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BLUE WHALE (*BALAENOPTERA MUSCULUS*) DISTRIBUTION IN THE EASTERN TROPICAL PACIFIC

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ABSTRACT

The distribution of blue whales, *Balaenoptera musculus,* in the eastern tropical Pacific (ETP) was analyzed from 211 sightings of 355 whales recorded during research vessel sighting surveys or by biologists aboard fishing vessels. Over 90% of the sightings were made in just two areas: along Baja California, and in the vicinity of the Costa Rica Dome (a large, stationary eddy centered near 9°N, 89°W), with the rest made along the equator near the Galapagos Islands, the coasts of Ecuador and northern Peru. All sightings occurred in relatively cool, upwelling-modified waters. Because these areas are the most productive parts of the ETP, and have relatively large standing stocks of euphausiids, it seems possible that blue whales select low latitude habitats which permit foraging. The waters off western Baja California were occupied seasonally, with a peak in sightings coinciding with the spring peak in upwelling and biological production. The Costa Rica Dome area was occupied year round, suggesting either a resident population, or that both northern and southern hemisphere whales visit, with temporal overlap. The modal group size was one for all areas and seasons, but the frequency of groups with two or more whales was significantly higher in sightings made near the Galapagos Islands and the coast of Ecuador and northern Peru.

Key words: blue whales, *Balaenoptera musculus,* distribution, oceanography, tropical Pacific.

Ecological aspects of blue whale distribution and feeding in high latitudes have been studied extensively from whaling operations (Beklemeshev 1960; Mitchell 1975; Nasu 1963, 1966; Nemoto 1957, 1959, 1970; Uda 1954; and others). The ecology of their distribution outside of the high-latitude whaling regions has been little studied (Gaskin 1982). A relative wealth of information on physical and biological oceanography of the eastern tropical Pacific (ETP)

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(*e.g.*, Blackburn 1968, Brinton 1979, Hansen and Herman 1988, Longhurst 1976, Love 1972, Wyrtki 1966), coupled with nearly 20 yr of sighting effort for cetaceans, provides an opportunity to study some aspects of blue whale distributional ecology in a tropical region.

Here we delimit the ETP oceanographically, following Wyrtki (1966), as comprising the Tropical, Equatorial and Transitional surface water masses of the eastern Pacific. These lie roughly within 25°N, 10°S, the American continents and 130°W.

The classical depiction of blue whale distribution (*e.g.*, Lockyer and Brown 1981, Mackintosh 1965) describes a seasonal migration between high latitudes, where they feed extensively and exclusively on euphausiids, and low latitudes where they mate and give birth, but do not feed. Since foraging has not been considered an important factor in their low latitude distribution (Mackintosh 1966), previously published information does not indicate what factors determine the choice of "winter" habitat.

While most blue whales are assumed to migrate to high latitudes during part of each year, data from both the Pacific and Indian Oceans indicate that some individuals may remain in low latitudes year round. Blue whales have been seen in all seasons off Peru (Donovan 1984) and in the Northern Hemisphere portions of the Indian Ocean (Yochem and Leatherwood 1985). Similarly, all individuals may not leave high latitudes each year; Kellogg (1929) reported sighting a few blue whales near South Georgia throughout the Antarctic winter.

When in temperate and tropical zones blue whales are known to occupy both pelagic and coastal shelf waters (Leatherwood and Reeves 1983, Yochem and Leatherwood 1985). In the eastern Pacific, blue whales have been reported from the Gulf of Alaska and near the Aleutian Islands (Nishiwaki 1966), in the mid-Pacific between 20°N and 35°N (Yochem and Leatherwood 1985), on and near the coastal shelves of North America (Kellogg 1929, Rice 1974, Scammon 1874) and South America (Aguayo 1974, Clarke 1980, Donovan 1984).

Whaling records from South American land stations indicate that blue whales were rarely captured north of about 30°S in the Peru Current (Clarke 1980, Mackintosh 1965), but Donovan (1984) reported 10 sightings made in two days between 4°S and 8°S within about 100 km of the coast. The Baja California peninsula and Gulf of California are known as gathering places for relatively large numbers of blue whales with peak abundance during the northern spring (Rice 1974; Sears 1987; Vidal *et al.*, in press).

