenced system (Table 3, right). Apparently, the UI^+ variability that will correspond to DF variability is totally contained in M6mT and there is additional analyzing variability in M6mT that is not part of UI^+. Other processes in addition to topical wind forcing off southern California and northern Mexico appear important in bringing dolphinfish within range of CPFV. These results and the results from the examination of multi-year events (above) suggest that these other processes may be associated with local adjustment to coastal trapped wave energy emanating from the tropical ocean.

Salinity changes

During 1970-1997 dolphinfish CPFV catch variation is at most weakly related to July salinity (6mS) at the La Jolla shore station (Fig. 7, heavy). However, when the 1989-1997 interval is removed from the correlation a stronger relationship is apparent, with the peak correlation in May (Fig. 7, heavy broken). In each case, lower salinities correspond to a higher dolphinfish catch (r^2 < 0). During the 1970-1988 period, lower salinity water associated with the offshore California Current was brought inshore prior to the appearance of dolphinfish. Figure 5a indicates that during 1976-1988 the California Current received intense cyclonic forcing by low pressure systems over the northeastern Pacific.

Norton and Crooke (1994) found that 0-50 m salinity tended to be low during increased dolphinfish catch off southern California in 1983 and 1992. The relationship of salinity (M6mS) to catch variation is shown by the lighter broken line in Figure 9a. M6mS plotted on a linear scale (min/max = 33.25/33.84) is seen to decrease during periods of relatively high catch in 1979, 1980, 1983, 1984, 1992 and 1993. Other recent years of high dolphinfish availability are characterized by higher M6mS. Norton *et al*. (1985) found that the 1979-1980 period was characterized by strong low pressure atmospheric forcing from the northeastern Pacific (also seen in Fig. 5a). The low salinity (Fig. 9a) and the attenuation of tropical El Niño forcing during 1979-1980 (Fig. 5b) suggests that the relatively high dolphinfish availability during this period was due to locally forced processes. These observations along with the generally low correlations between salinity and the other variables shown in Figure 7 and Table 2 indicate two physical forcing processes that bring dolphinfish within range of CPFV: one associated with lower salinity water from offshore and the other associated with higher salinity water from the south.

A climate trend is shown by the continuous decrease in salinity throughout the annual cycle during the recent 38 year period (Fig. 10a). Each transient to higher temperature and increased dolphin-

