Persistent Pelagic Habitats in the Baja California to Bering Sea (B2B) Ecoregion

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Abstract

The Baja California to Bering Sea (B2B) Marine Conservation Initiative seeks to establish a network of Marine Protected Areas within the Exclusive Economic Zones of the NAFTA countries- Canada, Mexico, and the United States. This network is designed to capture ecologically significant habitat for marine species of common conservation concern and pelagic regions of high productivity, with due consideration for the inter-annual sea surface temperature fluctuations of the El Niño Southern Oscillation (ENSO). Here, we present analytical methods that define pelagic habitat based upon the density of steep temperature gradients, or fronts, and we quantify their spatial and temporal persistence over a single ENSO cycle (1996-1999) to benefit marine conservation and marine management strategies.

We find that less than 1% of the Northeast Pacific ocean exhibits a persistent (> 8 mo/yr) concentration of temperature fronts (> .2km/km^2) within and between years. The Baja California Frontal System (BCFS) is the largest concentration found within the multinational federal waters, between 0 and 300 km east of Baja California Sur. The BCFS appears more active under La Niña conditions, while the next largest persistent concentration, North Pacific Transition Zone, appears more active under El Niño conditions. We demonstrate habitat functions associated with the BCFS for blue whales (*Balaenoptera musculus*), swordfish (*Xiphias gladius*), and striped marlin (*Tetrapturus audax*). We recommend management and protection for this pelagic "hotspot" to the Mexican government and the tri-national Commission for Environmental Cooperation.

Introduction

Pelagic habitat is an important component of marine management strategies that hope to protect highly migratory species like tuna, turtles, and whales. These species are all known to range over basin scales (Block et al., 2001; Bowen et al., 1995; Calambokides et al., 1990) with little regard for international maritime borders. Their annual migrations are tuned to the logic of comfort and resource abundance, tracking ocean conditions that favor warm winter water and nursing grounds for part of the year, and high productivity spurred in some areas by nutrients in the melting ice of summer flows in the other part of the year. While it was once thought that these migrations were direct, and without sustenance, it has been shown that some distant migrations use "stepping stones." For example, nearly half a million South American shorebirds stop in Delaware Bay to double their weight eating horseshoe crab eggs before continuing to nesting grounds in the Canadian Arctic (Harrington, 1996). In the Northeast Pacific, southward migrating blue whales are known to linger and feed as they migrate south on California and Baja California coasts (Mate et al., 1999). Marine management strategies that fail to identify pelagic "stepping stones" cannot guarantee full protection to pelagic species (Hyrenbach et al., 2000).

The United Nations Convention on the Law of the Sea granted coastal nations exclusive economic zones (EEZs) and provided exclusive rights to all waters and submerged lands within 200 nautical miles (370 km) of national coastlines (United Nations Convention on the Law of the Sea, 1982). This act doubled some national territories, and created new opportunities that bring contemporary concerns to bear upon marine managers in coastal nations. Benthic and pelagic seafood resources are valuable renewable natural resources, and sustain a major portion of the human diet in developed and developing nations. However, resource abundance can fluctuate on seasonal, interannual, and decadal scales (Kawasaki and Omori, 1988; Lluch-Belda et al., 1989). These resources are finite and exhaustible, a fact recently come to light in commercial fishing, in science, in law, and in the media. Pelagic resources are shared between the human population and marine populations. There is a compelling need to estimate pelagic resource abundance (e.g., Antarctic krill) to avoid the over-concentration of fishing effort (Hewitt et al., 2002). We must understand spatial and temporal variability in the open ocean if we ever hope to achieve sustainable maritime fisheries.

Pelagic fishery resources (e.g., tuna, anchovy, swordfish, and shark) can be particularly challenging for marine managers because these stocks are highly migratory, the fisheries for them are international and decentralized, and effort and landings are difficult to assess. The need for conservation and management of pelagic regions is growing due to the combined threats of pelagic overfishing (Worm et al., 2003; Pauley et al., 1998) and rapid developments in commercial (Roffer, 1987) and recreational (Roffer, 2000) fisheries technology. Studies of pelagic fish landings in the North Pacific indicate that these fishes stand at 10% of their historical abundance (Myers and Worm, 2003). The UN Fisheries and Agriculture Organization (1999) claims 21% of global fisheries are over fished, depleted, or recovering while 50% are at maximum capacity.

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Pelagic fisheries regulation traditionally takes the form of quotas, gear restrictions and time closures. These fisheries have thus far proven immune to spatial management strategies within national waters, because species aggregations and the features that drive them are ephemeral in space and time, and have not been well quantified. Yet, pelagic fisheries do have a spatial component and marine species can benefit from spatial management strategies. Commercial fishermen are known to focus their efforts on sea surface temperature (SST) and chlorophyll maps provided by commercial satellite fishing services (Terrafin, Roffer's, SeaStar) that collect data from the National Oceanic and Atmospheric Administration's (NOAA) Polar Operational Environmental Satellites (POES). Steep gradients in sea surface temperature and chlorophyll are known to provide habitat for some species, and aggregate others (Franks, 1992). High biological productivity is often attributed to these features, due to density-driven aggregation, and increased vertical flux resulting in high primary and secondary production (Olson et al., 1994: Olson and Backus, 1984; Owen, 1981; Fournier, 1979).