Few blue whale sightings have been reported for the tropical Pacific. Their absence off Baja California during November through January in Rice's (1974) data caused him to surmise that they had either moved south into Tropical waters, or west. Wade and Friedrichsen (1979) reported 20 sightings in the northern winter in the ETP (from the same sources included here), 19 of which were very localized off Central America near a major oceanic eddy, the Costa Rica Dome, centered near 9°N, 89°W (Wyrtki 1964). They cited previous blue whale sightings made there in 1928 (Kellogg 1929), and sightings at this location of unidentified rorquals made in 1975 (Volkov and Moroz 1977). Having data from only one season, Wade and Friedrichsen (1979) interpreted

this to be a wintering area, but noted that the high standing stock of zooplankton reported for the Costa Rica Dome may also permit feeding.

Berzin (1978) identified 24 of the rorquals cited by Volkov and Moroz (1977) off Central America as blue whales. From the sightings of blue whales off Central America during both March and June of 1975, Berzin (1978) speculated that they may represent a resident population. While two sets of sightings made two and one half months apart are weak grounds for such speculation, our results indicate that Berzin may well have been correct.

In this study we report 211 sightings of 355 blue whales in the ETP made during 1975–1988, and discuss seasonality, habitats occupied, and potential population structure for the region, including the possibility that a year-round occupation of the Costa Rica Dome area represents a resident population. We did not attempt an estimate of absolute abundance, feeling that to be beyond the scope of our data.

Materials and Methods

We compiled sightings of blue whales made in the ETP from two sources: (1) research vessel sighting surveys conducted by the U.S. National Marine Fisheries Service (NMFS) since 1974 specifically to search for cetaceans, and (2) sightings made by NMFS scientific observers on commercial tuna fishing boats operating in the ETP since 1968 and by Inter-American Tropical Tuna Commission observers since 1977. Beginning in 1975 the tuna vessel observers recorded data on vessel operations, allowing computation of an approximate index of searching effort (km traveled while searching). Research vessel searching effort has been recorded in detail (*e.g.,* Holt and Sexton 1989). Sightings and search effort were combined from both platform types, comprising 211 sightings made during 12,175,200 km searching in good sighting conditions (Beaufort 4 or less) and all months of the year.

Observers on both platform types were trained in cetacean field identification and recorded (at minimum) identifying characteristics, date and location of sighted animals. Nominal blue whale sightings were verified twice. First, upon return of an observer from a cruise all cetacean sightings were screened by data editors to see if minimal characteristics were recorded to provide identification to the species level. Second, we reviewed each sighting at the onset of this study for consistency of identification criteria (following Leatherwood and Reeves 1983). We also screened the sightings for possible duplicates—a concern given the vast amount of search effort included here—and found none.

The research vessels typically approached all sighted schools of small cetaceans and most large cetaceans to allow identification and counting of numbers present. The tuna vessels rarely diverted for large whale sightings because their targets were fish and dolphins, so that most large whales seen from these vessels were not identified unless close enough to the vessel for the scientific observer to examine them with hand-held binoculars. We assume this negative bias in representing absolute abundance to be constant throughout the year and for all parts of the ETP, so that tuna vessel observer data, like research vessel data,

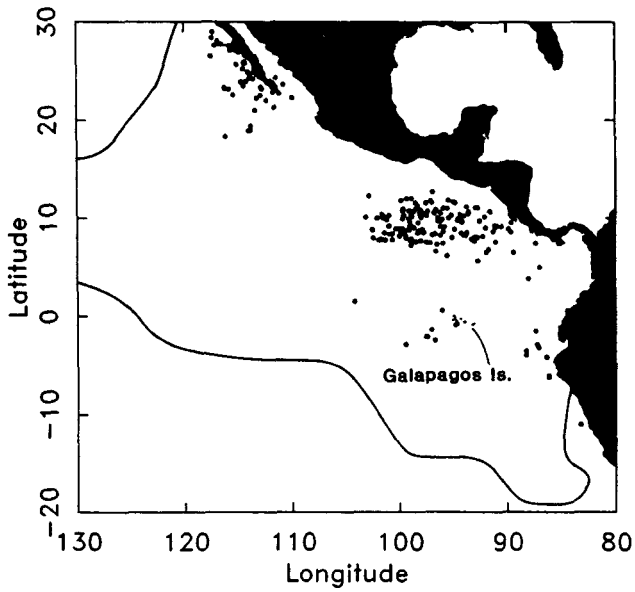

Figure 1. Spatial distribution of 211 blue whale sightings in the eastern tropical Pacific, 1974–1988. The boundary line encloses the area in which there was at least 185 km search effort per one degree latitude–longitude block.

provide an unbiased representation of spatial and seasonal distribution patterns for blue whales.

