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# Influence of ocean fronts on cetacean habitat selection and diversity within the CalCOFI study area

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## Abstract

The association between cetacean distributions and sea surface temperature fronts were examined within southern California's California Cooperative Oceanic Fisheries Investigations (CalCOFI) study area. Quarterly surveys were performed from July 2004 through March 2008 to obtain cetacean distribution data. To examine the distribution and frequency of thermal front activity, monthly composite Advanced Very High Resolution Radiometer (AVHRR) satellite sea surface temperature (SST) imagery were acquired. Using Windows Image Manager (WIM) a Single Image Edge Detection (SIED) analysis was applied to each monthly image to identify locations of front activity. Front results were imported into ArcGIS 9.3 and cetacean sighting points overlaid. The distance to front activity and species richness in proximity to thermal front activity was analyzed. Results indicate a seasonal variation in front activity within the CalCOFI study area. The frequency of front activity peaks during the summertime (30%) while winter and spring activity dwindle to almost half the activity levels (13%). The spatial distribution of front activity also varies with season; during the spring front activity is contracted in shore and along the continental shelf near the Channel Islands. However, as the seasons progress front activity heightens offshore. Cetacean distributions were compared to a randomly generated point distribution using a 2-Sample Kolmogorov-Smirnov Test. In forty-five percent of the cruises, mysticetes returned a unique distribution curve, of which eighty-nine percent were in favor of front activity. Odontocetes returned non-random distribution curves in forty-three percent of the cruises, however, only twenty-two percent of these distributions were in favor of SST fronts. Cetacean richness and SST front activity were examined at a 10 km spatial scale; however, results showed little correlation between heightened front activity and increased species richness.

## **Introduction**

Several mysticete and odontocete species forage within the productive waters of the California Current Ecosystem (CCE), which varies on seasonal, interannual, and multi-year timescales (Hickey 1979; Hayward and Venrick 1998; Mullin et al. 2000; Brinton and Townsend 2003; Chhak and Di Lorenzo 2007; Keister and Strub 2008; Munger et al. 2009). Cetaceans are highly mobile apex predators that feed on spatially patchy, short-lived aggregations of zooplankton, schooling fish and cephalopods. Seasonal and inter-annual variability in ocean habitat affects the vertical and horizontal distributions of cetacean prey species, which in turn affects the occurrence of marine mammals. Therefore, understanding how cetaceans may utilize environmental cues to exploit local resources will bring us closer to developing predictive models. These models in turn may be applied to management and conservation goals within southern California, a region influenced by anthropogenic impacts including military and industrial activities, to aid management and policy decisions.

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) are a partnership between the California Department of Fish and Game, National Oceanic and Atmospheric Administration (NOAA) Fisheries Service and Scripps Institution of Oceanography, formed in 1949 to study the ecological aspects behind the collapse of the sardine population off the California coast. Since 1949, the focus of CalCOFI has grown to encompass environmental monitoring of the California Current ecosystem, El Niño, and climate change. CalCOFI conducts quarterly cruises off southern California, collecting various hydrographic and biological data along a grid spanning six nominal lines between San Diego and Point Conception (Figure 1). Given this level of monitoring, CalCOFI provides an excellent platform to observe temporal and spatial variation in marine mammal distributions in relation to habitat variables. In

2004, marine mammal visual and acoustic line-transect surveys were added to the CalCOFI study. The goal is to integrate environmental and cetacean data to better understand the physical and oceanographic processes that influence cetacean distributions. This work is also being utilized for the development of ecological models, which can aid local management (Soldevilla et al. 2006).

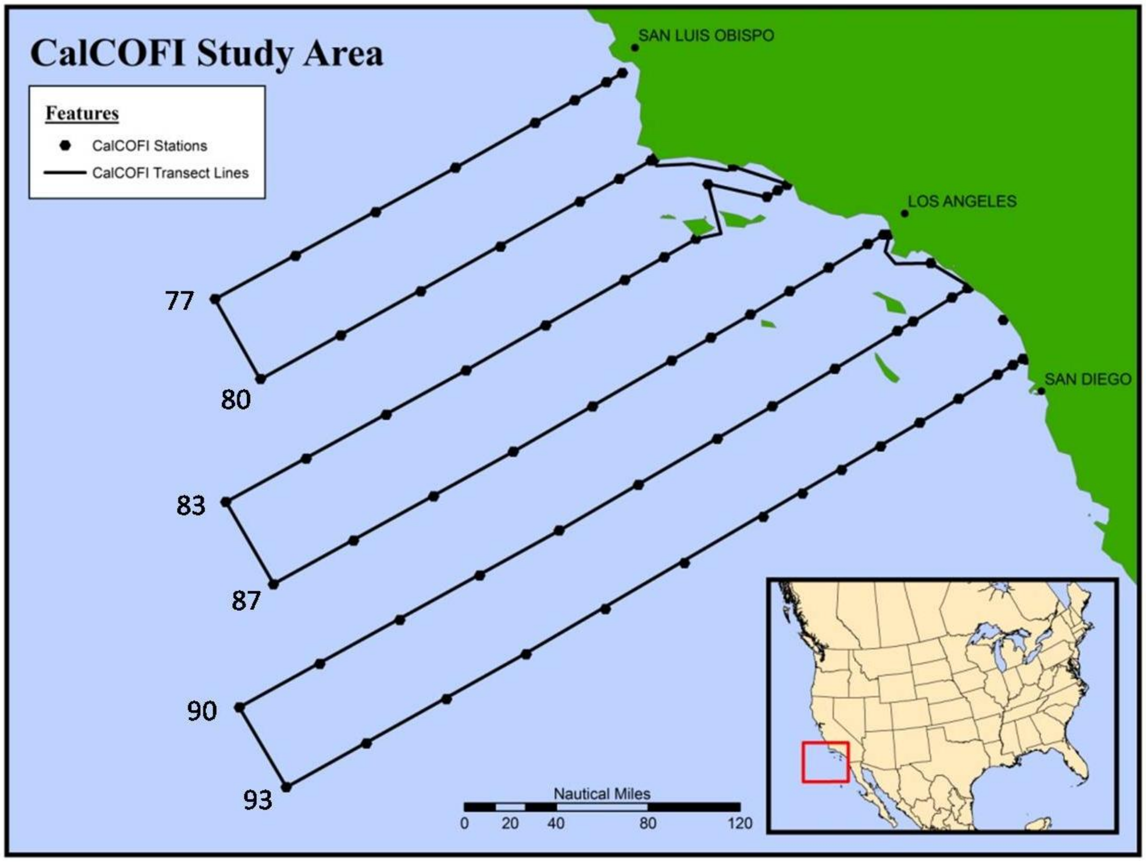


Figure 1: CalCOFI study area, located off southern California, showing numbered tracklines with hydrographic and net tow station.

The successful management of cetacean populations requires understanding the physical and oceanographic processes that influence their spatial and temporal distribution. To meet this objective there are a number of studies that have analyzed the relationship between cetacean abundance and distribution and local environmental factors (Croll et al. 1998; Fiedler et al. 1998; Forney and Barlow 1998; Burtenshaw et al. 2004, Barlow et al. 2009). Oceanic fronts are zones of strong horizontal gradients in physical and/or chemical and biological parameters, often characterized by enhanced productivity. The high nutrient flux in frontal zones results in increased concentrations of phytoplankton biomass (Wall et al. 2008), which in turn has implications for species in elevated trophic levels. Previous studies have linked euphausiids (Croll et al. 2005; Tynan et al. 2005), marine birds (Hoeffer 2000), toothed whales (Gannier and Praca 2007), cephalopods (Rodhouse et al. 1992), and fish diversity (Ainley et al. 2009; Alemany et al. 2009) with oceanic frontal zones. Due to spatial and temporal variability within the marine environment, cetacean distribution may reflect a selection of regions and habitats that supply regularly accessible prey. Therefore, identifying stable areas of heightened productivity and their relationship to protected marine species has important management implications.

Nutrient rich frontal zones have the ability to attract a variety of higher order taxa, functioning as oases of productivity. Locations where organisms concentrate regularly or where there is heightened biological activity are referred to as ‘biological hot spots’ (Palacios et al. 2006). Studying the species diversity of these preferred sites provides insight into the stability of a community. Enhanced species diversity results in an ecosystem that may exhibit resilience to external stressors such as invasive species, climate change, and others (Gudmundsson et al. 1998). A variety of diversity measurement indices have been developed to aid our understanding of a stable and resilient environment. Biodiversity can be measured at the genetic, species and ecosystem levels, although the species level is thought to hold the greatest value. Species diversity indices address the variety or number of unique species present and the relative abundance of each species.

It is important to consider locations with heightened diversity in the context of conservation and sustainable resource management. Analyzing diversity may serve as a tool for defining valuable management areas for a number of cetacean species. Regions that include persistent and biologically critical oceanographic features or processes to a variety of protected cetacean species could be identified as candidate Marine Protected Areas, which are more traditionally defined by ridged geographical boundaries rather than adaptively defining regions based on their oceanographic characteristics (Palacios et al. 2006). Understanding the drivers of diversity can allow us to predict how biodiversity will be affected when the environment is altered through anthropogenic or natural forces (Whitehead et al. 2008). Climate change is of growing concern, as it will undoubtedly alter oceanographic conditions, species distributions and food webs.

The objectives of this study are to contribute to the understanding of cetacean distribution, diversity, and foraging behavior within the California Current ecosystem. First, the amount of sea surface temperature front activity within the CalCOFI study area will be determined, over a four year period. Variability in front activity will be examined both temporally and spatially. The corresponding CalCOFI cetacean sighting data will be spatially linked to front activity to determine if cetaceans are responding to fronts. Finally, species richness will be compared to the level of front activity, to determine if proximity to heightened activity increases cetacean diversity. It was hypothesized that cetaceans would be positively associated with front activity. Results of the analysis indicate that mysticetes were distributed in favor of front activity, while odontocetes showed a random distribution. This suggests that frontal zones serve as attractive foraging areas for mysticetes.