Hydrographic fronts mark the boundaries between two dissimilar water masses. These fronts can be detected in satellite imagery derived from passive remote sensing of infrared radiation emitted by the sea surface. SST products consist of a grid of cells (or pixels) with values for temperature. These products are available from NASA's Jet Propulsion Laboratory, and others, at different spatial and temporal scales. SST fronts are derived from edge detection algorithms, essentially slope functions that identify the highest rate of change in temperature across a surface, and discern this boundary between adjacent water masses. The density difference between these moving water masses acts to aggregate phytoplankton and zooplankton along the flow boundary, and to generate vertical advection in plankton and nutrients (Bakun, 1996). High concentrations of fish larvae and invertebrate larvae, and high primary productivity, are associated with shelf break and pelagic frontal features (Munk et al., 1995; Roughgarden et al., 1988)

Some species associations for pelagic temperature fronts are well documented. The endangered Loggerhead sea turtle (*Caretta caretta*) migrates along a 17° C isotherm in the Northeast Pacific Transition Zone (NPTZ) thought to aggregate jellyfish and other meroplankton (Polovina et al., 2000). Albacore tuna (*Thunnus alalunga)* landings are also concentrated along a .2 mg/m^3 chlorophyll isopleth north of the Hawaiian islands (Polovina et al., 2001; Kimura, 1997; Laurs et al., 1984). The presence, position, and strength of temperature fronts guide the Hawaiian and the North Atlantic longline fisheries for swordfish (*Xiphias gladius)* (Seki et al., 2002; Podesta et al.,1993). Regionally, bluefin tuna (*Thunnus thynnus)* (Schick et al, in review) in the Gulf of Maine, piscivorous seabirds in the Alaskan Aleutian Islands (Decker and Hunt, 1996; Kinder et al., 1993), neon flying squid in the Northeast Pacific (Gong et al., 1993) and sperm whales (Davis et al., 2002) and butterfish in the Gulf of Mexico (Herron et al., 1989) have also been shown to concentrate along frontal boundaries. These hydrographic features drive fisheries and species, so it seems proper that they drive some form of marine management strategy.

The North American Commission for Environmental Cooperation (CEC), established in 1993 to implement the environmental provisions of the North American Free Trade Agreement (NAFTA), is developing a network of Marine Protected Areas (MPAs) for Baja California to Bering Sea (B2B) region. This program seeks to identify both ecological and institutional linkages within the Exclusive Economic Zones (EEZ) of Canada, Mexico, and the United States, including Alaska. One project of the network is to define priority conservation areas (PCAs) for both benthic and pelagic habitats, using physical, biological, and social data with special consideration for interannual variation, e.g., El Niño Southern Oscillation (ENSO). To accomplish this task, we developed methods of analysis to define persistent pelagic habitat, and to quantify species associations for those pelagic habitats. Here we present spatial analysis methods we used to define pelagic habitats based upon steep temperature gradients, or fronts, in the Northeast Pacific.

Methods

We present a comparison of sea surface temperature frontal density across the Northeast Pacific for the years 1996-1999. These years include one of the most dramatic ENSO regime shifts on record (Chavez et al., 1999). The ENSO year June 1997 to June 1998 represents a strong El Niño and June 1998 to June 1999 represents a strong La Niña. (Patzert, pers. comm.) Using this approach, we capture frontal features in alternate ENSO phases. We map the distribution of large frontal concentrations for the Northeast Pacific, and quantify their persistence within and between years. We use these as proxies for high secondary productivity. We test this assumption qualitatively by comparing the strongest and most persistent frontal concentrations to published fisheries literature, and to residential behavior in tagged blue whales. Blue whales (*Balaenoptera musculus*) are an international transboundary stock recovering from overexploitation (Calambokides, et al., 1990) and they are a species of common conservation concern for Canada, Mexico, and the United States.

Frontal features are ephemeral in space and time, shifting north and south by 10 to 1000 km depending on the season, the year, and the state of ENSO. Some oceanic fronts are more stable, formed by persistent topographically steered convergences (Wolanski and Hamner, 1988) of warm and cold water masses (e.g., the Gulf Stream, the Loop Current, the California Current). These continental features are excluded here using techniques that minimize the search radius within a moving window over the grid surface. Frontal density analysis is one of three investigations designed to discriminate "ecological value" from satellite derived information. SST, altimetry, and primary productivity analyses all informed B2B's Priority Conservation Area (PCA) mapping exercise for Pacific North America. PCAs are defined as continentally unique areas of high biodiversity or ecological value, under anthropogenic threat, with opportunities for conservation. The B2B analysis extent is defined spatially at 12 N to 72 N, 90 E to 180 E and temporally between January 1996 and December 1999 (Etnoyer et al., 2002). Pelagic "ecological value" analyses were restricted to data sets that encompassed the entire B2B extent in space and time (Morgan et al, in press).

NASA's Jet Propulsion Laboratory (JPL) Physical Oceanography Distributed Active Archive Center (PO.DAAC) makes several SST data sets available from their PO.DAAC Ocean ESIP Tool (POET: http://seablade.jpl.nasa.gov/gui/) including daily, weekly, and monthly 9 km resolution Advanced Very High Resolution Radar (AVHRR) available from 1985 through mid-2003 and weekly18 km Miami Multichannel Sea Surface Temperature (MCSST) available from January of 1981 through January of 2001. NOAA Coastwatch West Coast Regional node offers 2.5 km monthly and bi-weekly composites for the survey time period, but not for the spatial extent. This information was only used to compare to lower resolution datasets.