Relative densities of blue whales were computed for one-degree latitude–longitude blocks. Density estimates were calculated as whales seen per km searched during periods of good sighting conditions (Beaufort 4 or less), in one-degree squares for which there was at least 185 km searching effort. This minimum effort level was selected following Polacheck's (1983) sensitivity analyses of tuna vessel observer data for estimating cetacean encounter rates. Relative density estimates were made by calendar quarters, pooled over 1975–1988, to examine intra-annual variation. There were too few sightings per year to allow meaningful examination of inter-annual variation.

Group size estimates were analyzed by sub-areas within the ETP, to test for intra-regional differences, using contingency table analysis with all sightings of three or more pooled into one category.

Results

All sightings were made within three (or perhaps four) relatively small areas (Fig. 1), while a much larger total area was searched with at least the minimum amount of effort (Fig. 2). The largest subset consists of 150 sightings made off Central America in a distinct aggregation bounded by 85°W–10°W, and about 6°N–13°N, centered near the Costa Rica Dome. An aggregation of 43 sightings

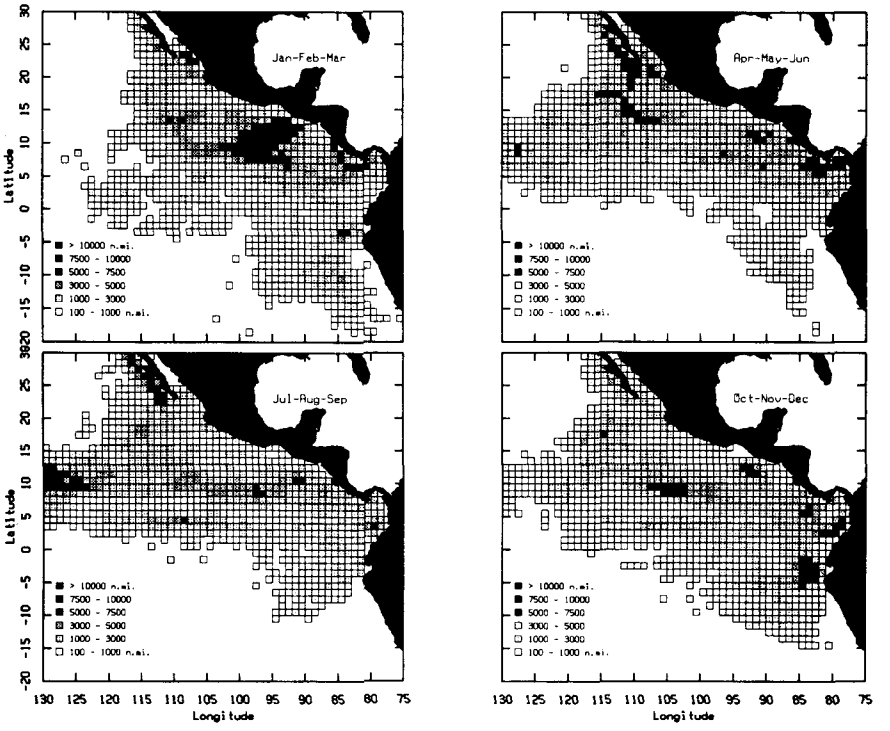

Figure 2. Searching effort for cetaceans in the eastern tropical Pacific, by calendar quarter, 1975–1988. Data are combined from research vessel surveys and from scientific observers onboard tuna purse seiners. Only one degree latitude–longitude blocks with at least 185 km (100 n. mi.) searching are included.

occurred along Baja California. Smaller numbers of sightings were made off Ecuador and northern Peru (11), and near the Galapagos Islands (7).

The aggregation off Central America occurred during all four calendar quarters (Fig. 3), but was most dense during January–March, when it was also distinctly separated from the coast. During the second and third quarters there was an apparent shift to the east, with more sightings made near the coast, and very few made west of 95°W.