## Materials and Methods

### *Study Area*

The focal area for this study is within the CalCOFI transect grid off the southern coast of California, USA (Figure 1). The transect lines extend roughly 555 km offshore. Circulation within the Southern California Bight is characterized by the cold, south flowing California Current (CC) centered about 200–300 km offshore, and the Southern California Eddy and Southern California Countercurrent, which brings warm water northward along the coast (Lynn and Simpson 1987; Hickey 1992).

### *Marine Mammal Sighting Data*

During the quarterly CalCOFI cruises, marine mammal sighting data were collected from July 2004 through March 2008 using Scripps Institution of Oceanography R/Vs New Horizon (NH), Roger Revelle (RR) and the National Oceanic and Atmospheric Administration (NOAA) R/V David Starr Jordan (JD). During daylight hours, two marine mammal observers were stationed on the bridge wings (NH, 8.1 m above water), flying bridge (JD, 11m), or 03 level (RR, 13.2 m). The observers performed ninety degree scans off the port and starboard sides of the ship; equipped with 7x50 power binoculars to locate and identify cetaceans while the ship transited at 10 knots between stations. The ship was unable to deviate from the trackline to approach animals; however, "big eye' binoculars (25x50 power) aided long distance species identification (Munger et al. 2009; Soldevilla et al 2006). During a marine mammal encounter, the observers recorded the angle and number of reticles to the sighting, identification was made to the species level, group size estimated, as well as any behavioral cues. Survey effort was stopped when sea state conditions of Beaufort 6 or greater or visibility less than 1 km were encountered. Opportunistic surveys were also performed during the return journey, transiting from line 77 to San Diego; these sightings were included in the analysis. All sighting positions were corrected to reflect the location of the cetaceans rather than the ship's position.

### *Satellite Data*

Satellite images of sea-surface temperature (SST) derived from the Advanced Very High Resolution Radiometer (AVHRR) and processed with the Pathfinder Version 5.0 algorithm were obtained from NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the NASA/ California Institute of Technology Jet Propulsion Laboratory (ftp://podaac.jpl.nasa.gov/). Composite monthly, ascending pass (daytime) images at 4 km resolution were gathered for June 2004 through June 2008.

### *Thermal Front Detection*

To identify thermal front activity within the CalCOFI study area Windows Image Manager (WIM) software was used. The AVHRR monthly composite images were imported into WIM and cropped to the study area. For each image the Value Scaling was converted from Pixel Value to SST-Pathfinder, C. To detect fronts within the image Cayula and Cornillion's (1992) Single Image Edge Detection (SIED) algorithm was applied using a variable window size (Deihl et al. 2005). The algorithm examines the image at three

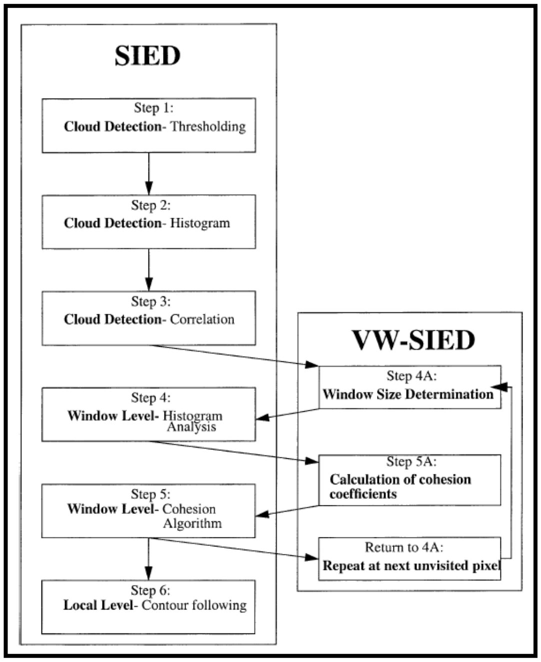


Figure 2: Flowchart of the SIED algorithm process detailing the additions for the variable window process. Source: Diehl et al. 2002.

levels: picture level, window level (Figure 2). At the picture level the image is screened for any cloud contamination (Steps 1-3). After the clouds have been located and masked, the edge detection begins at the window level (Steps 4A-4). The window level uses overlapping 'windows' of square pixel arrays to investigate the statistical likelihood of an edge (front) by first performing a histogram analysis. The modification made by Diehl et al (2002) uses semivariogram analysis in two directions (x and y) to determine the best window size, rather than a 32x32 fixed window of square pixel arrays, as was originally written by Cayula and Cornillion (1992). Temperature fronts are 'step edges', which are defined by a thin region of separation between areas of constant temperature. If the histogram shows bimodality the statistical relevance of each front is analyzed. Finally, the potential edge is examined for cohesiveness and smoothness, to ensure the edge is not a result of contaminated pixels (ie. cloud masses) and contours drawn (Steps 5A-6).

### *ArcGIS 9.3 Analysis*

To determine the level of spatial and temporal differences in thermal front activity the outputs produced in WIM were exported to ArcGIS 9.3. Each image was georeferenced and their fronts digitized. All data was projected into USA Contiguous Equidistant Conic with a central meridian of -120.75. A 10km

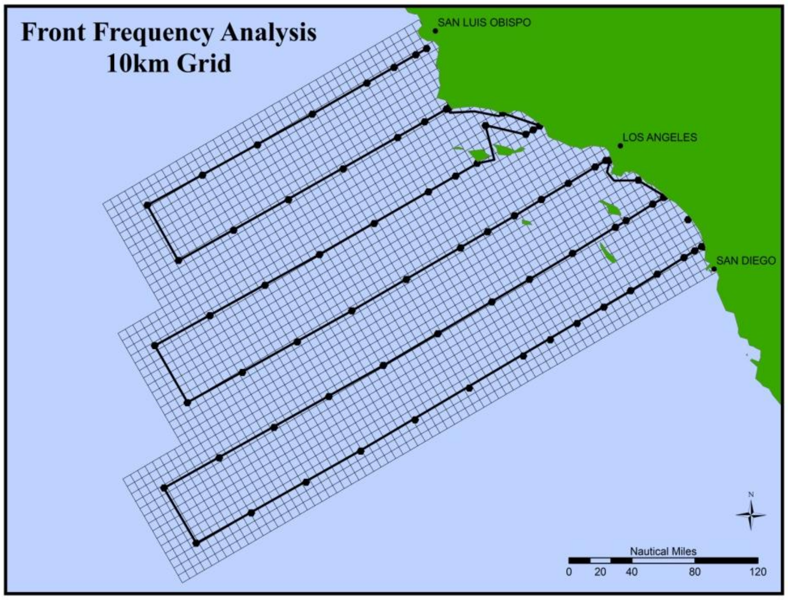


Figure 3: CalCOFI study area divided with a 10 km grid for analysis.

grid was overlaid onto the study area and the frequency of front activity extracted for each cell (Figure 3). The frequency of front activity was then graphed according to seasonal activity and cumulative activity.

To examine cetacean diversity within the CalCOFI grid, cetacean sighting data was imported into ArcGIS 9.3. Sighting points were linked to the 10km grid cell they fell within. The Menhinick Diversity Index, which examines species richness, was calculated for each cell (Magurran 2004). The resulting species richness value was plotted against the frequency of front activity for each cell to determine if a relationship exists.

To examine the spatial distribution of cetacean sightings relative to thermal front activity the CalCOFI cruise sighting points were overlaid onto the corresponding month's front activity. A Spatial Join was applied to the cetacean sighting data linking it to the nearest SST front and generating a distance calculation in meters. These distance outputs were exported and analyzed at the suborder level (Odontoceti and Mysticeti) and to the species level for individual species which dominated the overall sample.

To determine if the cruise sightings were distributed randomly with respect to thermal fronts 100 trials each consisting of 100 random points was generated along the trackline where visual effort occurred using the Create Random Points tool. Distance from these random points to the nearest front was calculated with a Spatial Join. The distance outputs from both the randomly generated points and cetacean sighting points were exported as tables and brought into Matlab 7.0 for further analysis.

***Matlab 7.0***

For each cruise the generated distance outputs were examined with a 2-Sample Kolmogorov-Smirnov Test. This non-parametric test examines the distribution curves of the two data vectors to determine if they are from the same continuous distribution. The null hypothesis is that they are from the same continuous distribution; the alternative hypothesis is that they are from different continuous distributions. The test generates a cumulative fraction plot which allows you to understand how the data is distributed, as well as a three output variables: H, p-value, and D statistic. If the H value equals one the test rejects the null hypothesis at the 5% significance level; 0 otherwise. The D statistic indicates the maximum vertical distance between the two distribution curves.

## **Results**

### ***Thermal Front Analysis***

Thermal front activity was quite varied within the CalCOFI study area. Results of the thermal front analysis indicate that the locations of front activity vary spatially on both monthly and seasonal time scales. Overall there appears to be a cyclic pattern, with front activity highest in the summer months and lowest in the winter and early spring (Figures 4a-4b). Mapping the cumulative front activity from June 2004 to June 2008 (Figure 5) we see that front activity is greatest coastally and along the continental shelf, where the California Current, traveling toward the equator, is interacting with the bathymetry to enhance upwelling. However, when we break the data up according to season (Figures 6a-d) we find that there is quite a difference in the spatial pattern of the front activity. During the spring the frequency of front activity appears to be highest on the continental shelf near the Channel Islands and inshore along the coastline. Summer time front activity appears decrease along the coastline, activity increases around Point Conception and a strip of high SST front activity appears to follow the continental shelf break. In the fall the front activity hugging Point Conception begins to break down and areas farther off shore, near CalCOFI line 90, begin to dominate in front activity. During the winter, CalCOFI lines 93 and 90 show the highest level of activity.