Monthly averages minimize cloudiness (no data values) by averaging cloud-free data values. Clouds still obscure between five and fifteen percent of monthly averaged AVHRR. Large storm systems can hover in the Gulf of Alaska for weeks at a time. Edge detection algorithms run on daily AVHRR would therefore register a false paucity of temperature fronts in the Gulf of Alaska. Therefore, Miami MCSST, an interpolated cloud-free data product, was chosen to better represent the hydrographic regime of North Pacific waters. We tested the effect of temporal scale on edge detection by comparing frontal density persistence (described below) values in weeks per year to the frontal persistence values in months per year, and found temperature fronts derived from monthly 18 km interpolated SST satisfactory for a four year inter-annual study of the strongest most persistent hydrographic temperature fronts in the Northeast Pacific.

Mean monthly probability of front occurrence has precedent in studies of North Atlantic waters by Ullman and Cornillon (1999). Still, monthly averaged SST is not an ideal product for thermal edge detection. Edge detection algorithms run over a monthly averaged grid surface might confound a single front meandering over several weeks into many fronts which are fixed in position over the course of a month's time. This is a potential source of error. Theoretically, these artifacts would be evenly distributed throughout the dynamic regime of the Northeast Pacific, and error distributed evenly across a surface, we believe, should still lead to fairly accurate relative measures.

Temperature gradients are also scale dependent and can be highly fractured, with dozens of steep temperature gradients across a 100 km transect (Ullman and Cornillon, 1999). In an effort to better understand the effects of spatial scale upon edge detection, we compared edge position and line length across all these scales: 18 km MCSST, 9 km AVHRR, and 2 km Coastwatch for NOAA Subregion J, east of Baja California Sur.

We ran a slope function across a 3 pixel x 3 pixel (48 km x 48 km for the 18 km MCSST, 7.5 km x 7.5 km Coastwatch SST, etc.) moving window to identify the rate of change in temperature values, and we set a threshold for the highest rate of change (.02° C/ km), the top 10% in a histogram of flux across the grid surface. We converted those cell value features to lines by connecting the centerpoint of grid cells with greater than .02° C change between pixels. Figure 1 shows three different months of line output over three months averaged SST. We calculated the linelength in kilometers, and density of these lines in km/km^2, for each month over four years, across the Northeast Pacific.

Differences between the total predicted linelength of 18 km MCSST interpolated data (2800 km) and 9 km AVHRR data (1905 km) for the first week in January

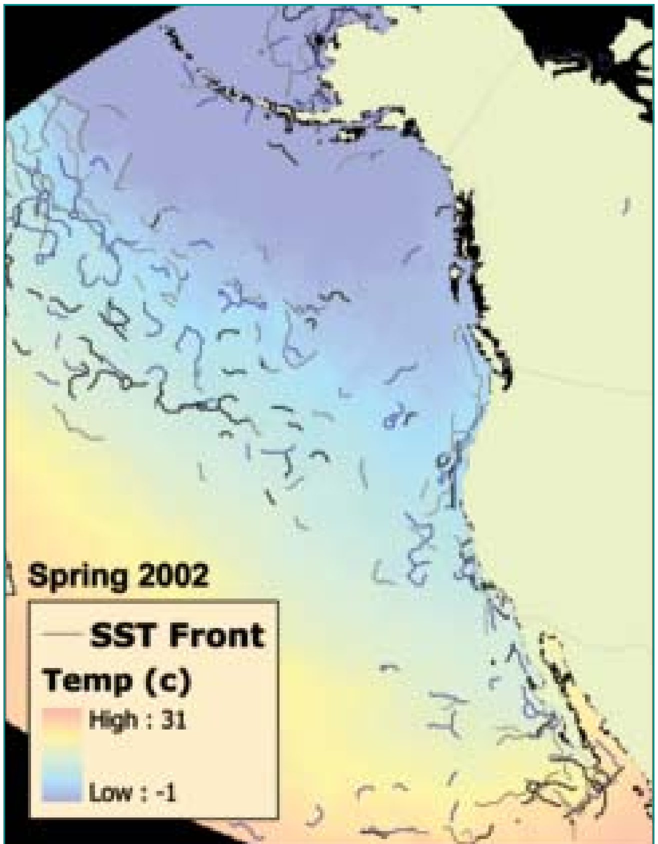

Figure 1*. Three months of steep temperature gradients overlaid on March-May averaged 2002 MCSST data*

1998, for example, were small, but differences between 2 km Coastwatch data (10,500 km), MCSST, and AVHRR for this month were large, with MCSST underestimating higher resolution line length by 80%. The frontal features were spatially consistent across all scales, but autocorrelated between coarse and medium scales.

Another moving widow calculation estimated the density of monthly frontal features, in kilometers, of front per pixel, and we set a "high density" threshold for the top 10% (6.5 km per 18 km^2) of those cell values. We generate binary monthly grids (1= high density, 0 = not high density), summing them to generate a grid of frontal density persistence values, in months per year. This strategy is akin to one an analyst might use to identify a "windy pass" in the terrestrial environment, rather than demarcate individual gusts and breezes. We use the resulting summed monthly grid to generate annual (June to May) maps of high density persistence. The maps identify only those aggregations that persist for more than three months (in green). A value of twelve (in red) means the region exhibits a high concentration of steep temperature gradients throughout the year (Figure 2). We compare the area of extent for persistent (> 8 mos) concentrations SST fronts between years.