Blue whale sightings near Baja California varied seasonally (Fig. 3). During April–June, sightings were made from south of Cabo San Lucas to north of 25°N, the northern limit of the study area. Very few blue whales were seen there during July–September. During October–March blue whales were observed off Baja California, but only near the southern tip, and a little farther south near the Revillagigedo Islands (near 19°N, 111°W). The few sightings made along the equator and near the coast of South America may represent one or two aggregations.

The modal group size recorded for all seasons and aggregations was one, with single whales accounting for 67% of the sightings. There was a significant

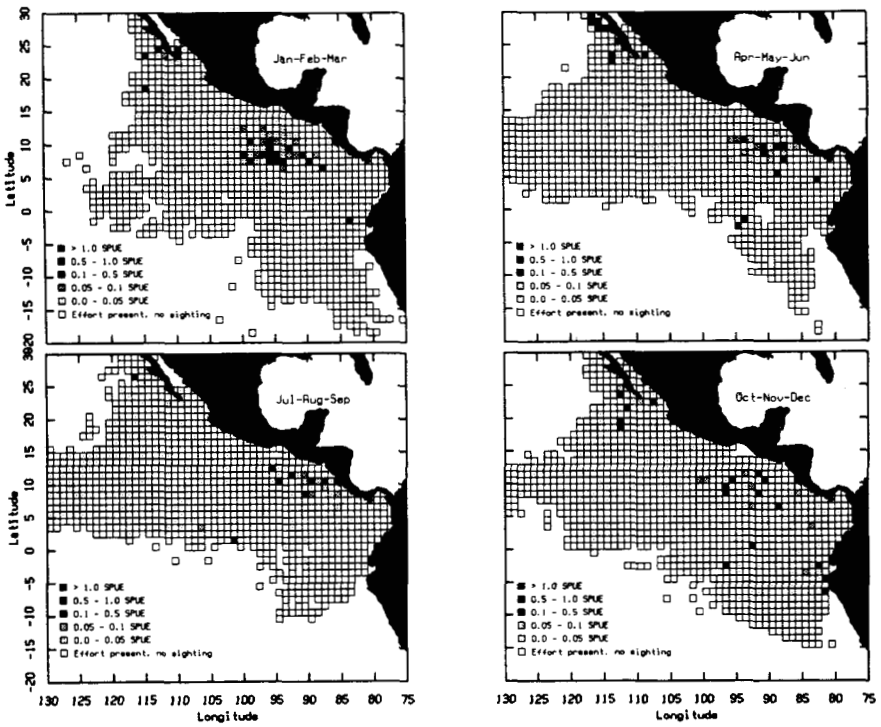

Figure 3. Relative abundance of blue whales (sightings per 370 km searched during periods of Beaufort 4 or lower) by calendar quarter: a) Jan–Feb–Mar; b) Apr–May–Jun; c) Jul–Aug–Sep; d) Oct–Nov–Dec. Only one degree latitude–longitude blocks with at least 185 km (100 n. mi.) searching are included.

difference in the group size frequency among the aggregation areas (Table 1). A partitioning of the chi-square statistic indicates that the largest departures from expectation (under the null hypothesis of no group size differences among areas) are from area 3 (near the Galapagos Islands and South America), where there were more pods of 2 and 3+, and fewer single whales, than in the other areas.

Discussion

Spatial patterns and habitat characteristics—All aggregations of blue whales identified here occurred in "upwelling-modified" waters, similar to the distribution of common dolphins, *Delphinus delphis,* in the ETP (Au and Perryman 1985). Baja California and Peruvian coastal waters form the low latitude terminations of very prominent eastern boundary current upwelling systems (Barber and Smith 1981). The Galapagos Islands are in the area of maximum intensity of equatorial upwelling, resulting from divergent flow of surface currents, island effects and the change in direction of Coriolis forces at the equator (Vinogradov

Table 1. Group size estimates for blue whales sighted in the eastern tropical Pacific, 1974–1988, by area: "1" is near Baja California (north of 15°N), "2" is off Central America near the Costa Rica Dome (4°N to 15°N), "3" is equatorial and off Peru and Ecuador (south of 4°N).

