

Eastern Tropical Pacific Dolphin Habitat Variability

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Environmental variability in the eastern tropical Pacific Ocean (ETP) and its potential effect on dolphin habitat and estimated abundance are examined here using physical oceanographic data publicly available in National Oceanic and Atmospheric Administration databases and a subset of the biological data (phytoplankton pigment concentration) collected on the following National Marine Fisheries Service (NMFS) dolphin abundance surveys: Monitoring of Porpoise Stocks (MOPS, 1986-1990) and *Stenella* Population Abundance Monitoring (SPAM, 1998). Environmental variability in coastal waters, representing the habitat of coastal spotted dolphins, is not considered because coastal waters were not sampled well on MOPS surveys and spatial variability in these waters is not resolved by available data.

ENSO Variability

Interannual variability in the eastern equatorial Pacific is greater than in any other region of the world's oceans, due to a natural cycle of the Pacific's ocean-atmosphere system called the El Niño-Southern Oscillation (ENSO). The eastern equatorial Pacific is part of the ETP area in which NMFS and the Interamerican Tropical Tuna Commission (IATTC) monitor dolphin abundance. The core area of distribution of the two depleted dolphin stocks (northeastern offshore spotted and eastern spinner), with a southern boundary at 5°N, is north of the eastern equatorial Pacific.

ENSO variability has been documented in the written record for hundreds of years (Quinn et al., 1987). It is evident in paleoclimatic records, with slight changes in amplitude and frequency, for thousands of years (Diaz and Markgraf, 1992). For example, a recent paper suggests that the frequency of ENSO variability increased progressively over the period from about 7000 to 5000 years ago (Rodbell et al., 1999), but such changes could not explain recent short-term changes in dolphin populations. Warming and cooling events, known respectively as El Niño and La Niña, now recur at periods of three to six years. Since 1970, El Niños have occurred in 1972-73, 1982-83, 1986-87, and 1997-98, with weak events in 1976-77 and 1991-92.

Monthly anomalies of indices reflecting the state of the ocean-atmosphere interaction known as ENSO are plotted in Figure 1: the Southern Oscillation Index is a standardized sea level pressure difference across the Pacific, the Niño-3 surface temperature anomaly and Trade Wind Index are anomalies of ocean temperature and surface winds in the eastern equatorial Pacific. El Niño is marked by low SOI, high Niño-3 temperature anomaly, and weak trade winds. La Niña is marked by anomalies of the opposite sign. The plots show that the MOPS surveys (1986-1990) were preceded by a strong El Niño in 1982-83. During MOPS, a moderate El Niño in 1986-87 was followed by a

strong La Niña in 1988. From 1989 through 1996, variability in the tropical Pacific was relatively low, except for a weak El Niño in 1991-92. Goddard and Graham (1997) interpret this period as a series of 3 events that were not fully realized. Their explanation involves a persistent warm patch in the central equatorial Pacific that interfered with the ocean-atmosphere interaction that normally results in oscillations between warm and cold states.

A strong El Niño began in mid-1997, one year before the start of SPAM98. This event slightly surpassed the 1982-83 event by all ENSO indices (Fig. 1). The 1997-98 El Niño ended during May 1998, when trade winds returned to near-normal strength, equatorial surface waters cooled from above-normal to below-normal temperatures, and precipitation decreased in the central and eastern equatorial Pacific. The NOAA/Climate Analysis Center reported in February 1999: Cold episode conditions continued to strengthen throughout the tropical Pacific during January..., we expect the cold episode to last at least for the next six months. Through January 1999, however, the 1998-99 La Niña cold event had not matched the amplitude of the 1988 event (Niño-3 surface temperature anomaly of -1.0°C , compared to -1.8°C).

Decadal-scale Variability

Temporal variability on scales longer than the nominal 4 years of ENSO has been observed in the North Pacific. Some time series are long enough to resolve this variability as decadal-scale or interdecadal (period of ~ 20 yrs), while studies of shorter time series have identified climate or regime shifts. From 1977 through 1988, an intensified winter Aleutian low resulted in major changes in the North Pacific: anomalous northerly winds in the central and western Pacific cooled surface waters, while anomalous southerly winds brought warmer and moister air along the west coast of North America and into Alaska (Trenberth and Hurrell, 1994). These changes had been identified as part of a 1976-77 climate shift (Ebbesmeyer et al., 1991), but are now recognized as unusually strong interdecadal variability.