We then compare the location of residential feeding behavior for Mate's tagged whales to the density of frontal features within our study area. Blue whales have been shown to capitalize on oceanographic regions (chlorophyll rich upwelling fronts) characterized by high productivity (Fiedler et al., 1998), and aggregate to feed upon krill within the Channel Islands (Mate et al., 1999). Satellite tagged blue whales in 1995 traveled directly from the Channel Islands down along the coast of Baja California during which time they are presumably either feeding or looking for food (Mate et al., 1999). Residential behavior is defined here as ten or more days within a 200km radius. Residential behavior by several blue whale individuals in a recurrent region, we assume, indicates a key habitat for this Marine Species of Common Conservation Concern at the CEC. Residential behavior at high trophic levels may also point to increased biological productivity, and a pelagic habitat for many other species. Therefore, we broaden the concept of a pelagic habitat with a review of fisheries literature to identify cross-taxa habitat functions for the largest, most persistent concentration of SST fronts in Pacific North American federal waters.

Results

Persistent concentrations of high frontal density are not omnipresent in the Northeast Pacific under either ENSO regime. Less than one percent (.52 %) of the grid cells exhibited a high density of temperature fronts for nine months or more, even under the most active conditions (La Niña, 1998-1999). These cells were all concentrated in a zone 500 km by 250 km, centered about 150 km off the coast of Pacific Baja California Sur, referred to here as the Baja California Frontal System (BCFS). We define the BCFS not as a single persistent front, but as a dynamic region characterized by a persistent high concentration of frontal features generated by the confluence of the cool southbound California Current and warmer northbound Davidson Current (a.k.a. the California Counter-Current) as it intersects the Baja California Peninsula.

The Northeast Pacific as a whole was less active (in terms of concentration and persistence) for SST fronts under El Niño (1997-1998) conditions (.29% of cells in the grid were active nine months and more), but the BCFS system remained the most persistent, and the most active region for temperature fronts in the Northeast Pacific between years (Figure 2). Persistent high-density cells were found outside of Mexico's EEZ in 98-99 in the North Pacific Transition Zone (> 9 mos/yr) and the Channel Islands, as seasonal (3 mos) and subannual concentrations (< 9 mos). Regions exhibiting seasonal (3 mos) activity account for less than 10% of the Northeast Pacific Ocean when summed. La Niña years appear more active for frontal features (9.35% are high-density cells for three months or more) than El Niño years (8.4% are high-density cells three months or more). We identified four small

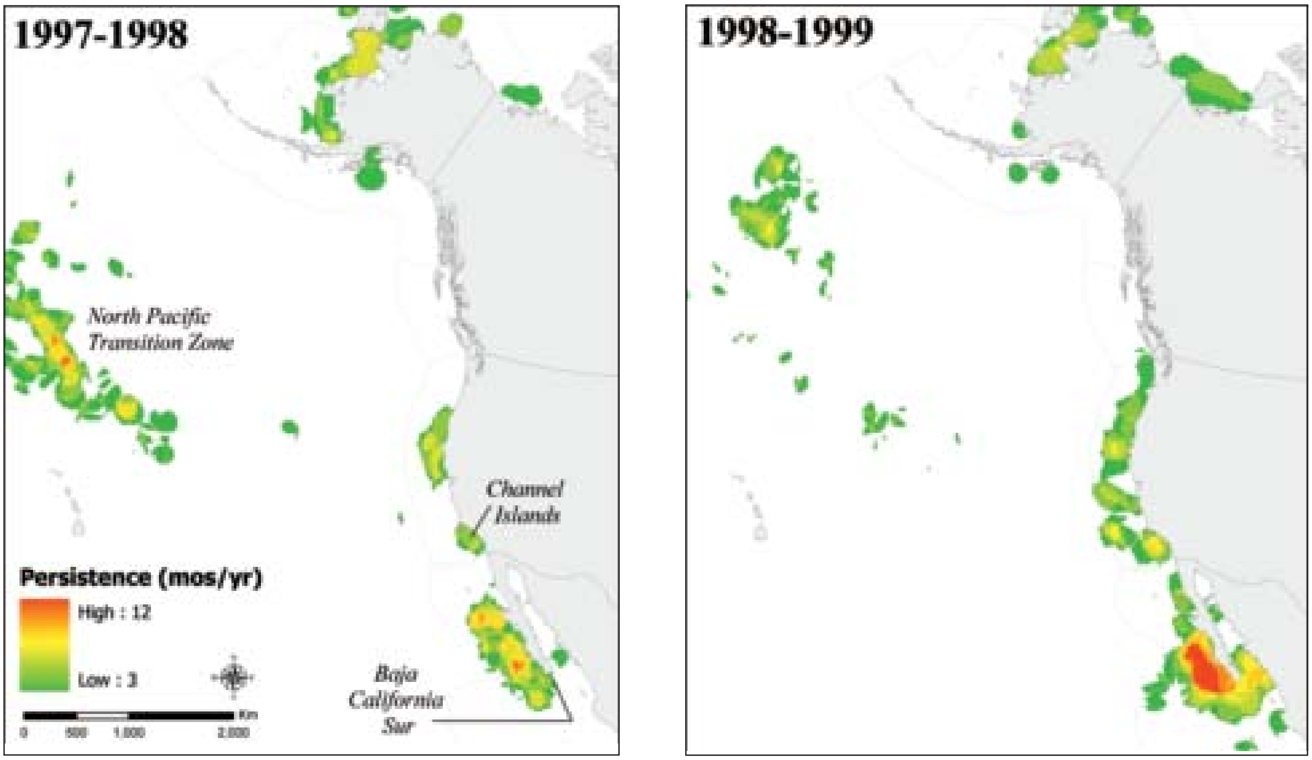

Figure 2. Persistence, in months per year, for concentrations of sea surface temperature fronts in the Northeast Pacific. Red values indicate exceptional densities of temperature gradients: 12 months per year. Green values indicate seasonal concentrations. The years defined June 1997-1998 (El Niño) and June 1998-1999 (La Niña) vary most in intensity near Baja California Sur and the North Pacific Transition Zone.