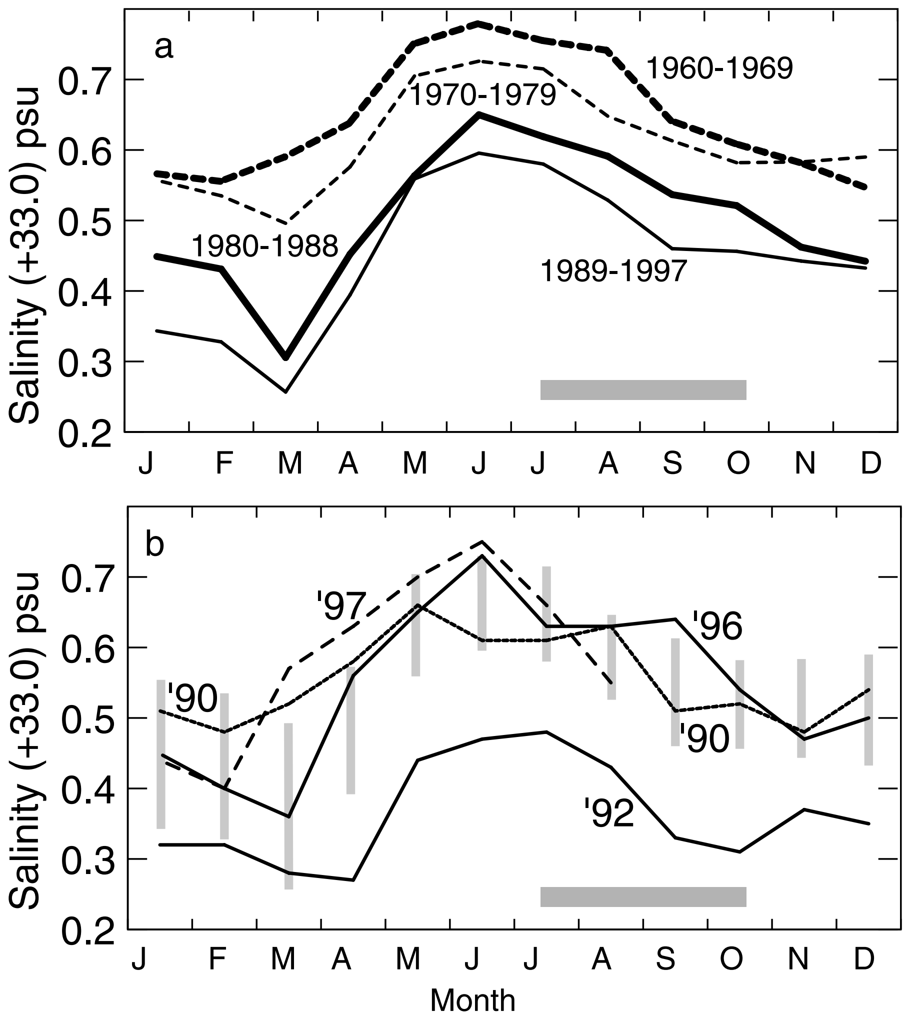

FIG. 10. – Annual cycles of salinity at La Jolla shore station (6mS). Panel a shows the annual cycle averaged for the 1960-1969 (heavy broken), 1970-1979 (broken), 1980-1988 (heavy) and 1989-1997 periods. Panel b compares 1990, 1992, 1996 and 1997 monthly mean values to the range of salinity (vertical shaded bars) between the 1970-1979 and 1989-1997 mean cycles (panel a). Shaded horizontal bars show the season of dolphinfish availability to southern California CPFV.

fish availability is accompanied by transients to lower mean salinity. These observations suggest that there are two time scales involved. The process characterized by an influx of lower salinity water has occurred at the climate time scales (Fig. 10a) and can be intensified at shorter scales as in 1979-1980 (Fig. 9a).

The high salinity process which appears to operate on El Niño and interannual scales is examined in Figure 10b. The ranges between 1970-1979 and 1989-1997 mean salinity values (Fig. 10a) are shown as vertical bars in Figure 10b. These bars provide references for examining the annual cycle of salinity during 1990, 1992, 1996 and 1997 when CPFV catches exceeded 2.0 x 10^4 fish. In 1990, 1996 and 1997 relatively high salinity occurred throughout the year, but in 1992 monthly salinity values were significantly lower than the 1989-1997 mean annual cycle (Fig. 10b). Higher catches in 1990, 1996 and 1997 were clearly accompanied by more saline water than most of the other years of the 1989-1997 period (Fig. 10b). Salinity during the first six months of 1992 was higher than the corresponding period in 1993, 1994 and 1995 (not shown), years when dolphinfish were not as plentiful. Therefore, 1992 shows the presence of the high salinity mechanism because its salinity was higher compared to other years in the 1989-1997 interval. At the same time the relatively low salinity during 1992 compared to 1990, 1996 and 1997 suggests the low salinity mechanism. Both northward and eastward advection are important in bringing dolphinfish within range of CPFV during 1992 (Fig. 2).

The annual salinity cycle for 1991 was between the cycles shown for 1992 and 1996, but the ocean temperature was low, particularly in May (Fig. 6c). Data from the equatorial ocean shows strong downwelling long wave generation during late-1989, 1990 and 1992, but weak or absent downwelling long wave generation in 1991 (Kessler *et al*., 1995). Enfield (1987) has shown that these long wave disturbances can be detected along the west coast of North America poleward to about 37°N. It is likely that the equatorial sequence of long wave generation during 1989-1992 was important in controlling dolphinfish availability to CPFV anglers and that the relatively high salinity in 1991 was due to coastal upwelling rather than long wave enhanced advection of high salinity water from the south.

DISCUSSION

A puzzle of climate investigations is that the scale of change investigated reduces the number of degrees of freedom in the analysis below the level at which the analysis itself will conclusively indicate mechanisms involved in the climate transients investigated. This difficulty holds for the present study as well. An additional difficulty in the present investigation is that there have been two important mechanisms making dolphinfish available to CPFV anglers. During some periods, decreased local and topical wind-forced upwelling and onshore transport appear more important. In other periods, sea temperature and anomalous northward advection appear more important in making dolphinfish available to southern California CPFV anglers. In addition, multi-year and interannual events interact to affect dolphinfish availability. It is not completely accurate to model multi-year events as prolonged seasonal or interannual events, but alternatives are limited and some insight may be gained by this procedure.