Graham (1994) argues that surface temperature and wind anomalies of -0.5°C and 0.5ms^{-1} in the central and eastern equatorial Pacific during 1977-82 indicate a changed background state in the tropical Pacific that was linked to and perhaps even forced the changes observed in the North Pacific. However, Trenberth and Hurrell (1994) argue that the variability was atmospherically forced in the North Pacific. In any event, the decadal equatorial anomalies were only a fraction of typical ENSO anomalies. Although biological effects on phytoplankton and fish have been described for North Pacific interdecadal variability (Venrick et al., 1987; Polovina et al., 1994), we are not aware of any such effects described in the tropics.

Dolphin Habitat Distribution and Availability

Surface temperature and thermocline depth are important components of dolphin habitat (Reilly and Fiedler, 1994; Fiedler et al., 1998). Figure 2 illustrates variability of these variables in the eastern equatorial Pacific and in the core area of distribution of the two depleted dolphin stocks. The Niño-3 series show the warm surface temperatures and deep thermocline of El Niño events, and the cool surface temperatures and shallow thermocline of La Niña events. Variability in the dolphin core area is about half that along the equator, and lags the Niño-3 series by several months.

Phytoplankton biomass, measured as surface chlorophyll concentration, is consistently higher along the coasts of Central and South America and in equatorial water, although the amplitude of this pattern exhibits ENSO-related variability (Fig. 3). During MOPS 1987, when the 1986-87 El Niño was at its peak, and to a lesser extent during MOPS 1986, chlorophyll was low in the ETP, both along the equator and to the north. During MOPS 1988, when the 1988 La Niña was at its peak, chlorophyll was high throughout the MOPS area. During SPAM 1998, chlorophyll was high along the equator, where La Niña conditions were strengthening. Chlorophyll was still relatively low north of the equator, where effects of the 1997-98 El Niño were persisting, but higher than in 1987.

Reilly and Fiedler (1994) used canonical correspondence analysis (CCA) to relate dolphin community composition to variation in the environment measured on the 1986-1990 MOPS surveys. They found that habitat preferences of important dolphin species (and stocks) could be differentiated and that spatial distributions of species within and between yearly surveys could be explained by habitat variables including surface temperature and salinity, thermocline depth and strength, and phytoplankton biomass (chlorophyll concentration). Fiedler and Reilly (1994) used the CCA results with long time series of monthly temperature fields to study the temporal variability of species habitats.

CCA is an eigenvector ordination technique, like principal components analysis, but fits nonlinear unimodal (Gaussian) models to the species abundance data (measured as encounter rate of schools). Habitat suitability is the relative species abundance predicted at a point in space and time in response to linear combinations of measured environmental variables. Habitat availability (H) is the spatial mean of this response over the survey area.

Habitat suitability for the two critical dolphin stocks (northeastern offshore spotted and eastern spinner) was calculated for the MOPS and SPAM surveys using a six-variable model from CCA (surface temperature, thermocline depth and strength, surface salinity and sigma-t, and surface chlorophyll). Temperature and salinity data were taken from surface and subsurface fields generated by the NCEP data assimilation system that uses a general circulation model to fill gaps (Behringer et al., 1998). Thermocline depth was estimated as 20°C isotherm depth and thermocline strength as the difference between depths of the 15 and 20°C isotherms. Surface chlorophyll was measured on the surveys.

Both depleted dolphin stocks have a center of distribution in warm tropical surface water north of the equator in the ETP (Reilly and Fiedler, 1994), a habitat characterized by warm surface temperature and a moderately shallow and strong thermocline. Eastern spinner dolphins are more strongly linked to warm surface water (Fiedler and Reilly, 1994). Yearly fields of habitat suitability (Fig. 4) show that, for both species, the distributions of suitable habitat varied only slightly between years, although the amplitude of the pattern varied somewhat more (for example, the extent of habitat suitability <0.1 along the equator in 1988). The 1998 habitat patterns were within the range of patterns observed during MOPS.

Time series of habitat availability (relative mean habitat suitability) were calculated using a three-variable model from CCA (surface temperature and thermocline depth and strength).