concentrations (averaging ~500 km^2) of frequent (6-8 mos) frontal concentration in the Northeast Pacific during the El Niño year of 1998—the North Pacific Transition Zone, Point Conception offshore, the Channel Islands, and BCFS. We also identified many offshore seasonal concentrations dispersed throughout the region.

Satellite telemetry on live pelagics reveals that the four tagged blue whales transiting the BCFS in October and November of 1998 lingered between two weeks and twenty-nine days within a radius of 225 km (Figure 3). Residence time in the BCFS varied from 11 to 25 days before continuing southeast, or losing data transmission. One whale (blu404175) traveled 2250 km in 16 days before taking up residence in the BCFS for 15 days within an 80 km radius. Individual whale movements consistently overlap frontal features, or maintain positions between two frontal features (Figure 4). Only one of two whales from 1995 displayed similar residential behavior in the BCFS. All six whales described in Mate et al. (1999) display similar residential behavior in the Channel Islands, where we find a high subannual concentration of frontal features.

A literature review of BCFS and species associations indicates truly exceptional landings of the swordfish *(Xiphias gladius)* (Sosa-Nishizaki and Shimizu, 1991) by 35 years of Japanese tuna longliners in the North Pacific, and the highest catch per unit effort (CPUE) over 10 years for striped marlin (*Tetrapturus audax*) in the entire Pacific (Squire and Suzuki, 1991; Figures 5 and 6). The region we refer to here as an "exceptionally persistent high concentration of temperature fronts in Mexico's Pacific EEZ" is referred to in fisheries literature as simply "the waters off Baja California." That vague terminology contrasts markedly with the depth of investigations into monthly catch per unit effort (CPUE) for tuna and billfish fisheries in the Pacific. Sosa-Nishizaki and Shimizu (1991) describe the waters off Baja California in terms of Japanese longline tuna boat concentration, saying "the size of this area begins to diminish from April, stays small in August and September, then expands again from October to reach its maximum in December."

Discussion

The North Pacific Transition Zone, Baja California Frontal System, and Channel Islands pelagic regions are shown here to be rare, spatially explicit, and persistent concentrations of steep temperature gradients in the Northeast Pacific within and between years. The