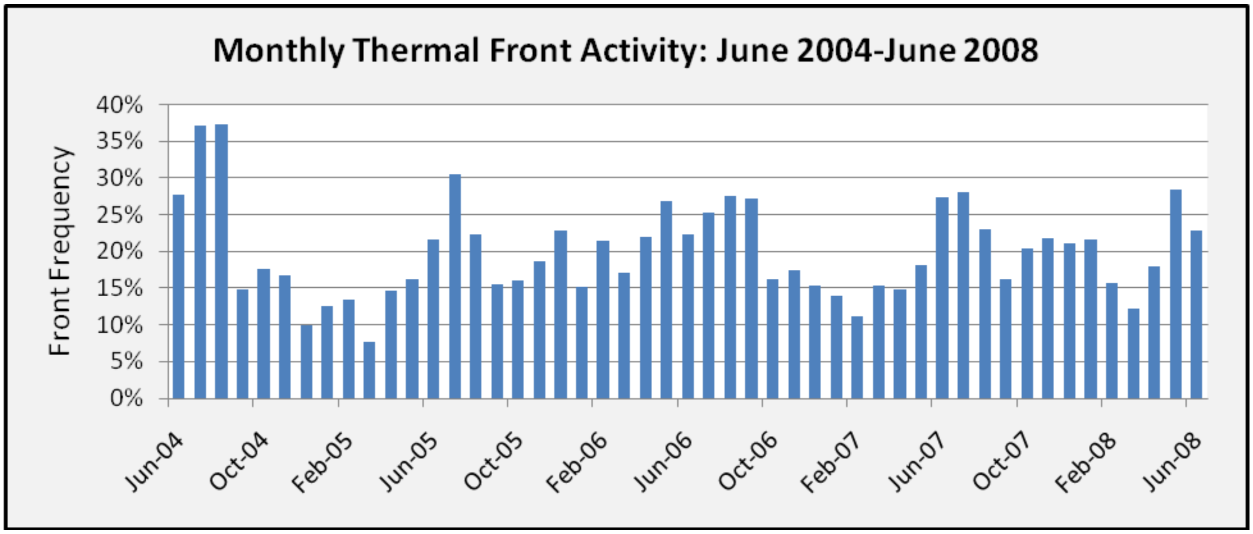


Figure 4a: The above graph shows variations in SST front activity over a four year period: June 2004 through June 2008. There appears to be a cyclic rhythm to front activity. Front activity peaks in the summer months, while low points are found in the winter and early spring.

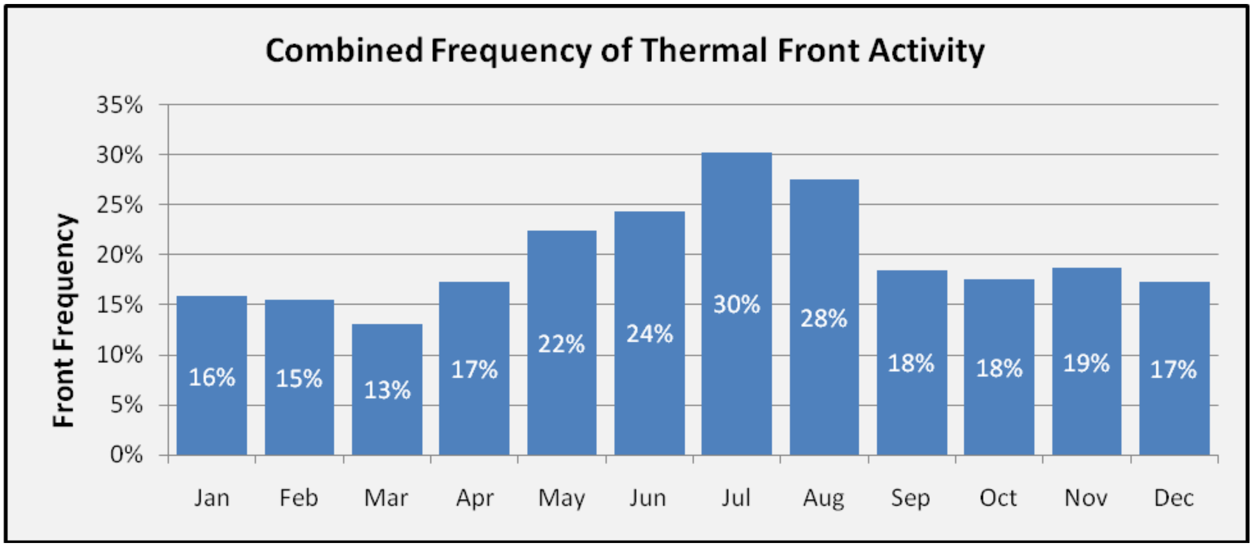


Figure 4b: This graph shows the frequency of thermal activity grouped by month. The graph indicates that the level of front activity is at its highest in July, while March shows the lowest level of activity.

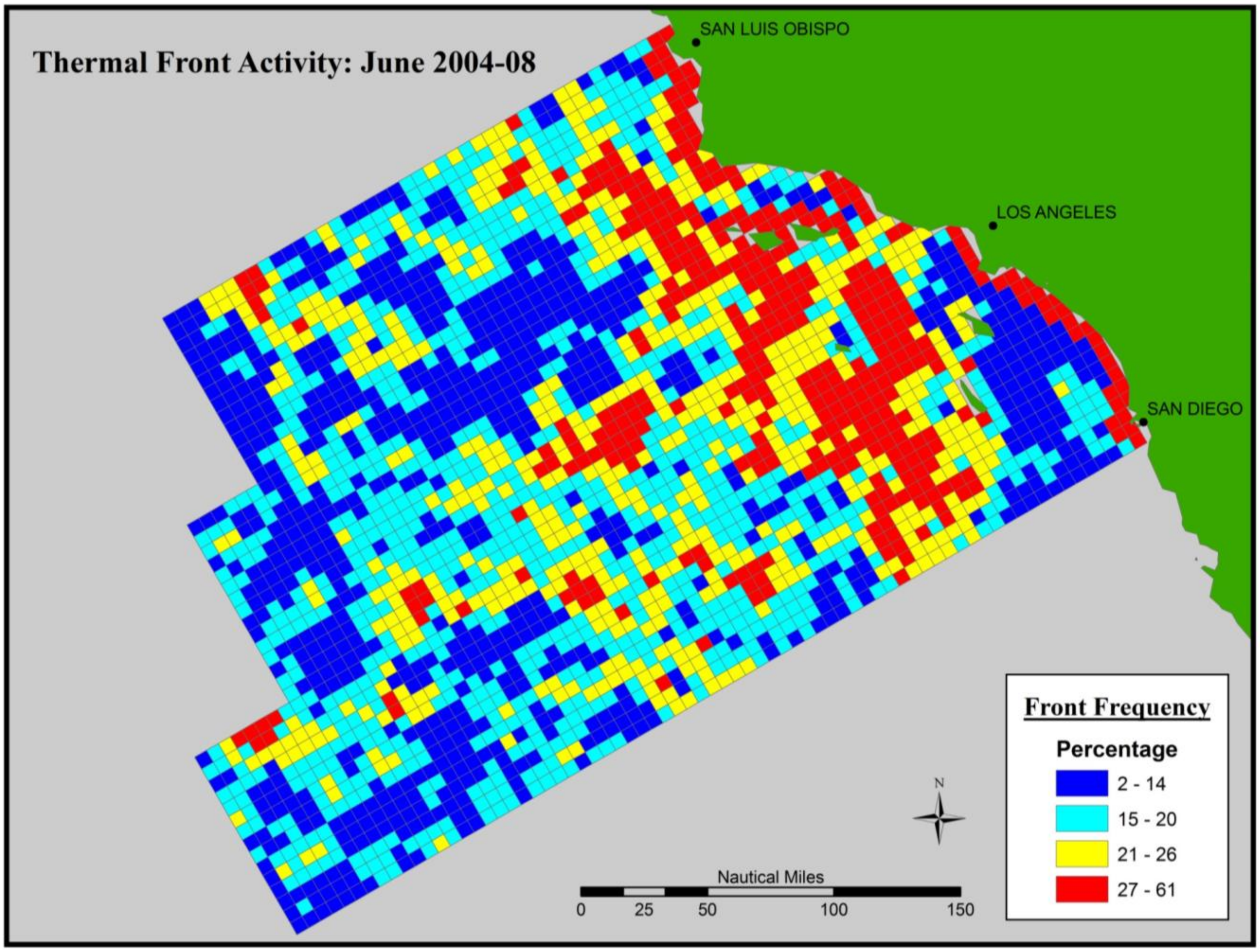


Figure 5: Combined SST front activity for June 2004 through June 2008. The frequency of front activity is greatest along the continental shelf break and inshore beside the coast. As the California Current travels toward the equator it interacts with the varied bathymetry; a combination of seamounts, island slopes surrounding the Channel Islands and a shelf break south of south of Point Conception. These physical structures enhance turbulence and mixing, which is visible through the front detection process.