Temperature data were obtained from two sources: 1) 1980-1998 from the NCEP data and 2) 1970-1979 surface temperature and isotherm depth fields from MBT, XBT, and CTD profiles in the NOAA/National Oceanographic Data Center World Ocean Database 1998 CD-ROM Data Set (Conkright et al., 1998) gridded with the objective analysis algorithm of da Silva et al. (1994). The 1970-1998 time series of monthly habitat availability values for NE offshore spotted and eastern spinner dolphins are strongly correlated ($r=+0.92$), although variability of eastern spinner habitat availability is considerably greater than offshore spotted habitat availability (Fig. 5). Both stocks show high habitat availability during El Niño events in 1972-73, 1982-83, 1986-87, and 1997-98.

In comparison, common dolphins have been rarely involved in the tuna fishery and are distributed in cool upwelling-modified waters off Baja California, along the countercurrent thermocline ridge (10°N), and in the equatorial cold tongue (Reilly and Fiedler, 1994). Estimated habitat availability for this species is low during El Niño events. Striped dolphins are not set upon by purse-seiners and are widely distributed in the eastern Pacific. Variability of habitat availability for this species is very low seasonally and almost negligible between years.

Conclusion

Year-to-year variability, caused by the El Niño-Southern Oscillation, in 1997-1998 was similar to that observed before and during the 1986-1990 MOPS surveys, both in the eastern equatorial Pacific and in the dolphin core area. Effects on dolphin distribution that might bias abundance estimates are not evident in yearly MOPS results, because the survey area is large enough to encompass interannual shifts in distribution (Wade, 1994; Gerrodette et al., 1998). Spatial fields of dolphin habitat suitabilities and phytoplankton biomass (chlorophyll concentration, an index of ecosystem productivity) for 1998 were within the range of variation observed during MOPS. The large-scale spatial pattern of these variables has not changed from year to year, only the amplitude of the pattern. This indicates that changes in the basic structure of the environment have not occurred over the last decade. Time series of ENSO indices, mean habitat suitability, and other environmental variables show no evidence of a recent regime shift or other long-term change that might affect population growth rates of depleted dolphin stocks.