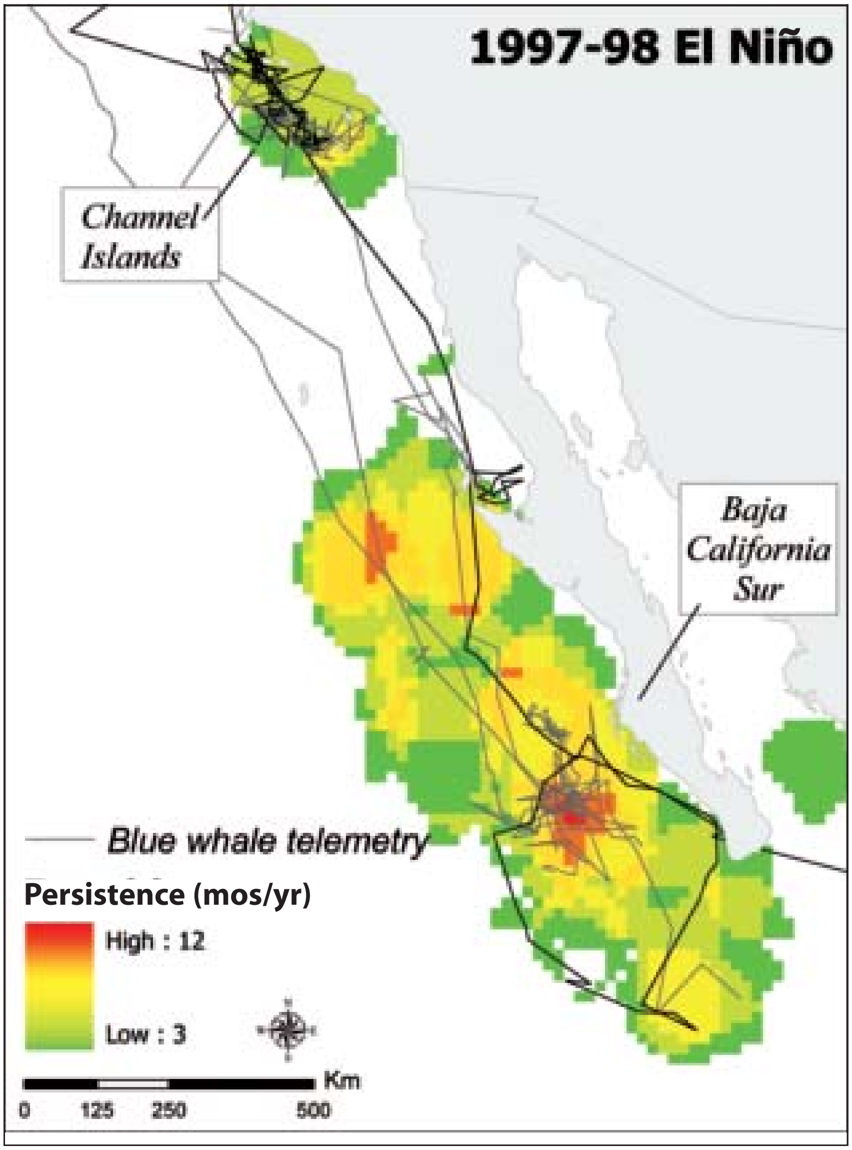

Figure 3. Blue whale telemetry from Bruce Mate, OSU overlaid on frontal density persistence values.

latter regions fall within the boundaries of the Baja to Bering (B2B) Marine Conservation Initiative. We recommended two ecologically valuable pelagic habitats for consideration as Priority Conservation Areas based upon this analysis—the BCFS and the Channel Islands. We have shown that these features are unique within the Northeast Pacific, they are persistent, they fall within an EEZ, and they provide habitat for commercial and endangered species. The Channel Islands satisfy threat and opportunity criteria, but the BCFS does not, so the BCFS was designated an "important oceanographic area" in the B2B PCA mapping exercise.

Temperature fronts near the BCFS are generated by mixing of the cool southbound California Current as it meets the warmer waters of northbound Davidson Current (also the California Counter-Current). The Gulf of California likely advects warm nutrient-laden water into the cooler waters of the BCFS, so it is possible that SST fronts themselves are only a physical part of the greater trophic exchange equation. The fisheries literature describes "expansion" in the BCFS area beginning in October. This coincides with the residence periods of our southward migrating blue whales. These whale migrations are presumably triggered by decreasing day length, increasing moonlight, or dropping September temperatures that may or may not signal resource abundance in the BCFS. Perhaps even the genetic memory of migratory experience imparts a softer departure date for blue whales feeding off Alaska.

It is remarkable that the 35 years of longline CPUE data described earlier does not consider interannual variability. Our analysis suggests that the temperature fronts around Baja are reduced during an El Niño year. El Niño may force warm, homogenous waters northward, or downward where they may be poorly resolved by the MCSST data. It is also possible that the dynamics of mixing are truly repressed under El Niño conditions.

Satellite telemetry from blue whales clearly demonstrates residence times of 15 to 30 days in and around this frontal system. Aerial surveys from Gendron (2002) further support our contention that the BCFS is an explicit pelagic habitat for blue whales. Still, commercial fisheries data proved to be the best quantitative measure of productivity to the highest trophic levels. Those data are coarse (5 degree) but they span the entire ocean basin, providing 50 years of evidence that the BCFS is as unique for fisheries in the Northeast Pacific as it is for temperature gradients. The coincidence of Swordfish, striped marlin, and blue whale populations begs important questions-for example, What are they eating? What other species frequent the area? Swordfish and striped marlin are known to be non-selective, feeding on squid, anchovy, and mackerel. Blue whales are thought to feed exclusively on krill. Therefore, these waters either support separate and abundant prey populations, or one of these pelagics is switching prey.