Differences in ocean change mechanism have been shown in two ways. First, assessing the differences of regression relationships over different time intervals has isolated mechanisms associated with local wind-forced upwelling and an additional component related to coastal ocean temperature elevation. Second, analyses of multi-year means and interannual changes in coastal ocean salinity have shown that in addition to climate trends, two or more process - one characterized by increased salinity and the other characterized by decreased salinity- are important in making dolphinfish available to CPFV anglers**.**

Results obtained from analysis of the 1970-1997 period can be used with caution to interpret large-scale changes that distinguish the 1948-1972 period when a few hundred dolphinfish were the typical catch from the 1973-1997 period, when the average catch, was several thousand fish. The early period was characterized by higher SLP over the northeastern Pacific (Fig. 5a). Higher pressure over the northeastern Pacific suggests lower cyclogenesis and conditions favoring vigorous southward flow and cooler ocean temperatures throughout the CCS (Chelton *et al.,* 1982). In addition, higher SLP over the northeastern Pacific before the mid-1970s suggests greater coastal CCS upwelling (Bakun, 1973; Gill, 1982). Increased coastal upwelling is correlated negatively with increased dolphinfish abundance (Table 2, Fig. 8).

Since remote connections between the CCS environment and the tropical atmosphere are well known (Enfield, 1987; Clarke, 1992; Shriver *et al*., 1991; Norton and McLain, 1994; White, 1994; Meyers *et al*., 1996; Ramp *et al*., 1997), it is not surprising that SLP changes in the western tropical Pacific can be associated with dolphinfish habitat extension off northern Mexico. Before 1976, western tropical Pacific SLP (Fig. 5b) was characterized by excursions below the average and below -1.0 sd. The suggestion of this in terms of factors affecting dolphinfish availability, is that less downwelling long wave energy radiated via the equatoral and coastal wave guides (Enfield, 1987; Clarke, 1992; Meyers et al., 1998) to the dolphinfish habitat off northern Mexico. Consequently, the effects of locally enhanced coastal upwelling were augmented, isopycnals slanted more steeply upward toward the coast enhancing southward geostrophic transport, and the dolphinfish habitat was displaced southward. On interannual scales, 1975 and 1991 have large-scale environmental conditions similar to those dominant before the mid-1970s**.**

Conspicuously different interannual conditions, favoring northward habitat extension, occurred during 1957, 1990 and 1997 (Figs. 5 and 6, Table 1). These conditions are more representative of the period since 1990.

Geostrophic flow patterns off southern California

For the fall of 1992, geostrophic flow is seen to be clockwise around a warm water protuberance from the south (Fig. 2). There is weak onshore flow in the channel between the islands (dark shading) and the mainland. Southward flow was found next to the coast. In contrast, flow patterns characteristic of high salinity and high dolphinfish availability years (1990, 1997) have a northward geostrophic flow (20-25 cm/sec for 0/500m) along the coast shoreward of 118°W (Norton and Crook, 1994; Anon., 1997). It is likely that the vigorous northward coastal currents and elevated temperature and salinity observed during 1990 and 1997 are in part local adjustments to downwelling long wave energy propagating from the south which depresses isopycnals near the coast. In addition topical wind-forced upwelling was reduced in 1990 and particularly in 1997 (Fig. 6d), so topical forcing was not counter to remotely forced processes.

Anthropogenic climate change

Accumulated climate change effects of greenhouse gas emissions and aerosol production by anthropogenic and other sources are not well understood or well quantified (Houghton *et al.*, 1996), but it is clear from this study that the Pacific basin environment has been characterized over the last 50 years by additive effects of successive transients in accord with the climate change hypothesis. There are trends to higher sea surface layer temperatures off southern California and northern Mexico. This is in accord with observations of a 0.3 to 0.6°C change in global surface air temperature over the last century (Folland *et al.*, 1990; Houghton *et al.*, 1996; Easterling *et al.*, 1997). The prolonged 1990-1995 El Niño and the extreme 1996-1998 El Niño (Figs. 5 and 6) and their world-wide teleconnections are possible manifestations of global climate change (Houghton *et al.*, 1996). Globally, 1997 was one of the warmest of the 20th century (Quayle and Crowe, personnel communication, 151 Patton Avenue, Ashville, North Carolina, USA.). This is also the case for six-meter temperatures collected at the La Jolla shore station (Fig. 5c). Dolphinfish were taken by CPFV in near record numbers during 1997. Global SST averages show a period of high variability about an apparently stationary mean from 1950 to the early to mid-1970s, followed by steady increases in temperature thereafter (Parker *et al.,* 1995; Houghton *et al.,* 1996). These patterns are also seen in the La Jolla shore station data and in changes in dolphinfish abundance.