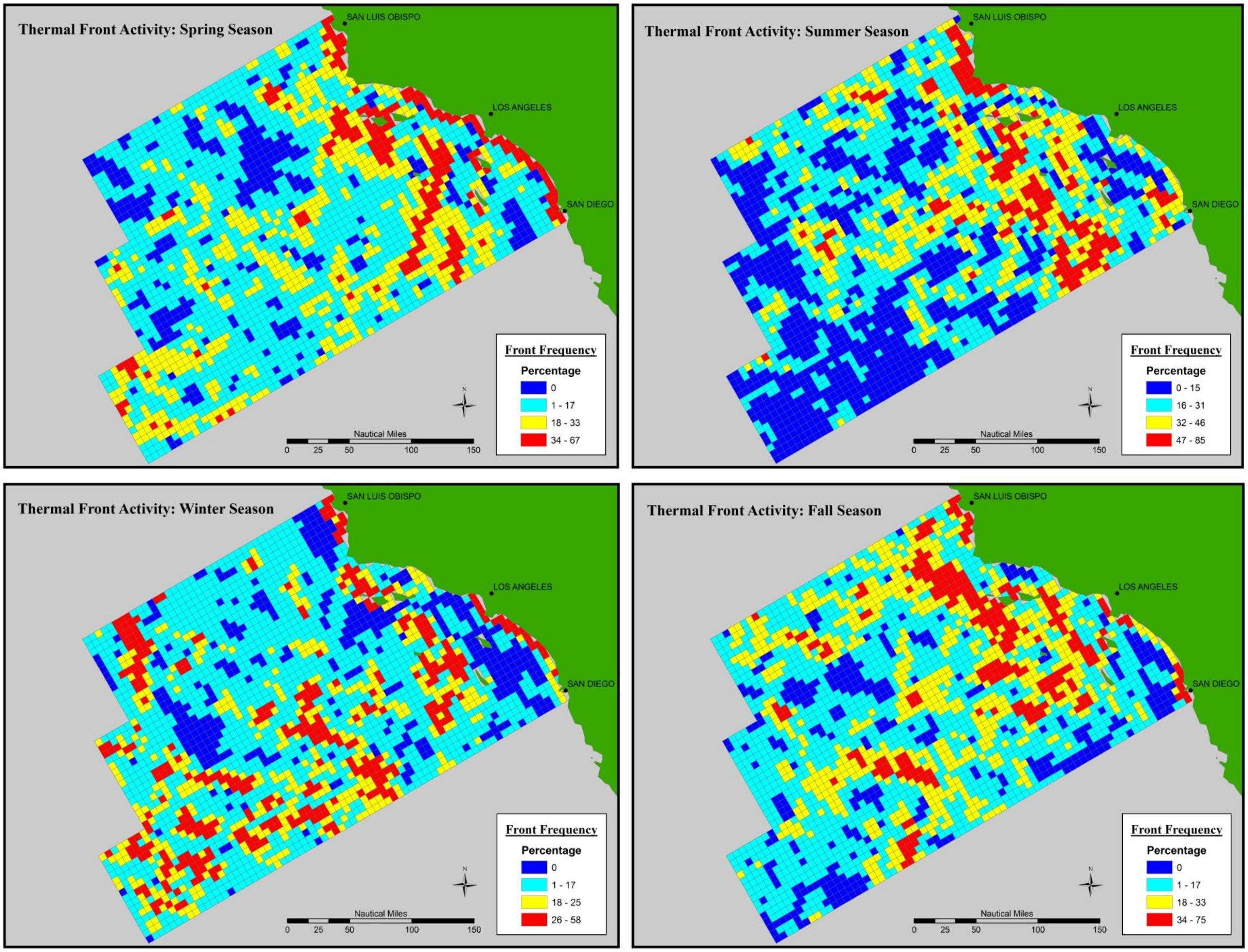


Figure 6a-d: Thermal front activity broken up by season. Along the continental shelf break there is a consistent zone of activity, running from Point Conception southward. As the season's progress there is a gradual shift in activity, moving offshore. a) Spring has high front activity occurring along the continental shelf and inland along the coast. b) During the summer season the area surrounding Point Conception begins to increase in front activity. There appears to be an increase in levels off shore, west of the Channel Islands, while inshore activity decreases. c) In the fall the heightened level of activity surrounding Point Conception appears to contract and activity shifts further off shore, in the southwest activity is beginning to increase. d) During the winter, front activity appears to be more equally distributed throughout the study area. Inshore along the coast the frequency of font activity is beginning to increase while in the southwest corner levels have reached their peak.

### *Cetacean Diversity*

Plotting the Menhinick Species Diversity value as a function of front activity shows a large amount of variability (Figure 7). At a spatial scale of 10km, there appears to be little to no relationship between species richness and the frequency of front activity. Applying a trendline to the data shows a shallow upsweep with an $r^2$ value of 0.0042.

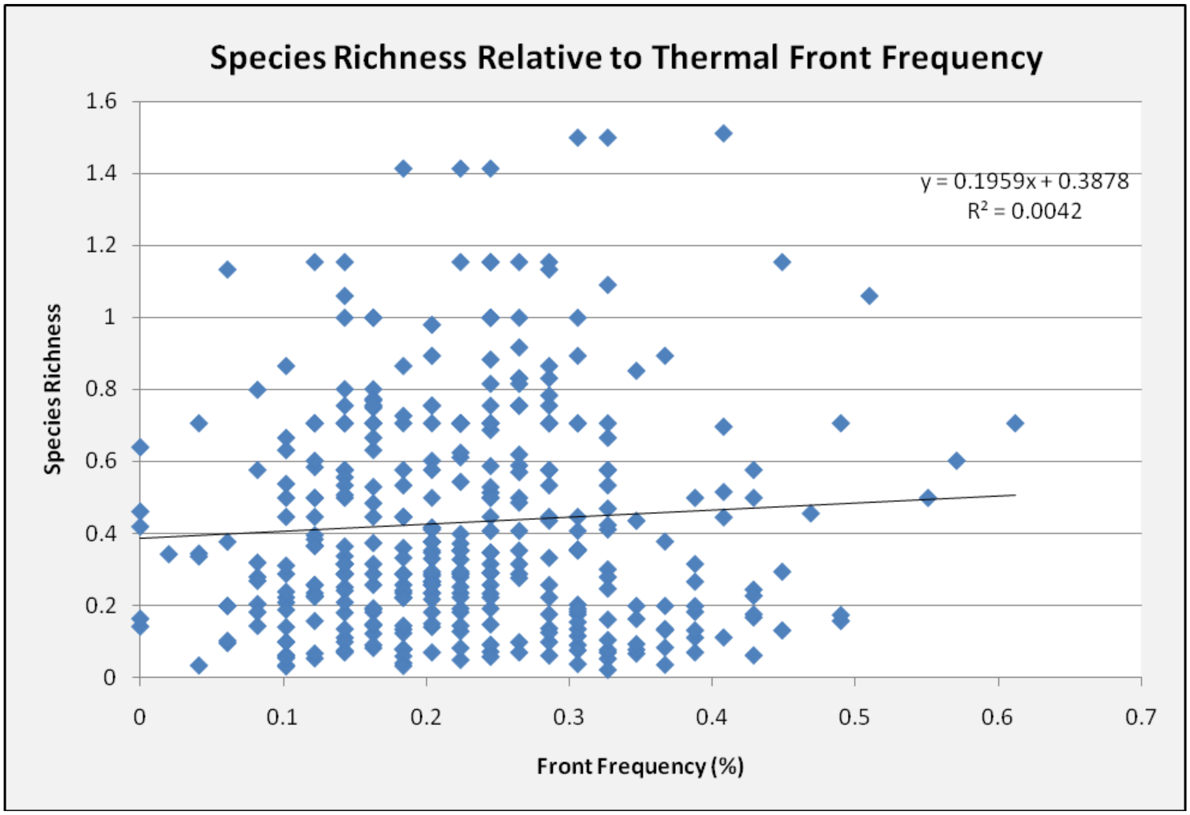


Figure 7: Plot of Menhinick Species Richness value as a function of front activity measured for each 10km grid cell.

### *Cetacean Sighting Distribution*

Distance to thermal front appears to be cyclic for both odontocetes and mysticetes, although mysticetes proved to be distributed closer to front activity than the odontocetes, 28.70 km as opposed to 20.66 km (Figure 8, 9a-c). Overall, minimum distance to fronts was encountered during the summer seasons while the maximum mean distance to front activity occurred in either the winter or spring seasons. Unlike other mysticetes, the gray whale's principal prey is benthic amphipods, which they filter from bottom sediments. In response to this difference in foraging behavior, the average mysticete distance to fronts were compared both with and without gray whales (*Eschrichtius robustus*). Removing gray whales from the analysis reduced the average distance to front activity for Mysticetes from 20.66 km to 16.40 km. Focusing on the dominant species within the study sample there appears to be difference in the association to fronts at the species level. Within the mysticetes there is a contrast in the mean distances between humpback (*Megaptera novaeangliae*), blue (*Balaenoptera musculus*) and fin whales (*Balaenoptera physalus*) (Figure 10-11). Overall, the humpback whale is found most closely associated with thermal front activity with an average distance of 8.3 km. Blue whales follow behind humpbacks at 16.4 km, while fin whales were found on average 21.7 km from the front, similar to what is observed for the common dolphin (*Delphinus*). The pacific white-sided dolphin (*Lagenorhynchus obliquidens*) and dall's porpoise (*Phocoenoides dalli*) showed similar mean distances to thermal fronts, while the maximum distance to front activity was associated with the risso's dolphin (*Grampus griseus*). The common dolphin was most closely associated with fronts with a mean distance of 25.2 km from front activity, which is half the distance observed in risso's dolphins (Figure 10-11).

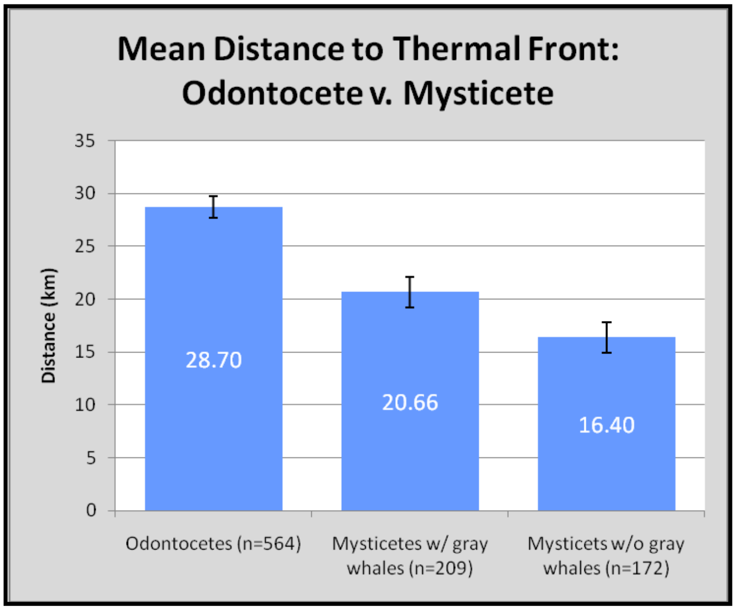


Figure 8: Average distance to SST front for mysticetes and odontocetes.