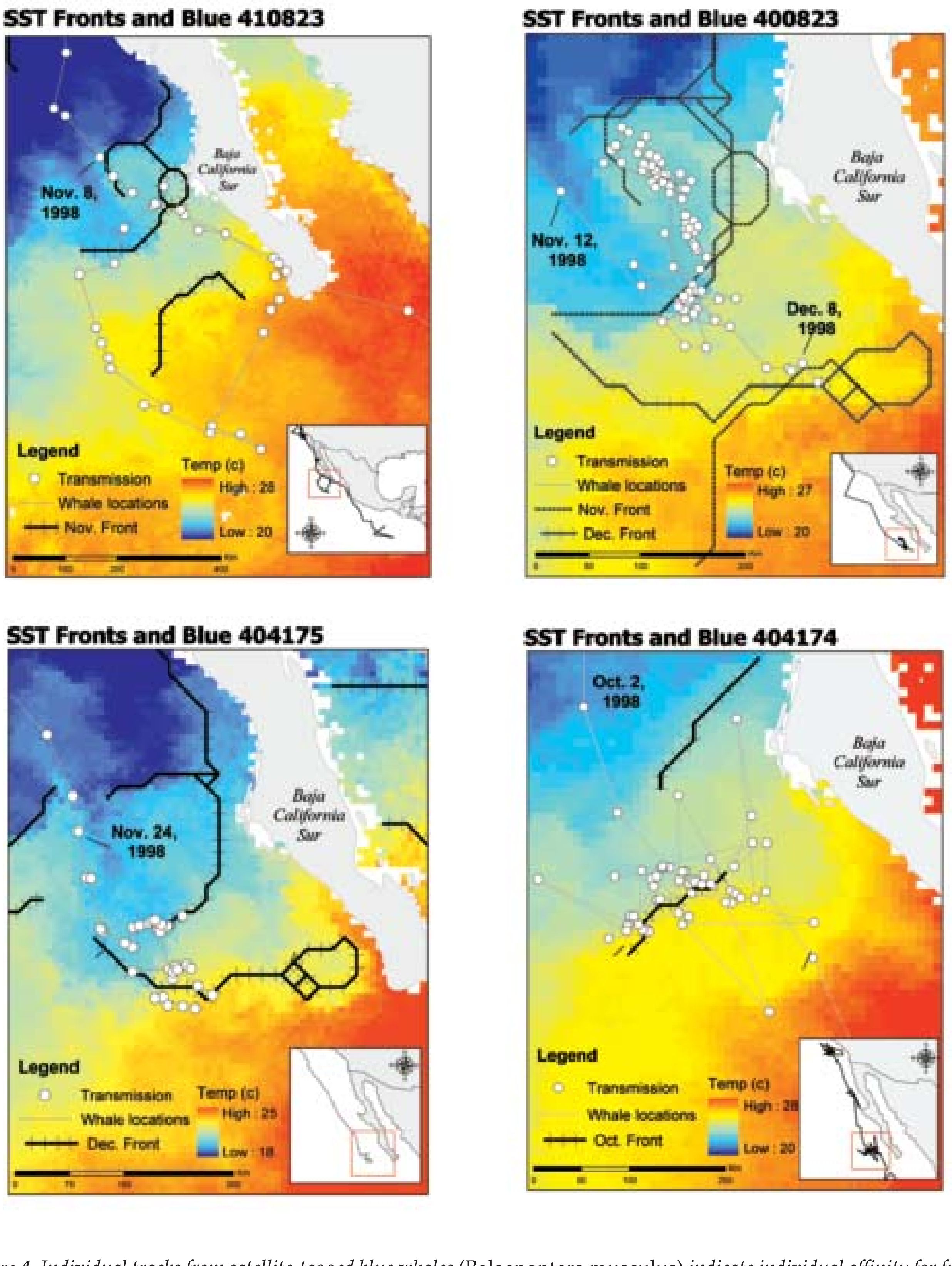

Figure 4. *Individual tracks from satellite-tagged blue whales* (Balaenoptera musculus) *indicate individual affinity for frontal features in and around the Baja California Frontal System. These whales were on a southeastern bearing before circling in the BCFS. A greater extent of their migrations are shown on insets to the lower right of each panel. Lines between locations indicate the chronological order of locations and do not represent the whales' actual tracks between locations.*

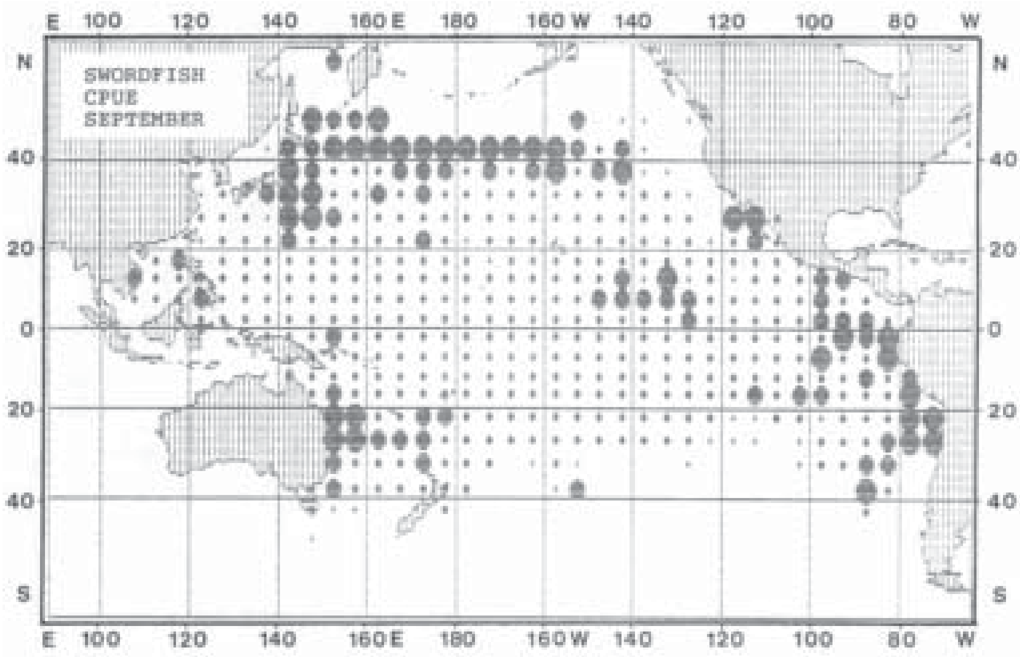

Figure 5. Reprinted from Sosa-Nishizaki and Shimizu, 1991. Monthly swordfish catch per unit effort (CPUE) from Japanese longliners, averaged over 35 years. Swordfish landings are consistently high off Baja California.

Something draws species to the BCFS from far away. Squire and Au (1990) observed a rapid rebuilding of striped marlin populations after the cessation of Japanese longlining in the Mexican EEZ in 1979, which they attributed to immigration from other areas of the Pacific into the "major feeding and growth area in the Northeast Pacific." For Loggerhead turtles like J. Nichol's *Adelita,* there is also evidence of distant emigration from this region, in a six-year, trans-Pacific journey from Baja California to Japan (Nichols et al., 2000). The BCFS is clearly known to Mexican researchers as a special place in Mexican waters. This study simply shows that the BCFS is a very special place in the entire North Pacific, and that it lies within the federal waters of the B2B Marine Conservation Initiative. This study also shows that smaller, less persistent frontal systems populate Northeast Pacific federal waters.