Recent analyses of available global ocean data show increasing sea surface temperature over large ocean areas during the last century. On 10^3 km scales, an increase of about 0.6°C per century is found off northern Mexico (Cane *et al.,* 1997). The 0.7°C sea temperature increase presented here for the 1948-1997 period is about double that found by Cane *et al.* (1997). The greater warming rate at the La Jolla shore station may be the result of proximity to land and seasonal heat storage by the topographically induced Southern California Eddy.

The subtropical regions of the world ocean have warmed. Temperature restraints on dolphinfish movement and reproduction have probably shifted poleward, expanding available dolphinfish range. The present report gives a specific example of how changes in the physical environment may facilitate habitat expansion processes. Changes in dolphinfish abundance off southern California and northern Mexico will depend on interaction of remote, local and topical forces occurring at seasonal to multi-decadal scales. Areas of decreasing dolphinfish abundance will also occur because in the current era of apparent change some ocean areas are expected to cool (Cane *et al.*, 1997), but total dolphinfish habitat may expand to more than 40% of the world ocean's surface layers if observed warming trends continue.

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REFERENCES

Anon. – 1997. Data report, physical, chemical, and biological data. Scripps Institution of Oceanography Reference 1970-1997 series.

Bakun, A. – 1973. Coastal upwelling indices, west coast of North America 1946-71. U. S. Dep. Comm., *NOAA Technical Rep.* NMFS-SSRF-671, pp.103.

Bernal, P.A. and J.A. McGowan. – 1981. Advection and upwelling in the California Current, In: F.A. Richards (ed.), *Coastal Upwelling*, pp. 381-399. Washington, D. C., American Geophysical Union.

Bjerknes, J.A. – 1966. Possible response to the atmosphere Hadley circulation to equatorial anomalies of temperature. *Tellus* 18: 820-829.

Box, G.P. and G.M. Jenkins. – 1976. *Time Series Analysis, Rev. Ed*., Holden-Day, Oakland, California.

Brinton, E. and J.L. Reid. – 1986. On the effects of interannual variations in circulation and temperature upon Euphausiids of the California Current. Pelagic biogeography. *UNESCO technical papers in marine science* 49, 25-34.

Brock, R.E. – 1984. A contribution to the trophic biology of Blue Marlin (*Makaria nigricans* Lacepede, 1802) in Hawaii. *Pacific Sci*., 38: 141-149.

Cane, M.A., A.C. Clement, A. Kaplan, Y. Kushnir, D. Pozdnyakov, R. Seager, S.E. Zebiak and R. Murtugudde. – 1997. Twentieth-century sea surface temperature trends. *Science*, 275: 957-960.

Chelton, D., P.A. Bernal and J.A. McGowan. – 1982. Large-scale interannual physical and biological interaction in the California current. *J. Mar. Res*., 40: 1095-1125.

Chelton, D.B. and M.G. Schlax. – 1996. Global observations of oceanic Rossby waves. *Science*, 272: 234-238.

Clarke, A.J.-1992. Low-frequency reflection from nonmeridonal eastern ocean boundary and the use of coastal sea level to monitor eastern Pacific equatorial Kelvin waves. *J. Phys. Oceanogr*., 22: 163-183.

Ditty, J.G., R.F. Shaw, C.B. Grimes and J.S. Cope. – 1994. Larval development, distribution and abundance of common dolphin, *Coryphaena hippurus*, and pompano dolphin, *C. equiselis* (family: Coryphaenidae), in the northern Gulf of Mexico. *Fish. Bull*., 92: 275-291.

Douglas, A., D. Cayan and J. Namias. – 1982. Large-scale changes in North Pacific and North American weather patterns in recent decades. *Mon. Wea. Rev*.,110: 1851-1862.