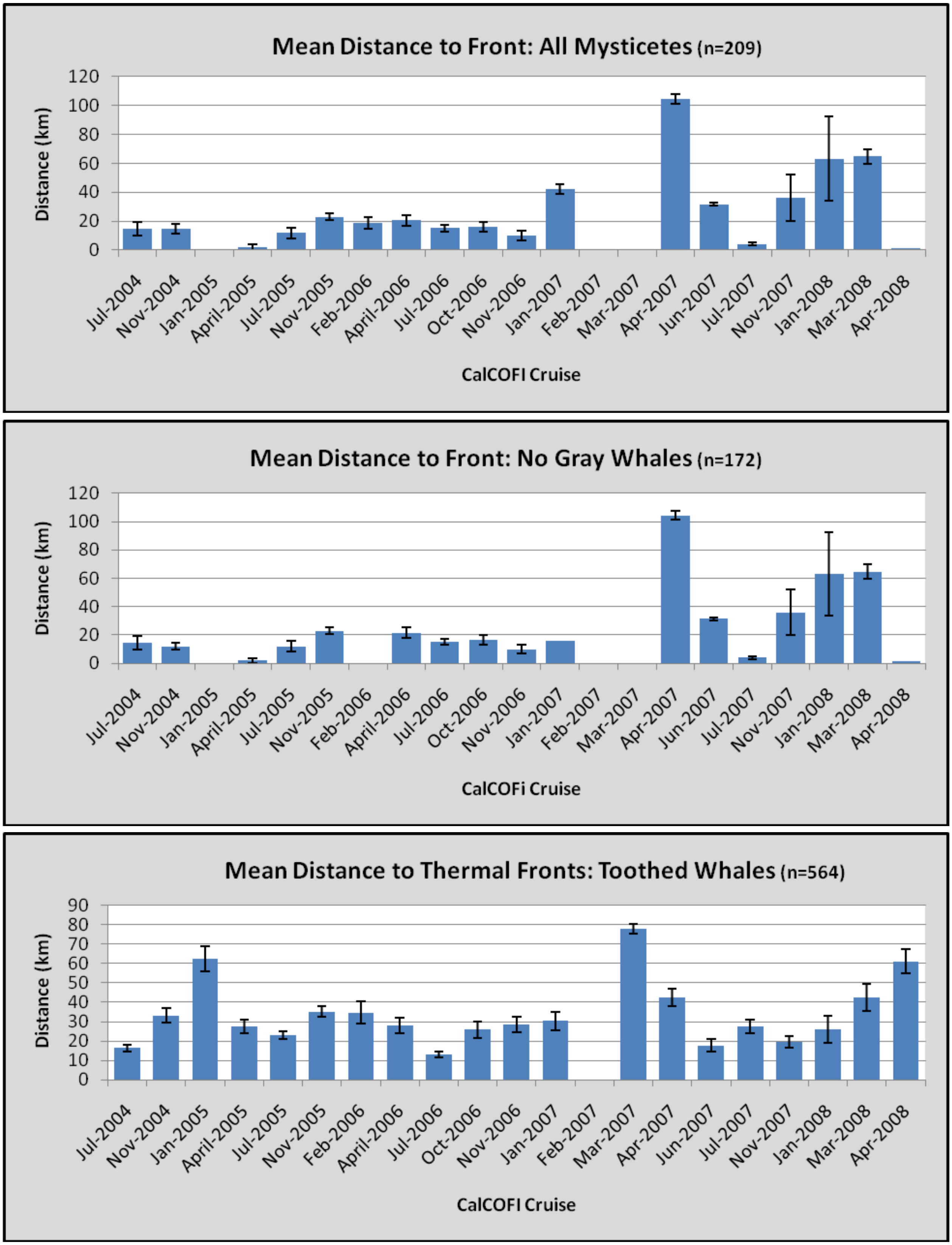


Figure 9a-c: Average distance to front for mysticetes and odontocetes. Distance appears to be cyclic for both suborders, distance to SST front is greatest in the winter while the lowest average distances are observed in the summer seasons.

| | Dolphin/Porpoise | | | | Baleen Whales | | |
|---|---|---|---|---|---|---|---|
| (km) | Common Dolphin | Pacific White-Sided Dolphin | Dall's Porpoise | Risso's Dolphin | Humpback Whale | Blue Whale | Fin Whale |
| **Mean** | 25.4 | 34.6 | 39.6 | 50.2 | 8.3 | 16.4 | 21.7 |
| **Median** | 21.5 | 25.0 | 37.3 | 52.3 | 7.0 | 11.3 | 14.8 |
| **Mode** | 0.0 | N/A | N/A | N/A | 0.0 | 0.0 | 0.0 |
| **Std Dev** | 20.9 | 30.8 | 27.7 | 29.4 | 10.0 | 14.3 | 21.8 |
| **Std Error** | 1.2 | 4.4 | 3.6 | 6.0 | 1.2 | 2.4 | 3.0 |
| **Min** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Quartile 1st** | 9.3 | 16.2 | 17.9 | 38.8 | 0.4 | 3.8 | 6.6 |
| **Quartile 3rd** | 36.4 | 47.7 | 57.3 | 69.0 | 11.3 | 28.3 | 30.1 |
| **Max** | 92.8 | 140.3 | 117.0 | 101.5 | 50.2 | 50.6 | 107.6 |
| **n** | 299 | 50 | 58 | 24 | 67 | 36 | 53 |

Figure 10: Descriptive statistics for seven of the most abundant species in the sample.

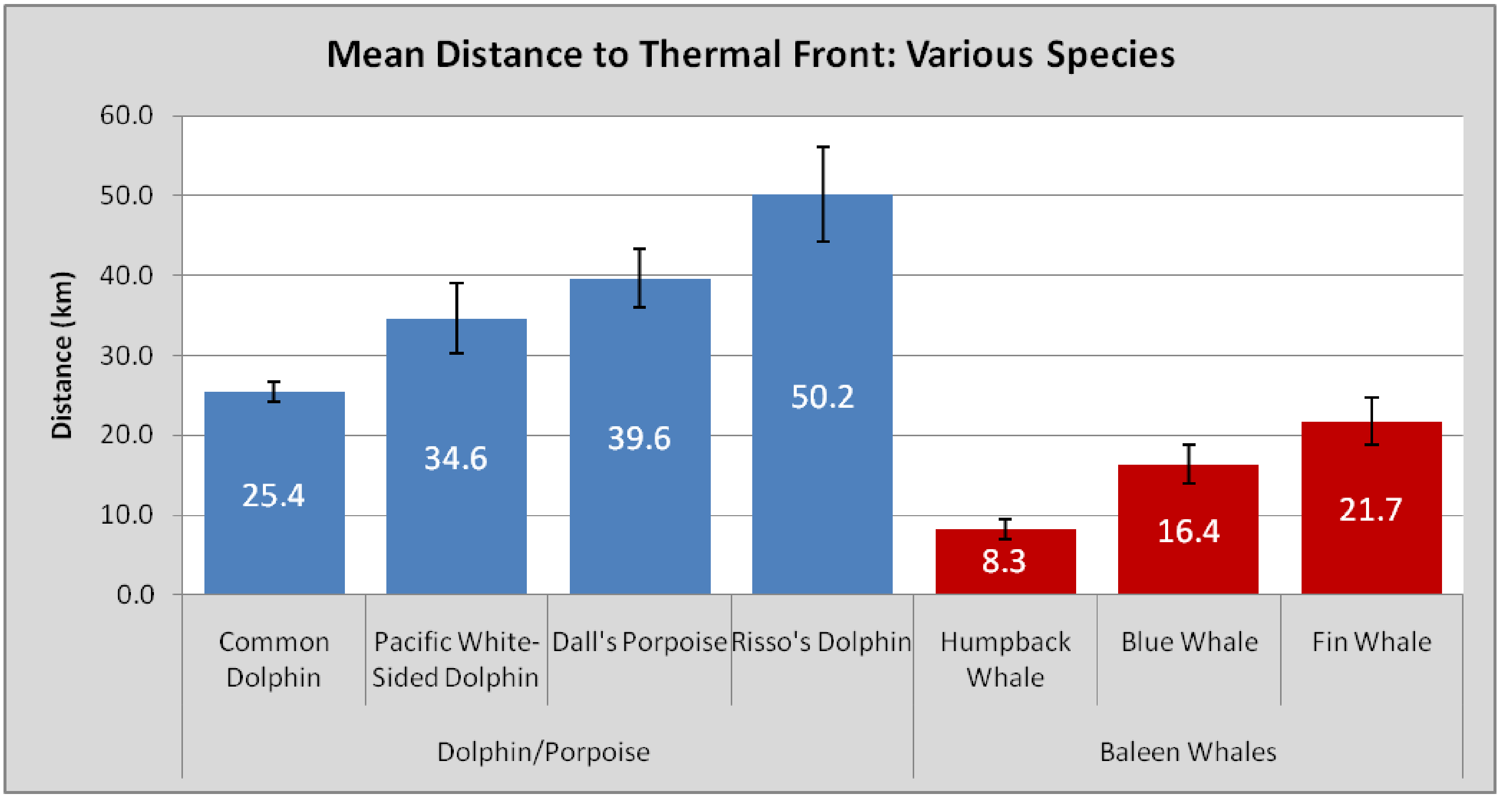


Figure 11: Mean distance to SST front for seven of the most abundant species in the sample. There are clear species specific differences in distribution relative to front activity. Within the dolphin/porpoise group the common dolphin is most closely associated with front activity. The Pacific white-sided dolphin and dall's porpoise are similarly distributed with regard to front activity, while the risso's dolphin is least associated with front activity. A comparison of baleen whales indicates that the humpback whale is most closely distributed to front activity, followed by the blue whale. Fin whales show the maximum mean distance to fronts.