Mexico has a history of fisheries research and management, but scientists and managers will need international support and recognition to extend Mexican management capacity into Pacific pelagic waters. Mexico felt the economic sting of "dolphin-safe tuna" standards in 1992. Even now, Mexico is protesting a US embargo of net caught tuna before the World Trade Organization. But these are gear and trade issues. The recreational fishing industry may offer some hope for spatial management in a continentally significant pelagic feature like the BCFS. Sport fishing for billfish has been a permitted activity in Mexico since 1937, with an economic value that rivals commercially fished tuna. Waters within 50 nautical miles of the Baja California coast have been reserved for sport fishing since 1983, with an adjacent "billfish protection zone" in the Pacific (Sosa-Nishikazi, 1998). At the very least, sport fishing puts some boats on-the-water with some limits, some standards, and some accountability. Squire and Au (1990) called for "core area management" in the waters off Baja California more than a decade ago. Fortuitously, that study reached its conclusion based upon fisheries biology, and this one reached the same conclusion based upon satellite oceanography.

These results best distinguish heterogeneous waters from homogenous waters across broad latitudes, and only in two dimensions. Further studies should investigate the most understudied, dynamic, and accessible of these areas, the BCFS, at a high spatial resolution in three dimensions, and seek to further quantify multi-specific species aggregations with an active live sampling program. Also, the general effect of temporal and spatial scale upon edge detection warrants some further investigation. Daily cloud-free interpolated sea surface temperature for the Northeast

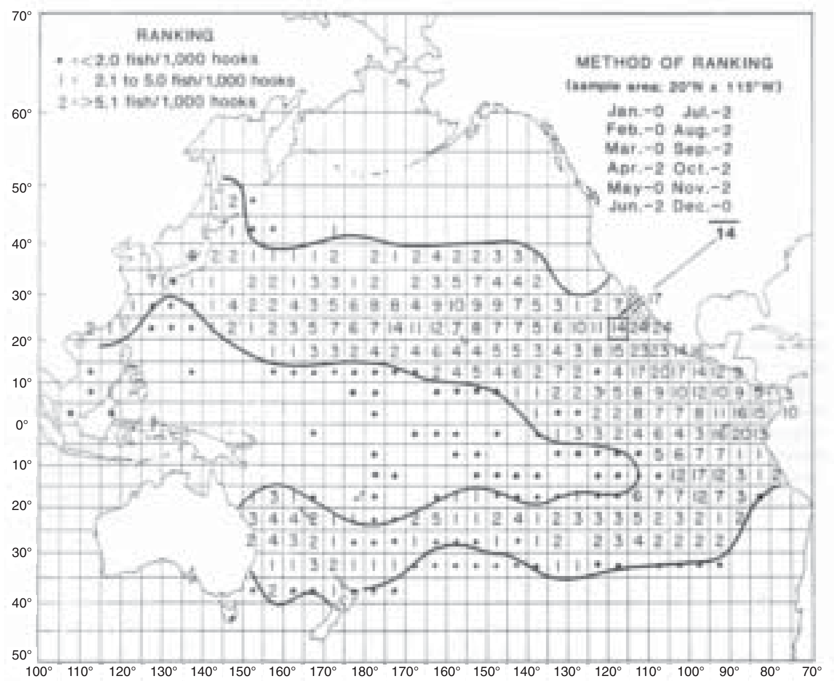

Figure 6. *Image reprinted from Squire and Suzuki (1991). The ranking system used in this analysis quantifies catch per unit effort for striped marlin in the Baja California Frontal System at > 5.1 marlin per 1000 hooks, 12 months of the year for 10 years. This is the highest possible rank.*

Pacific from the 1/16th degree Navy Layered Ocean Model, for example, may be well suited to this purpose (Rhodes et al., 2002). Ultimately, the finest examinations will pursue daily, high-resolution (< 4km pixel) sea surface temperature available from Coastwatch or from MODIS for small geographic regions, and these examinations will compare those daily SST data to daily blue whale telemetry. Billfishes may not surface enough to transmit daily geoposition.

The efficacy of results from interpolated coarse grain data should also be questioned and further examined. Satellite derived SST data are plagued by clouds, and edge detection algorithms often underestimate the density of temperature fronts (P. Cornillon, pers comm.). Considerable cloud contamination in the 9 km AVHRR monthly SST data seaward of British Colombia suggests that the interpolated 18 km Miami SST data are unlikely to resolve meaningful gradients north of Vancouver, Canada. It is our suspicion that a lack of high-density concentrations may not be indicative of a lack of meaningful convergences, though boreal waters north of Vancouver are dominated by Arctic waters, and more homogenous (in degrees C) than temperate waters.

The first step for conservation of pelagic habitat is to illustrate and describe features like those mentioned here, and to document their functions for species, and then to address the pressures upon them. Enforcement capacity for pelagic features is limited. Our understanding of these features is weak. Satellite-driven research design has a short history, but offers as much promise to management as it does to fisheries. Management and policy decisions will be made according to each country's needs and realities, but international organizations like the CEC must emphasize the need for pelagic management with similar satellite driven research. The CEC has officially recognized these pelagic features as "important oceanographic areas." We duly encourage the NAFTA countries to extend their management capacity to the frontiers of their EEZ, and to pursue pelagic protected areas for endangered and non-endangered marine species.

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Striped marlin 40 miles off Magdelena Bay, Baja California
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