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ENSO Indices

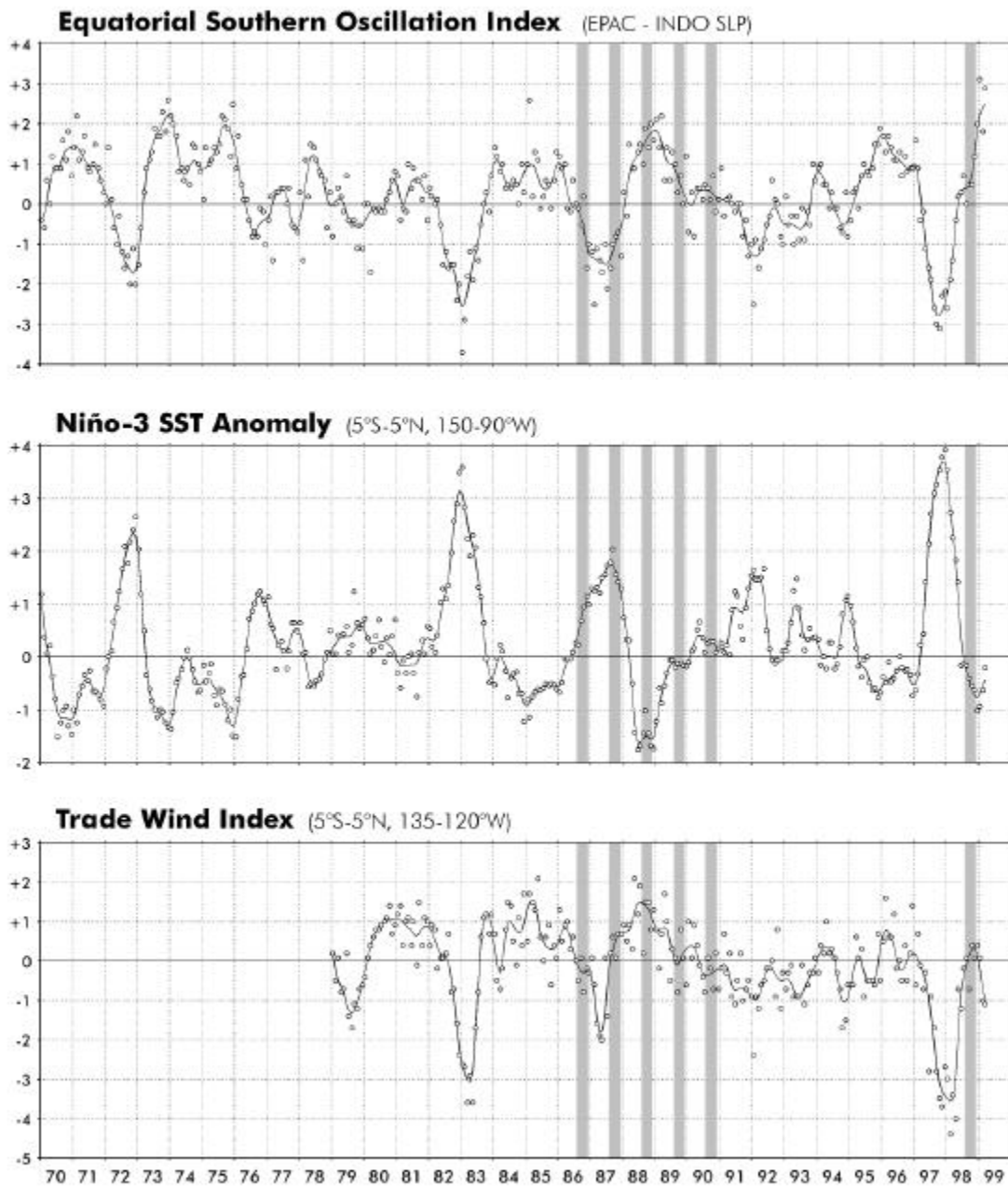


Figure 1. ENSO indices for the eastern equatorial Pacific through January 1999. Trade wind index is the 850-hPa zonal wind index (NOAA/NWS/Climate Prediction Center, Climate Diagnostics Bulletin). Gray bars mark MOPS (1986-1990) and SPAM (1998) surveys.