Easterling, D.R., B. Horton, P.D. Jones, T.C. Peterson, T.R. Karl, D.E. Parker, M.J. Salinger, V. Razuvayev, N. Plummer and P. Jamason and C.K. Folland. – 1997. Maximum and Minimum Temperature Trends for the Globe, *Science 277*: 364-367.

Emery, W.J. and K. Hamilton. – 1984. Atmospheric forcing of interannual variability in the northeast Pacific Ocean. *J. Geophys. Res*., 90: 857-868.

Enfield, D.B. – 1987 The intraseasonal oscillation in eastern Pacific sea levels: How is it forced?, *J. Phys. Oceanogr. 17*: 1860-1876.

Enfield, D.B. and J.S. Allen. – 1980. On the structure and dynamics of monthly mean sea level anomalies along the Pacific coast of North and South America. *J. Phys. Oceanogr*., 10: 557-578.

Friedlander, A. – 1995. The recreational fishery for blue marlin, *Makaira nigricans* (Pisces: Istiophoridae), in the US Virgin Islands, *Fisheries Research* 22: 163-173.

Folland, C.K., T.R. Karl and K.Y.A. Vinnikov. – 1990. Observed climate variation and change. In: J.T. Houghton, G.J. Jenkins and J.J. Ephraums (eds.), *Climate change, the IPCC Scientific assessment*, pp. 201 -238. Cambridge University Press, Cambridge.

Gill, A.E. – 1982. *Atmosphere-Ocean Dynamics*. Academic Press, New York, 662 pp.

Goldberg, S.R. and A.T. Aguilar. – 1985. Notes on spawning in the dolphinfish *Coryphaena hippurus* (Coryphaenidae) from Peru, *Bull. South. Calif. Acad. Sci*. 84: 51-52.

Hamm, D.C., Michael M.C. Quach and R.S. Antonio. – 1993. Fishery statistics of the Western Pacific, Volume 8., Southwest Fisheries Science Center, National Marine Fisheries Service, *NOAA Administrative Report* H-92-14, 65pps. (unpublished).

Haney, R.L. – 1980. A numerical case study of the development of large-scale thermal anomalies in the central north Pacific Ocean. *J. Phys. Oceanogr*., 10: 541-556.

Horel, J.D. and J.M. Wallace. – 1981. Planetary atmospheric phenomena associated with the Southern Oscillation, *Mon. Wea. Rev*., 109: 813-829.

Houghton, J.T., L.G. Meirra Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell Eds. – 1996. *Climate Change 1995, The science of climate change*. Cambridge University Press, Cambridge 572 pp.

Huyer, A. and R. L. Smith. – 1985. The Signature of El Niño off Oregon. 1982-1983, *J. Geophys. Res*., 90: 7133-7142.

Kessler, W.S., M.J. McPhaden and K.M. Weickmann. – 1995, Forcing of intraseasonal Kelvin waves in the equatorial Pacific, *J. Geophys. Res*. 100: 10613-10631.

Kraul, S.A.-1998. Seasonal abundance of the dolphinfish, *Coryphaena hippurus*, in Hawaii and the tropical Pacific Ocean. *Sci. Mar*. 63(3-4):261-266.

Lea, R.N. – 1998. The spotfin burrfish-An infrequent visitor, *Tidelines,* 18: 8.

Leet, W.S., C.M. Dewees and C.W. Haugen (eds.). – 1992. California's living marine resources and their utilization, *Sea Grant Extension Publication UCSGEP-92-12*, p. 257.

Lleonart, J., B. Morales-Nin, O. Reñones, S. Deudero, E. Massutí and P. Oliver. – 1998. Population dynamics and fishery of dolphinfish (*Coriphaena hippurus*) in the western Mediterranean. *Sci. Mar*. 63(3-4): 447-457.

Longhurst, A.R. – 1967. The pelagic phase of *Pleuroncodes planipes* Stimpson (Crustacea, Galatheidae) in the California Current, *California Cooperative Oceanic Fisheries Investigations Report.(CalCOFI) Rep*., 11: 142-154.

Lynn, R.J. – 1967. Seasonal variation of temperature and salinity at 10 meters in the California Current, *California Cooperative Oceanic Fisheries Investigations Report (CalCOFI) Rep.,* 11: 157-186.