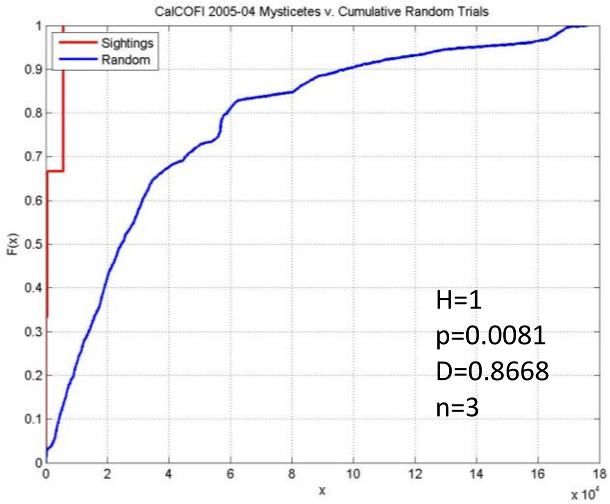
Results of the 2-Sample Kolmogorov-Smirnov Tests indicate mysticete and odontocete species exhibit different distributional relationships to front activity (Figure 12-15). Mysticetes received test values which indicated non-random distributions for fifty-five percent of the cruises. Statistically non-random distribution curves were identified in the summer and fall seasons. Eighty percent of those found to have non-random distributions also showed distributions skewed in favor of fronts. Winter cruises, which tended to be dominated by gray whales, never returned a rejection to the null hypothesis of similarity between the distributions, indicating sightings were randomly distributed in reference to front activity. Spring cruises returned the most variability, in both 2005 and 2006 the distributions were deemed from the same continuous distribution, while 2007 and 2008 were able to reject the null hypothesis of similarity and indicated oppositional relationships to front activity. Odontocetes show little to no relationship with front activity. The 2-Sample Kolmogorov-Smirnov Tests returned non-random distributions for ten out of twenty of the cruises. Of those cruises which proved non-random distributions, seventy percent showed distributions skewed in opposition to fronts.

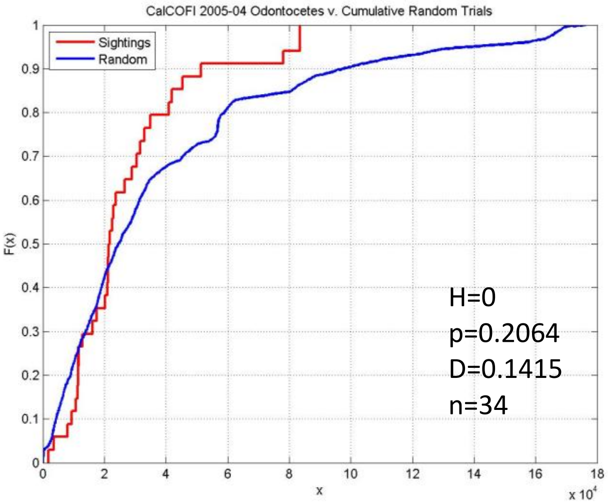
Figure12

## Spring Cruises– Mysticetes

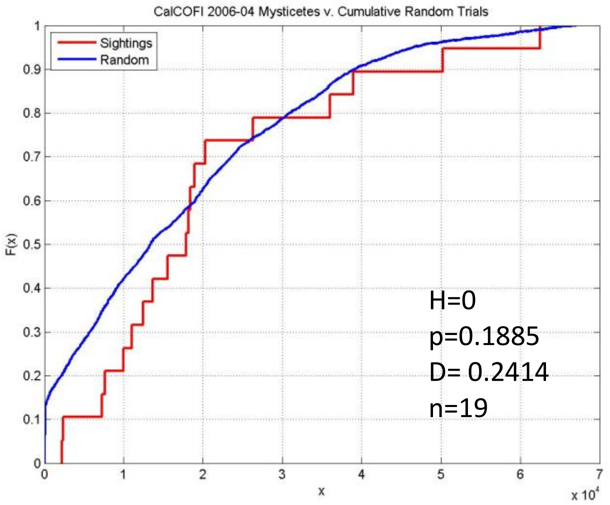
## Spring Cruises– Odontocetes

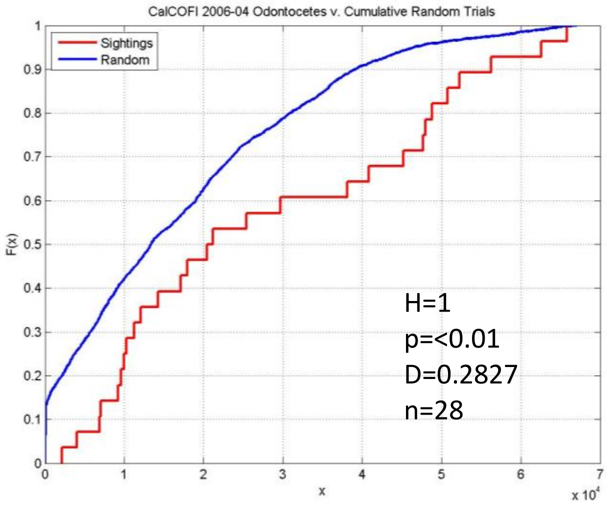
2005





2006





2007

**N/A**

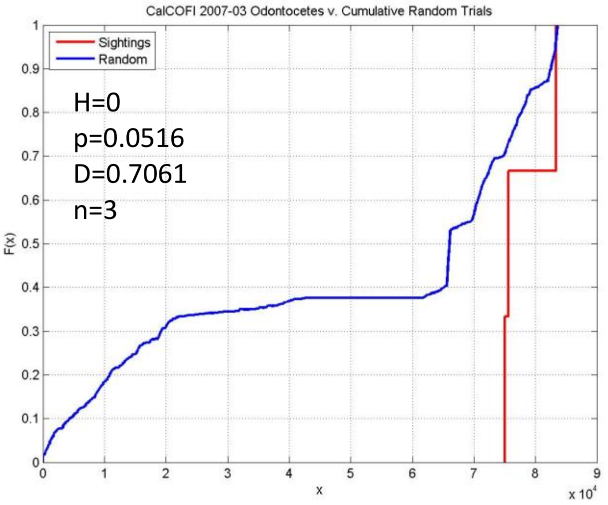
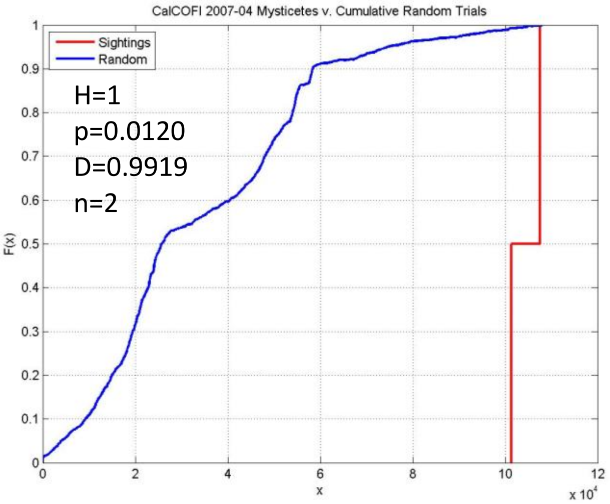


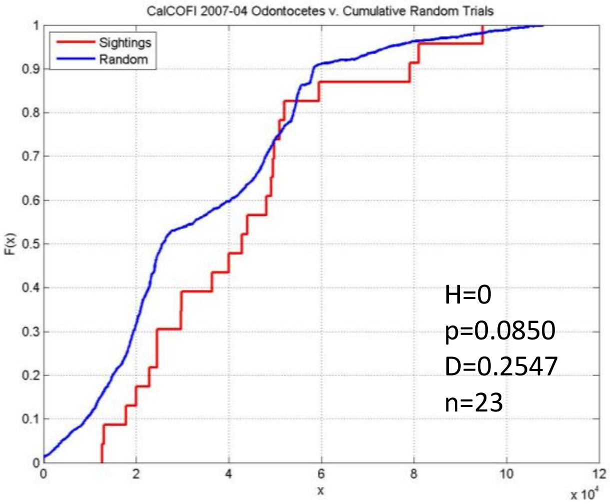
Figure 12 cont.