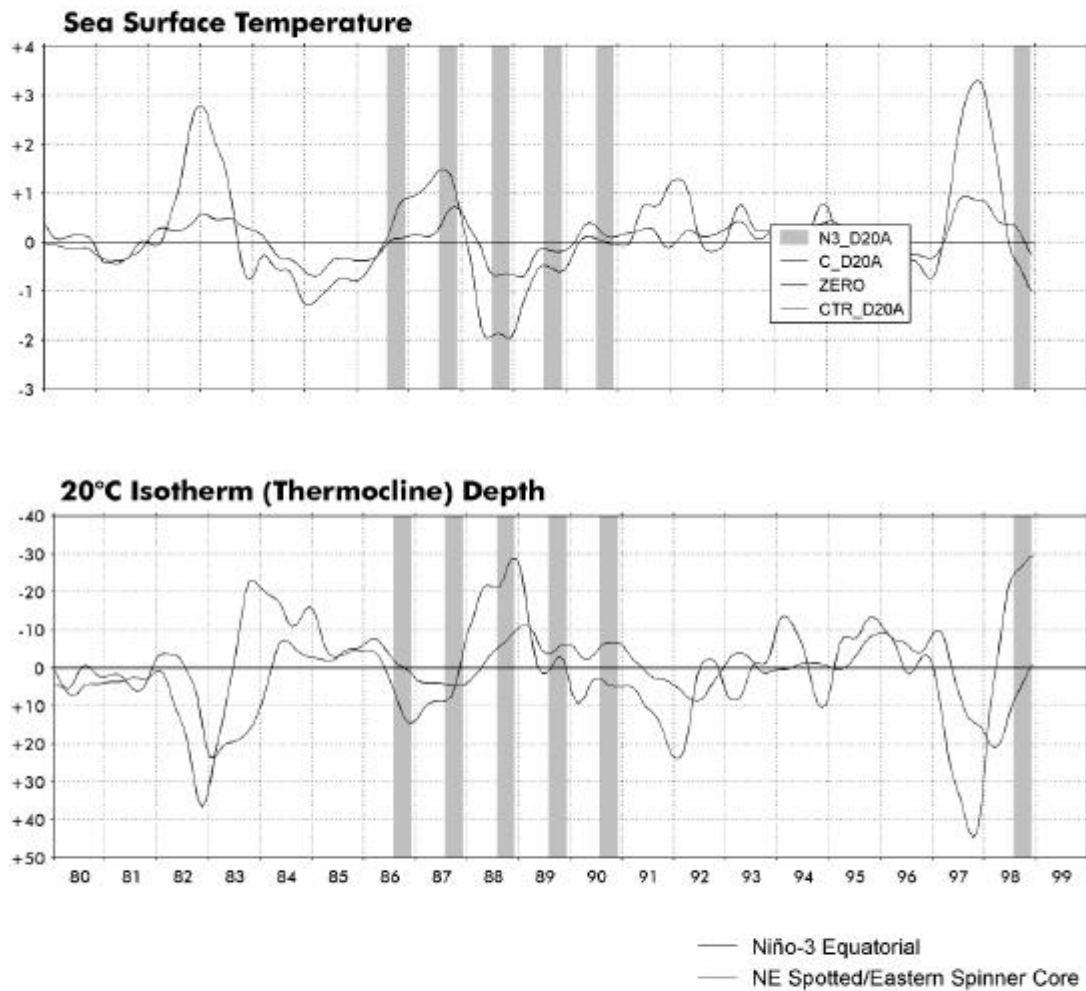


Figure 2. SST and thermocline depth anomalies (13-month running mean) for the eastern equatorial Pacific (Niño-3; 5S-5N, 150-90W) and the dolphin core area (5-20N, 110-81W). Data from NOAA/NWS/National Center for Environmental Prediction. Grey bars mark MOPS (1986-1990) and SPAM (1998) surveys.

Surface Chlorophyll (mg m^{-3})