Lynn, R.J. – 1983. The 1982-83 warm episode in the California Current. *Geophys. Res. Lett*., 10: 1093-1095.

Lynn, R.J. and J.J. Simpson. – 1987. The California current system: the seasonal variability of its physical characteristics. *J. Geophys. Res*., 92: 12947-12966.

Lynn, R.J. and J.J. Simpson. – 1990. The flow of the undercurrent over the continental borderland off Southern California. *J. Geophys. Res*. 95: 12995-13008.

Mahon, and H.A. Oxenford. – 1998. Precautionary assessment and management of dolphinfish in the Caribbean. *Sci. Mar*. 63(3-4): 429-438.

Massuti, E. and B. Morales-Nin. – 1997. Reproductive biology of dolphinfish (*Coryphaena hippurus* L.) off the island of Majorca (western Mediterranean). *Fish. Res*. 30: 57-65.

McGowan, J.A., D.R. Cayan and L.M. Dorman. – 1998. Climate-ocean variability and ecosystem response in the northeast Pacific, *Science* 281: 210-217.

McLain, D.R., R.E. Brainard and J.G. Norton. – 1985. Anomalous warm events in eastern boundary current systems. *California Cooperative Oceanic Fisheries Investigations Report (CalCOFI) Rep*., 26: 51-64.

Meyers, S.D., M.A. Johnson, M. Liu, J.J. O'Brien and J.L. Spiesberger. – 1996. Interdecadal variability in a numerical model of the northeast Pacific Ocean. *J. Phys. Oceanogr*., 26: 2635-2652.

Meyers, S.D., A. Melsom, G.T. Mitchum, and J.J. O'Brien. – 1998. Detection of the fast Kelvin wave teleconnection due to ENSO. *J. Geophys. Res*. (in press).

Miller, A. J., D. R. Cayan, T. Barnett, N. E. Graham and J. M. Oberhuber.-1994. Interdecadal variability of the Pacific Ocean: model response to observed heat flux and wind stress anomalies. *Climate Dynamics,* 9, 287-302.

Moser, H.G., R.L. Chandler, P.E. Smith, D.A. Ambrose, S.R. Charter, C.A. Meyer, E.M. Sandknop and W. Watson. – 1994. Distributional atlas of fish larvae in the California Current region: Taxa with less than 1000 total larvae. 1951-1984, *Calif. Coop. Oceanic Fish. Invest. (CalCOFI) Atlas* 32: 60-61.

Norton, J.G. and S.J. Crooke. – 1994. Occasional availability of dolphin, *Coryphaena hippurus*, to southern California Commercial Passenger Fishing Vessel Anglers: Observations and Hypotheses,*Calif. Coop. Oceanic Fish. Invest. (CalCOFI) Rep.,* 35: 230-239.

Norton, J.G. and D.R. Mclain. – 1994. Diagnostic patterns of seasonal and interannual temperature variation off the west coast of the United States: Local and remote large scale atmospheric forcing. *J. Geophys. Res*. 99: 16019-16030.