	Group size			
Area	1	2	3+	Total
1	32	4	7	43
2	103	29	18	150
3	6	7	5	18
Total	141	40	30	211
$\chi^2 = 13.52, P < 0.001$				

1981). The origin of the Costa Rica Dome is a subject of debate (Hofmann *et al.* 1981, Wyrtki 1964), but it is a large (200-km diameter), quasi-stationary, counter-clockwise eddy. It occurs at the eastern and shallowest end of a zonal ridge in the thermocline extending along 10°N. Named for its upward bulging of the thermocline layer, the Dome is a site of active upwelling and nutrient enrichment of the surface layer (Owen 1981).

The most notable ecological attribute of upwelling-modified areas, which comprise blue whale habitat in the ETP, is relatively high primary and secondary productivity (Barber and Smith 1981, Vinogradov 1981, Owen 1981). The eastern boundary current upwellings off Baja California and South America are among the most productive areas of the world's oceans (Barber and Smith 1981). The equatorial and Costa Rica Dome upwellings are among the most productive parts of the pelagic ETP (Love 1972).

Euphausiids, the predominant prey of blue whales (Nemoto 1970), are the dominant form of crustacean micronekton throughout the region (Blackburn *et al.* 1970), and all of the areas occupied by blue whales there support relatively large standing stocks (Blackburn 1968). The distribution of blue whales in the ETP coincides closely with that of a group of four species of euphausiids: *Euphausia eximia, E. gibboides, Nematobrachion flexipes,* and *Nyctiphanes simplex* (Brinton 1979). Brinton (1979) termed this recurrent species group the "marginal proliferators" of ETP euphausiids, noting their great abundance in the region's upwelling areas. Sears (1987) and Gendron and Sears (1989) observed blue whales feeding on large concentrations of *N. simplex* on a number of occasions during spring months of 1984–1989 near Loretto and La Paz, inside the Gulf of California.

Whaling data indicate that blue whales rarely feed in low latitudes (Mackintosh 1966), but the habitats they occupy in the ETP indicate that feeding may be an important part of their low latitude life history. In fact, our data suggest that they select particular areas in the tropics most conducive to feeding success. It is quite possible that the empty stomachs recorded for whales outside of polar latitudes (mostly from land stations in temperate waters) were those of

migrating whales, who fast during migration but engage in some foraging once they arrive at their "winter" areas.

Seasonal patterns—The April–June peak and July–September minimum in blue whale sightings recorded here along western Baja California are consistent with previously published information. The available data strongly suggest a fall migration south along the peninsula, into the Gulf of California (and perhaps farther south), followed by a spring migration north along the peninsula to the North Pacific. Rice (1974) reported a distinctly seasonal occurrence of blue whales off Baja California from both sightings and whaling records, with peak abundance from February through early July (when most were observed moving northward), and again in October (when most were observed moving southward), and no sightings from about November through January. Blue whales have been seen in the Gulf of California from January through August, but with peak presence in March–April (Sears *et al.* 1987; Vidal *et al.*, in press). The seasonal peak in blue whale occurrence along the Baja peninsula coincides with the spring and early summer peak in upwelling intensity and biological production (Bakun *et al.* 1974, Barber and Smith 1981).

Blue whales were recorded in all seasons off Central America. The Costa Rica Dome has likewise been observed in all seasons (Wyrtki 1964), always within about 200 km of 9°N, 89°W (Hofmann *et al.* 1981, Wyrtki 1964), even during the extreme 1982–1983 El Niño (Barberán *et al.* 1984). It is therefore one of the most predictable physical occurrences in the pelagic tropical Pacific. Studies of the biological oceanography of the Dome area disclosed no seasonal cycles, but rather a quasi-steady state in productivity and standing stocks from nutrients through micronekton (Blackburn 1966, King 1986), in contrast to the areas off Baja California and along the equator, which do undergo notable seasonal changes (Blackburn *et al.* 1970, Barber and Smith 1981). Gaskin (1982) concluded that the combination of high local productivity and considerable duration (as recorded for the Dome area) greatly favors the establishment of baleen whale populations.

It is difficult to make inferences about seasonality regarding the very few sightings made in this study near the Galapagos Islands and off Peru and Ecuador. We had limited sighting effort along the equator west of 100°W, and very little along the coast of Peru and Ecuador (Fig. 2), where previous studies indicate blue whales are relatively abundant (Donovan 1984, Clarke 1980). Sightings of blue whales made by whaling vessels operating out of Peru during 1976–1983 showed a seasonal peak during the southern summer (January–March), with a minimum during the southern winter and spring (May–December) (Donovan 1984).