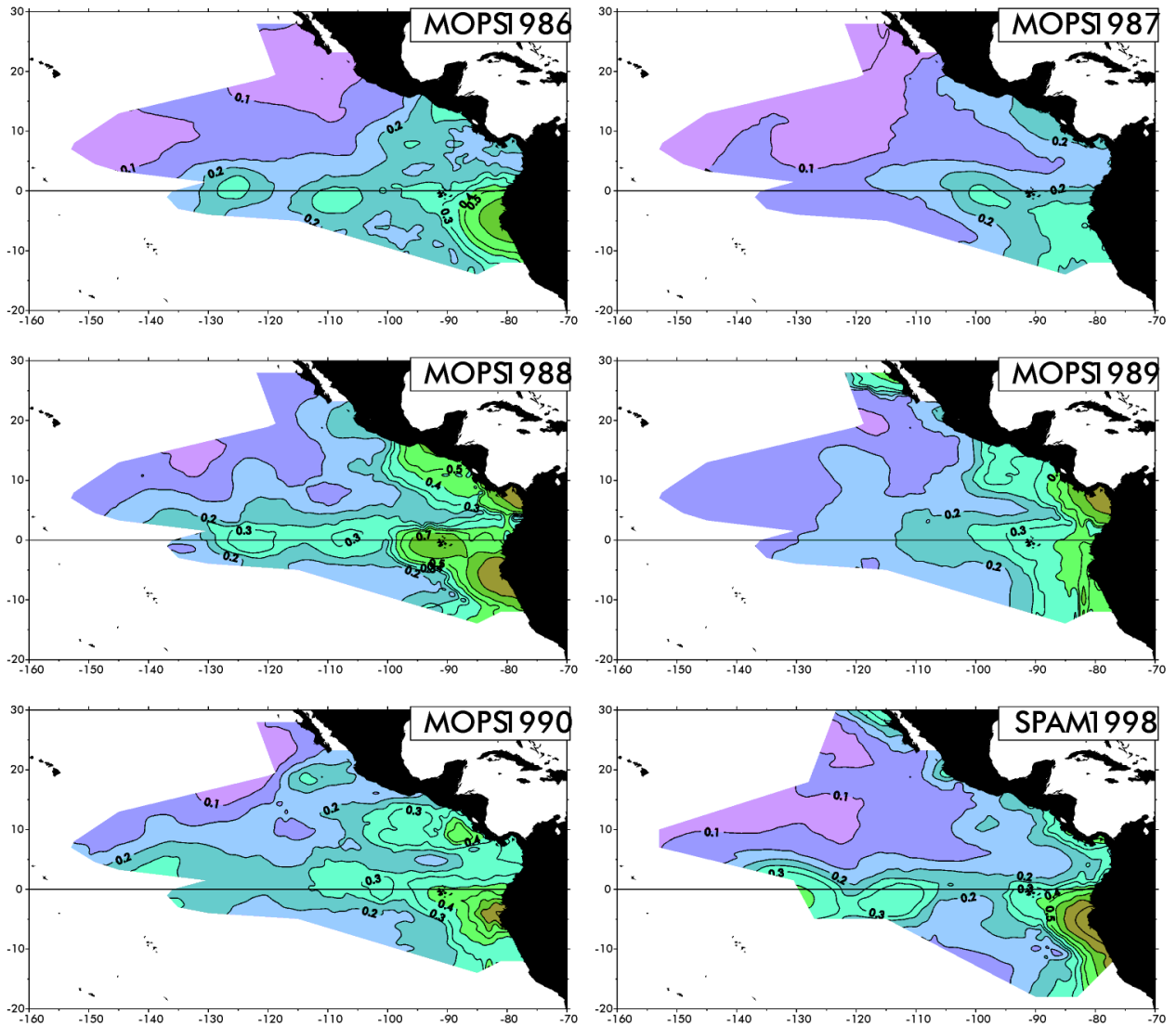


Figure 3. Surface Chlorophyll (mg m^{-3}) measured during August-November 1986 (n=817), 1987 (n=481), 1988 (n=1167), 1989 (n=852), 1990 (n=1748), and 1998 (n=1378).

Offshore Spotted Dolphin Habitat Suitability

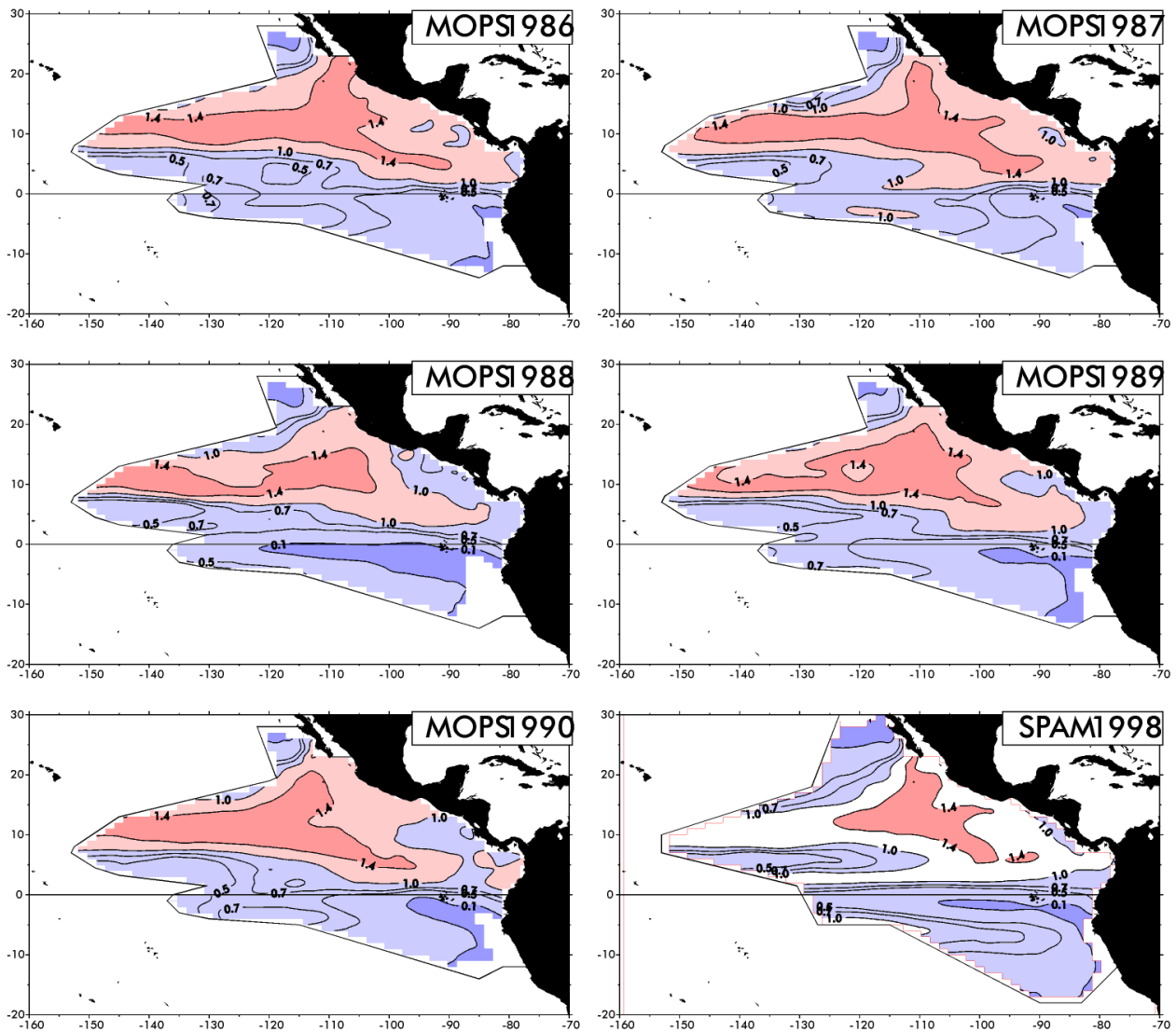


Figure 4a. Offshore spotted dolphin habitat suitability for August-November 1986, 1987, 1988, 1989, 1990, and 1998, calculated as described in the text.