## Spring Cruises– Mysticetes

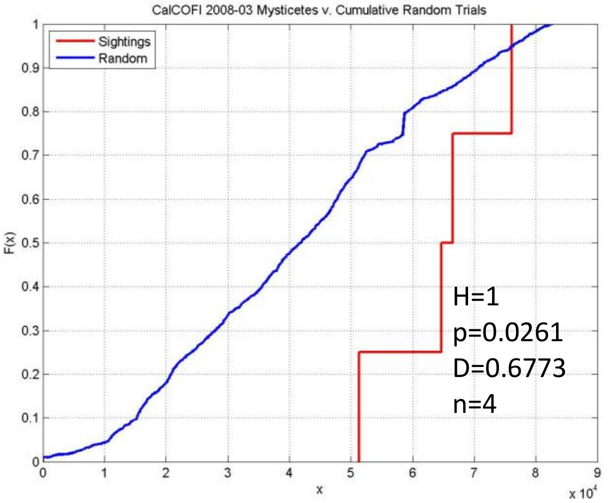
## Spring Cruises– Odontocetes

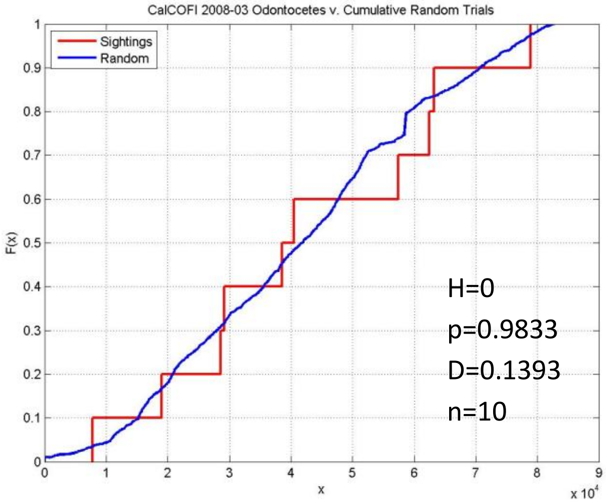
2007



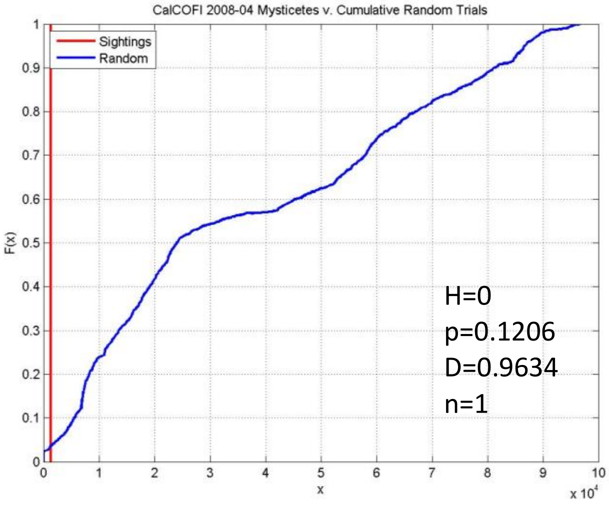


2008





2008



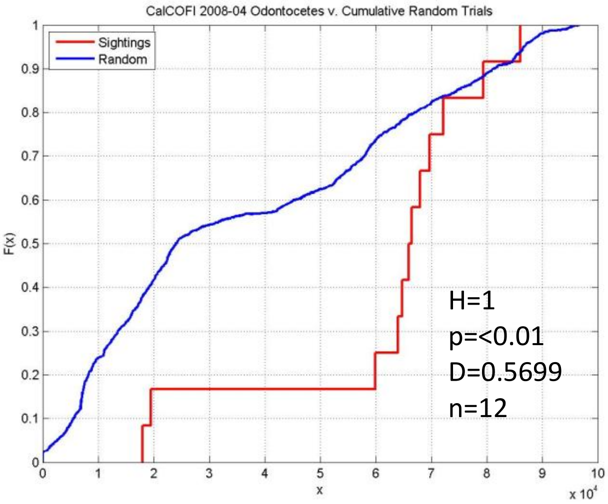
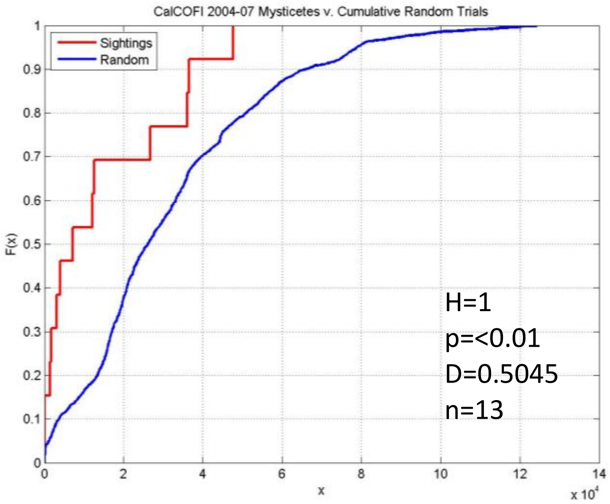


Figure 13 **Summer Cruises – Mysticetes** **Summer Cruises - Odontocetes**

2004



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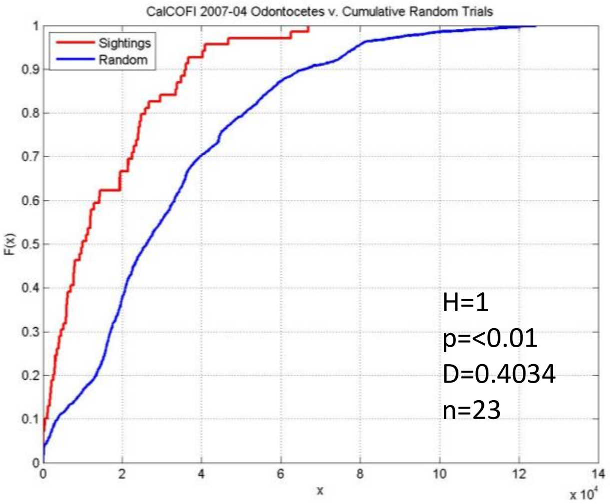
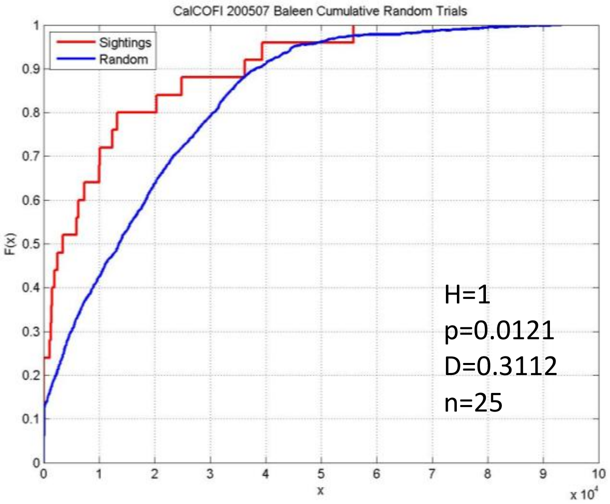
p=<0.01
D=0.5045
n=13

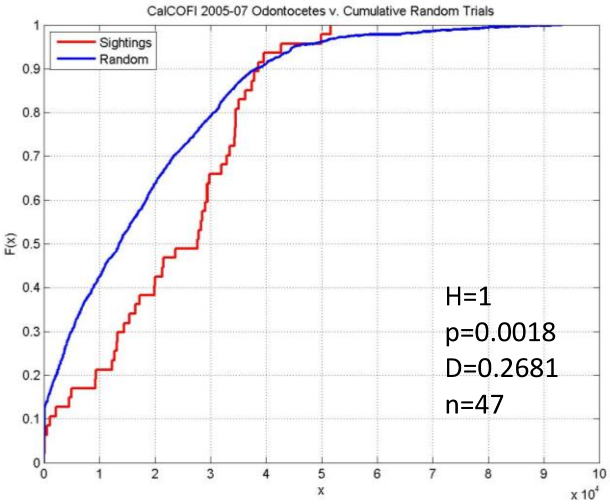


H=1
p=<0.01
D=0.4034
n=23

2005

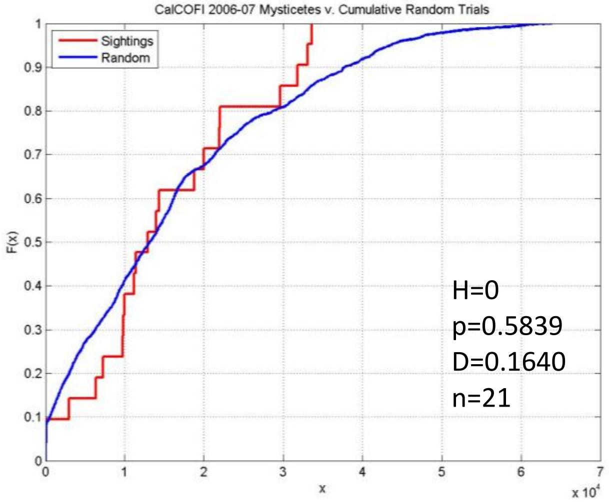


H=1
p=0.0121
D=0.3112
n=25

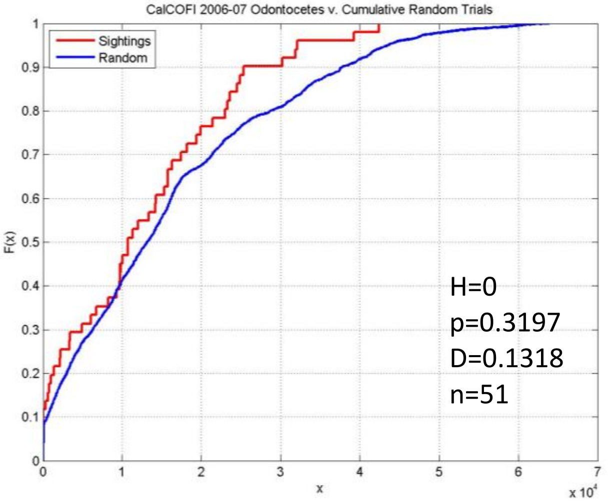


H=1
p=0.0018
D=0.2681
n=47

2006



H=0
p=0.5839
D=0.1640
n=21



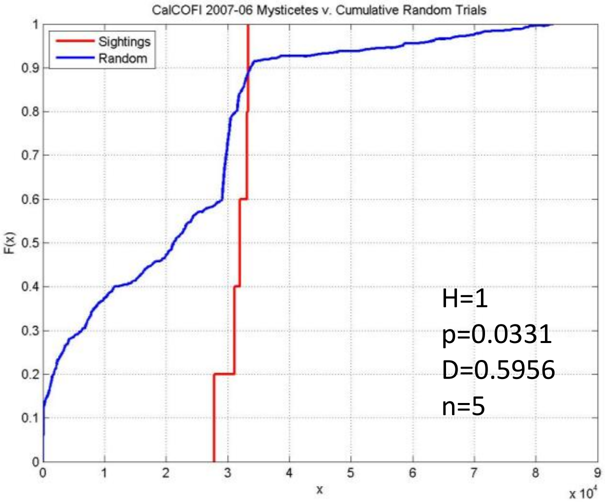
H=0
p=0.3197
D=0.1318
n=51

Figure 13 cont.