Norton, J.G., D.R. McLain, R.E. Brainard and D.M. Husby. – 1985. The 1983 El Niño event off Baja and Alta California and its ocean climate context. In: W.S. Wooster and D.L. Fluharty (eds.), *Niño effects in the eastern subarctic Pacific Ocean*, pp 44-72. Washington Sea Grant Program, University of Washington, Seattle.
Oxenford, H.A. – 1998. Biology of the dolphinfish (*Coryphaena hippurus*) in the western central Atlantic: a review. *Sci. Mar.* 63(3-4): 277-301.
Oxenford, H.A. and W. Hunte. – 1986. Migration of the Dolphin (*Coryphaena hippurus*) and its implications for fisheries management in the Western Central Atlantic, In: *Proceedings of the thirty-seventh annual Gulf and Caribbean Fishery Institute*, pp. 95-111. Cancun, Mexico, November 1984.
Palko B.J., G.L. Beardsley and W.J. Richards. – 1982. Synopsis of the biological data on dolphinfishes, *Coryphaena hippurus* Linnaeus and *Coryphaena equiselis* Linnaeus. *FAO Fish. Synop.*, 130, 28 pp.
Pares-Sierra, A. and J.J. O'Brien. – 1989. The seasonal and interannual variability of the California current system: A numerical model. *J. Geophys. Res.*, 94: 3159-3180.
Parin, N.V. – 1970. Ichthyofauna of the epipelagic zone, Academy of Sciences of the USSR, Institute of Oceanography, 1968, Translated from Russian by Israel Program for Scientific Translations for the U. S. Department of the Interior and the National Science Foundation, Washington, D. C., 206 pp.
Parker, D.E., C.K. Folland and M. Jackson.-1995. Marine surface temperature: observed variations and data requirements, *Climate Change* 31: 559-600.
Patterson K.E. and J. Martinez. – 1991. Exploitation of the dolphinfish *Coryphaena hippurus* L. off Ecuador: Analysis by length-based virtual population analysis. *Fishbyte* , 9: 21-23.
Peláez, J. and J.A. McGowan. – 1986. Phytoplankton pigment patterns in the California Current as determined by satellite. *Limnol. Oceanogr.*, 31: 927-950.
Quinn, W. H., V. T. Neal and S. E. Antunez de Mayolo. – 1987. El Niño occurrences over the past four centuries. *J. Geophys. Res.*, 92: 14449-14461.
Ramp, S.R., J.L. McClean, C.A. Collins, A.J. Semtner and K.A.S. Hays. – 1997. Observations and modeling of the 1991-1992 El Niño signal off central California. *J. Geophys. Res.*, 102: 5553-5582.
Rasmusson, E.M. and J.M. Wallace. – 1983. Meteorological aspects of the El Niño/Southern Oscillation. *Science* , 122: 1195-1202.
Reid, J.L., G.I. Roden and J.G. Wyllie. – 1958. Studies of the California Current System. *Calif. Coop. Oceanic Fish. Invest. (CalCOFI) Rep.* 6: 27-57.
Rienecker, M.M. and C.N.K. Mooers. – 1986. The 1982-1983 El Niño signal off northern California. *J. Geophys. Res.*, 91: 6597-6608.
Sakamoto, R. and S. Kojima -1998. Review of dolphinfish biological and fishing data in Japanese waters. *Sci. Mar.* 63(3-4): 375-385.
Sette, O.E. and J.D. Isaacs (eds.) – 1960. The changing Pacific ocean in 1957 and 1958 (symposium)., *Calif. Coop. Oceanic Fish. Invest. (CalCOFI) Rep. 7*: 14-217.
Schwing, F.G., M. O'Farrell, J. Steger and K. Baltz. – 1996. Coastal upwelling indices, west coast of North America 1946-1995.*NOAA Technical Memorandum,* NMFS-SWFSC-231, pp. 207.
Shriver, J.F., M.A. Johnson and J.J. O'Brien. – 1991. Analysis of remotely forced oceanic Rossby waves off California. *J. Geophys. Res.* 96: 749-757.
Simpson, J.J. – 1984. El Niño-induced onshore transport in the California current during 1982-1983. *Geophys. Res. Lett.* 11: 241-242.
Simpson, J.J. – 1992. Response of the Southern California current system to the mid-latitude North Pacific coastal warming events of 1982-1983 and 1940-1941. *Fish. Oceanogr.* 1: 57-79.
Thomson, C.J. and S.J. Crooke. – 1991. Results of the southern California sportfish economic survey. *NOAA Technical Memorandum* NMFS NOAA-TM-NMFS-SWFSC-164, pps. 87.
Trenberth, K.E. – 1995. Atmospheric circulation and climate changes, *Climate Change* 31: 427-453.
Trenberth, K.E. and J.D. Shea. – 1987. On the evolution of the Southern Oscillation. *Mon. Weather Rev.* 115: 3078-3096.
Velleman, P.F. and D.C. Hoaglin. – 1981. *Applications, Basics and Computing of Exploratory Data Analysis.* Duxbury Press, Boston, Massachusettes, 354 pp.
Wallace, J. and D. Gutzler. – 1981. Teleconnections in the geopotential height field during the northern hemisphere winter. *Mon. Wea. Rev.* 109: 784-812.
White, W.B. – 1994. Slow El Niño-Southern Oscillation boundary waves *J. Geophys. Res.* 99: 22737-22751.
Young, P.H. – 1969. The California partyboat fishery 1947-1967, *Calif. Dept. Fish and Game, Fish Bull.* 145, 91 pp.