Eastern Spinner Dolphin Habitat Suitability

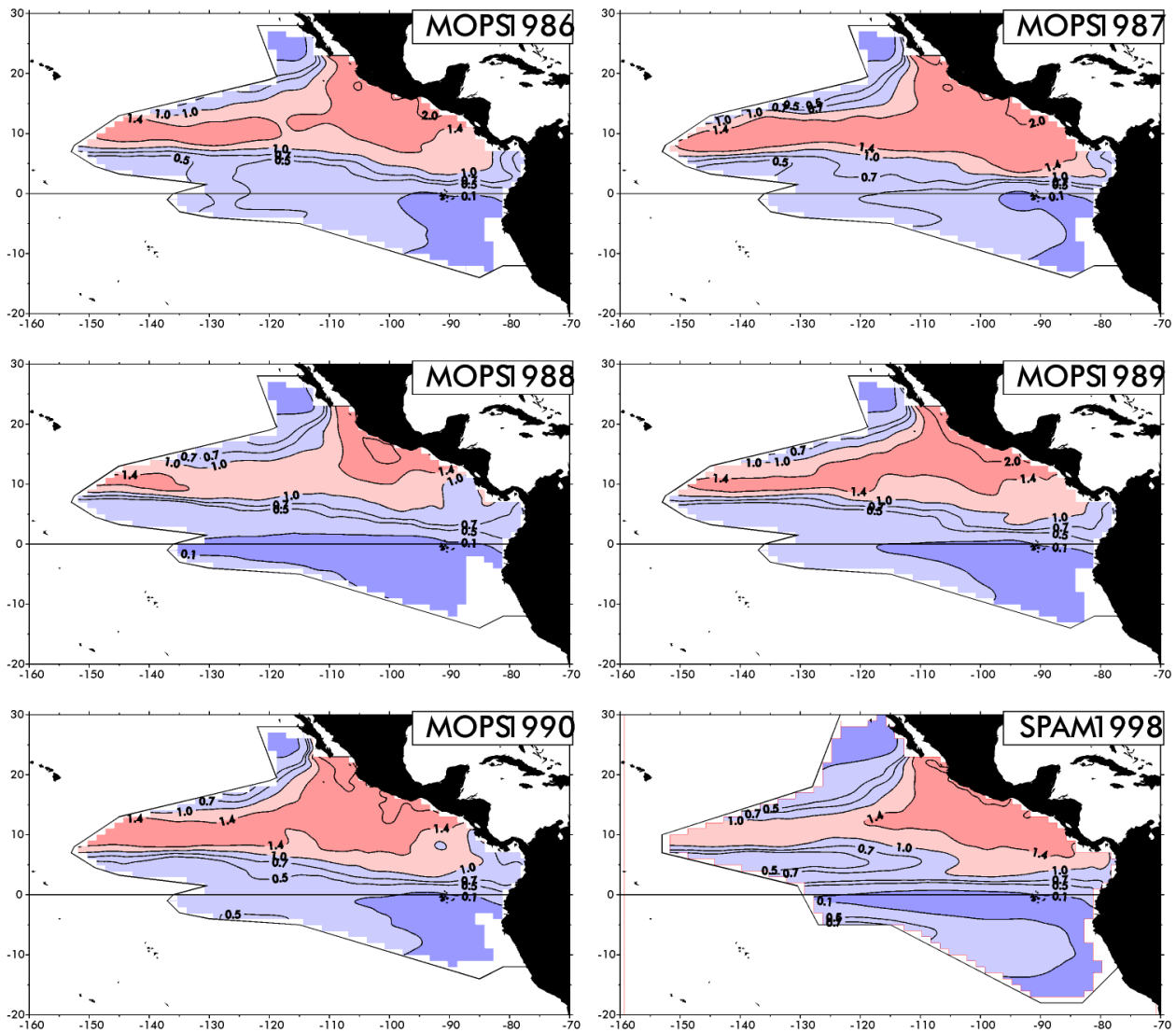


Figure 4b. Eastern spinner dolphin habitat suitability for August-November 1986, 1987, 1988, 1989, 1990, and 1998, calculated as described in the text.