Population identity—The blue whale sightings reported by Donovan (1984) and this study from equatorial waters and South American coast may represent the northernmost extension of the SE Pacific population, found along the South American coastal shelf and into the Antarctic (Mackintosh 1966). The cool water habitat they occupy extends up the coast to at least northern Peru and (seasonally) offshore along the equator with the extension of Peru Current into the South Equatorial Current (Wyrtki 1966). However, Donovan (1984) re-

ported a southern summer peak in sightings off northern Peru, and noted this was inconsistent with the seasonal pattern expected for S. Hemisphere whales, which should be feeding then near Antarctica.

The blue whales sighted along western Baja California are almost certainly part of the NE Pacific population, which extends along the outer coast to at least northern California, with shore station captures reported from as far north as Vancouver Island (Kellogg 1929, Rice 1974, Scammon 1874). It is possible that this population also includes those blue whales sighted and captured in the Gulf of Alaska and near the Aleutian Islands (Nishiwaki 1966, Yochem and Leatherwood 1985).

It is difficult to connect the whales sighted near the Costa Rica Dome with either the NE or SE Pacific populations on the basis of present information. The Costa Rica Dome sighting aggregation is curiously present in all seasons, spatially separate from the other aggregations. There is no prominent stream of sightings between the Dome area and other areas (Fig. 1), as would be expected in an historical summary for a population that migrates seasonally.

Some hypotheses to explain the year-round presence and distinct spatial separation of the aggregation in the vicinity of the Costa Rica Dome are: (1) it consists of Northern Hemisphere animals in northern winter, Southern Hemisphere whales in southern winter (northern summer), coming and going via undetected routes; (2) it consists primarily of juveniles, not taking part in the full migration (as has been observed for other species of baleen whales: Gaskin 1982); (3) it is a resident, year round, distinct population. Berzin (1978) and Donovan (1984) both proposed that the blue whales off Central America could be part of a resident population that also included those whales seen off Peru.

The January–March density peak in relative abundance of blue whales near the Dome would imply that they are N. Hemisphere whales, but it is difficult to reconcile this connection with the distinct spatial gap between the Dome aggregation and the aggregation near Baja California. Given the rarity of blue whales, it is possible that N–S migrants from the area could escape notice, especially between the Dome aggregation and the equator. This is less likely to the north, where we have much more sighting effort, in all seasons. An inshore migration along the Mexican mainland is possible, but would likely have been observed by Mexican scientists studying baleen whales (O. Vidal, personal communication).

Taxonomic status—Since pygmy blue whales (*Balaenoptera musculus brevicauda* Ichihara 1966) were first described it has become evident that their distribution is much wider than originally thought (Berzin 1978). Donovan (1984) reported the likelihood that blue whales seen in equatorial and Peruvian coastal waters on the 1975 International Decade of Cetacean Research cruise were pygmy blues. This was based on observations of the Japanese whalers who made the sightings on the IDCR cruise and had seen both types in the Antarctic. However, Donovan (1984) and Ichihara (1981) stated that the two types could not be distinguished unequivocally in the water. Given this ambiguity, we attempted no subspecific designations of the sightings reported here. Likewise, we consider Berzin's (1978) designation of ETP blue whales as *B. m. brevicauda*

to be premature, given the absence of morphometric or genetic data on blue whales from this region.

Concluding remarks—The primary reason for blue whales' migration to low latitudes is most likely related to thermal balance and calving success (*e.g.*, Lockyer and Brown 1981). However, we propose that foraging may be an important secondary factor. That is, once in low latitudes, blue whales select habitat which allows feeding.

The hypotheses discussed here regarding the population structure of ETP blue whales (including the possibility of a resident population), and the ecological processes underlying their occupation of upwelling-modified habitats, can be tested by a program of concentrated, contemporaneous sighting effort and oceanographic studies, and by photo-identification and/or biopsy-dart based genetic analyses. Photo matches or demonstration of genetic similarity between whales from the Costa Rica Dome and another area would be sufficient to indicate continuity. The sub-specific taxonomic status of ETP blue whales could also be addressed by such genetic analyses. Behavioral and oceanographic observations could address the following questions: are the whales feeding near the Dome? What species of euphausiids, if any, are aggregated in their immediate vicinity? Do they mate and/or calve there? Are the same individuals seen there year round?

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