Dolphin Habitat Availability

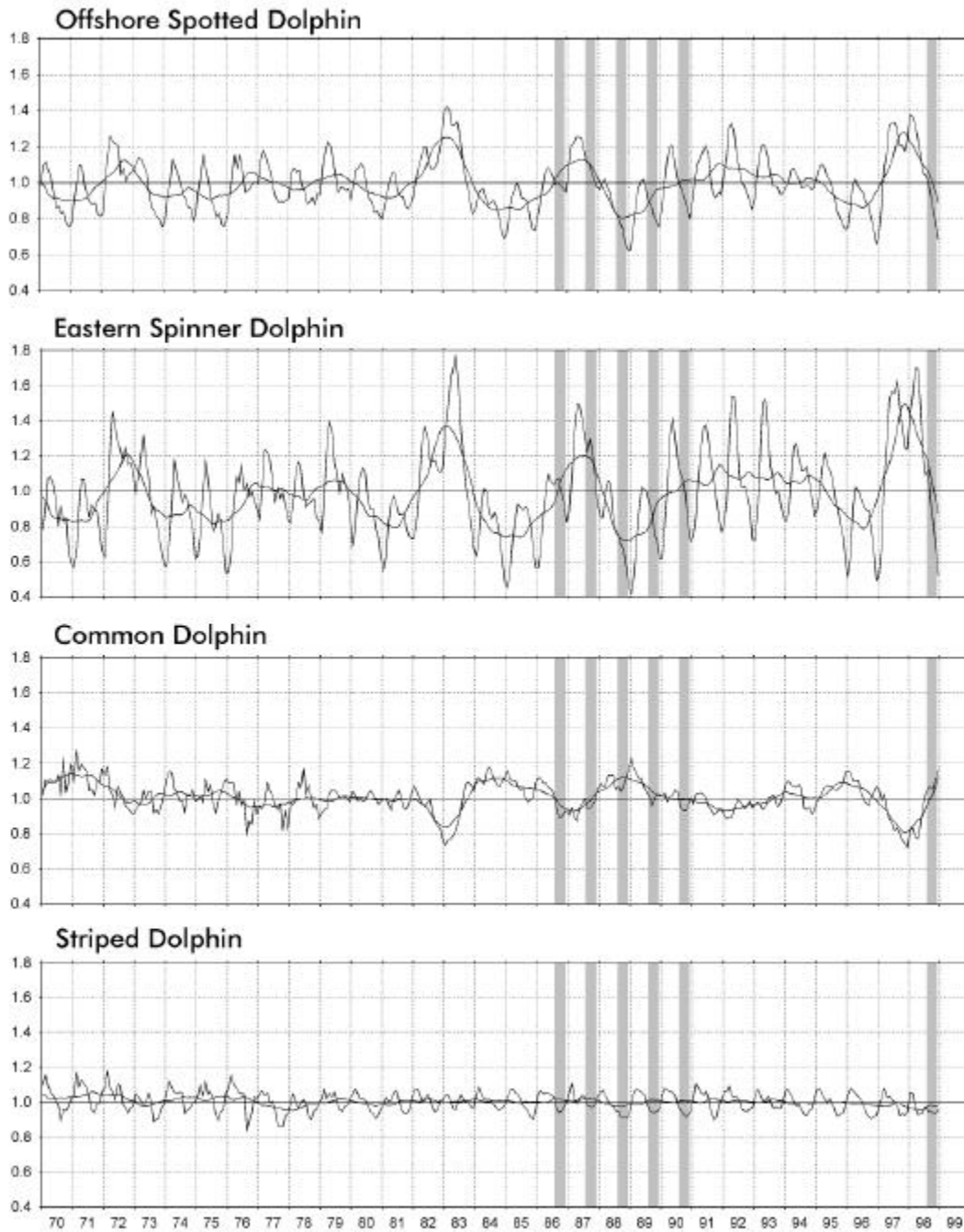


Figure 5. Dolphin habitat availability (H) in the MOPS survey area, monthly (thin line) and 13-month running mean (thick line), calculated as described in the text. Grey bars mark MOPS (1986-1990) and SPAM (1998) surveys.