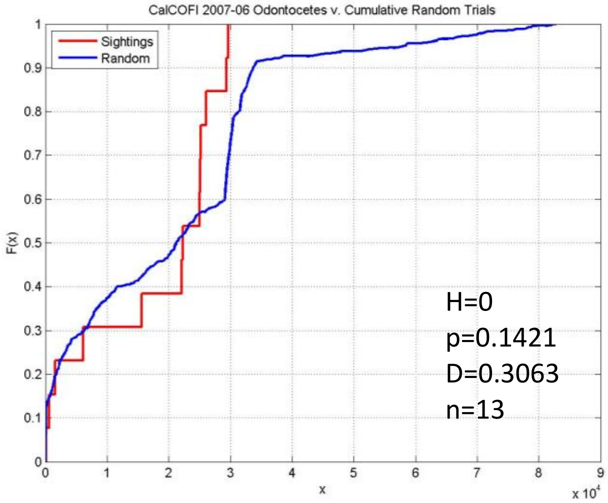
## Summer Cruises – Mysticetes

## Summer Cruises - Odontocetes

2007

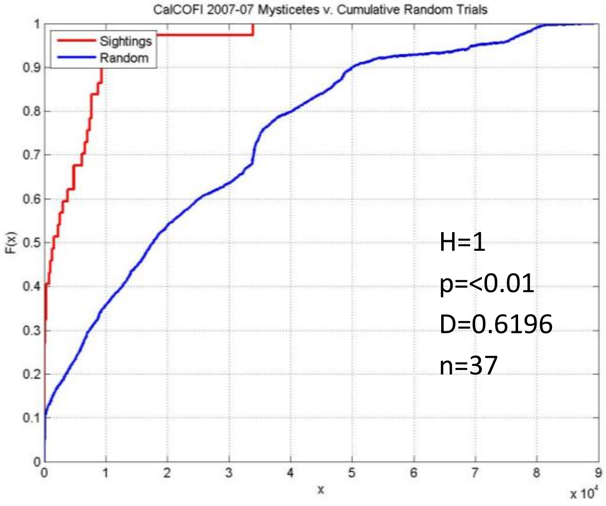


H=1
p=0.0331
D=0.5956
n=5

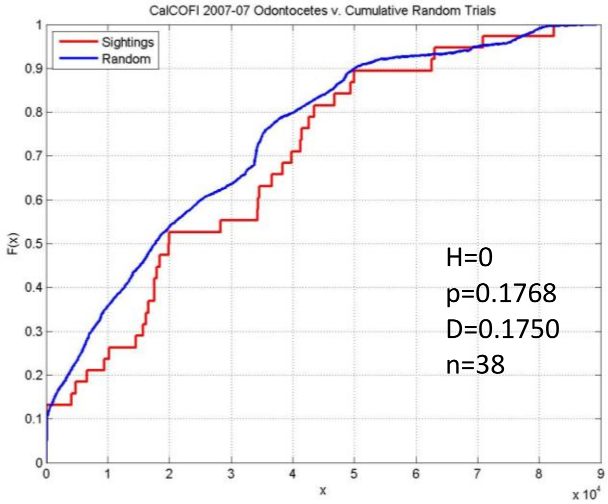


H=0
p=0.1421
D=0.3063
n=13

2007



H=1
p=<0.01
D=0.6196
n=37



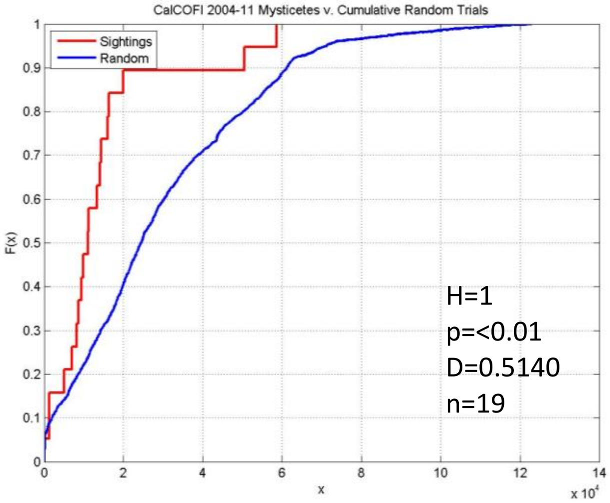
H=0
p=0.1768
D=0.1750
n=38

Figure 14

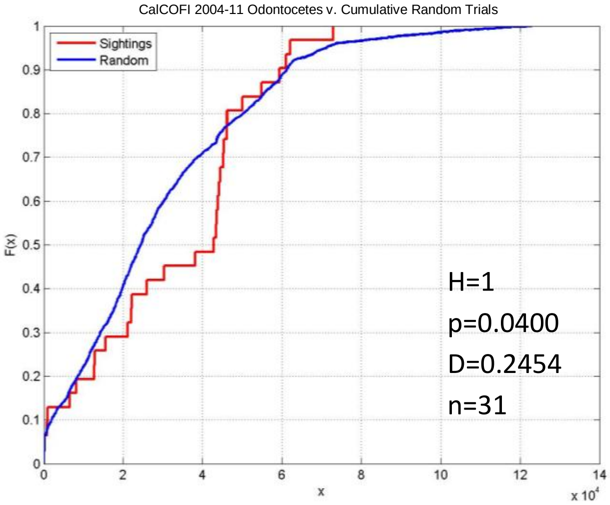
## Fall Cruises – Mysticetes

## Fall Cruises - Odontocetes

2004



H=1
p=<0.01
D=0.5140
n=19

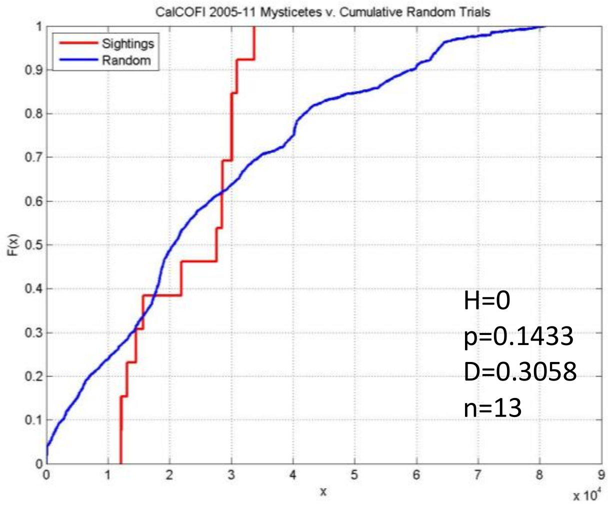


H=1
p=0.0400
D=0.2454
n=31

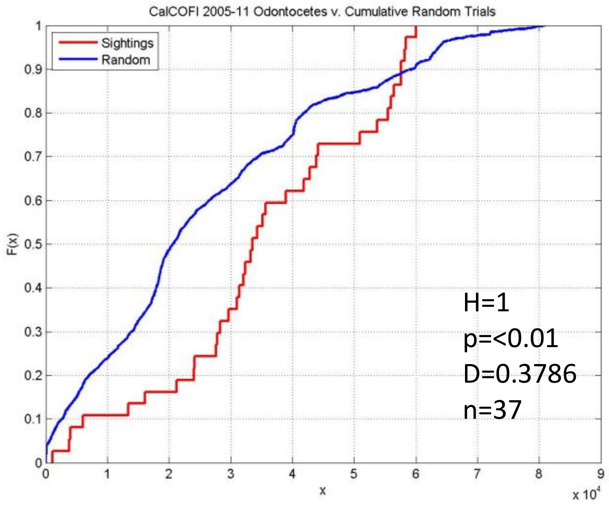
Figure 14 cont.

**Fall Cruises – Mysticetes** **Fall Cruises - Odontocetes**

2005

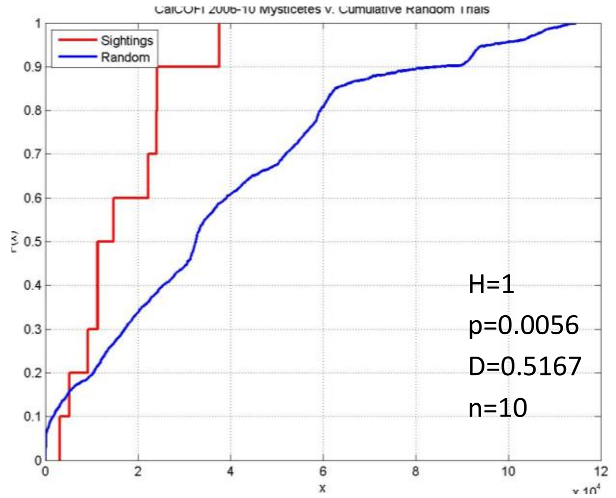

CalCOFI 2005-11 Mysticetes v. Cumulative Random Trials

H=0
p=0.1433
D=0.3058
n=13

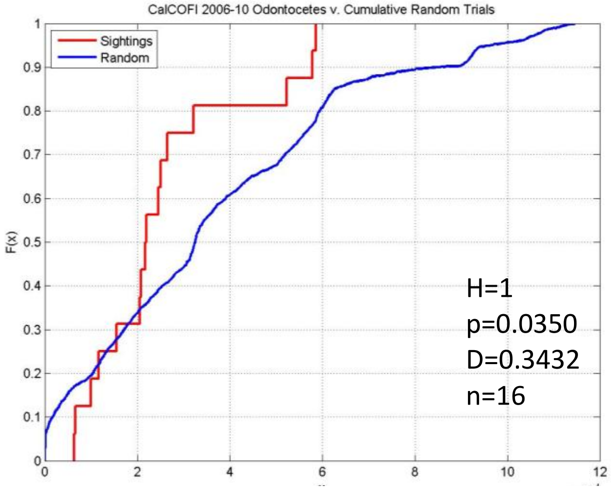

CalCOFI 2005-11 Odontocetes v. Cumulative Random Trials

H=1
p=<0.01
D=0.3786
n=37

2006

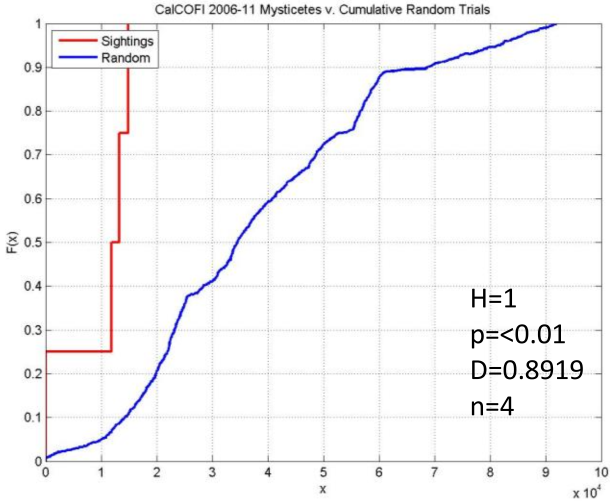

CalCOFI 2006-10 Mysticetes v. Cumulative Random Trials

H=1
p=0.0056
D=0.5167
n=10

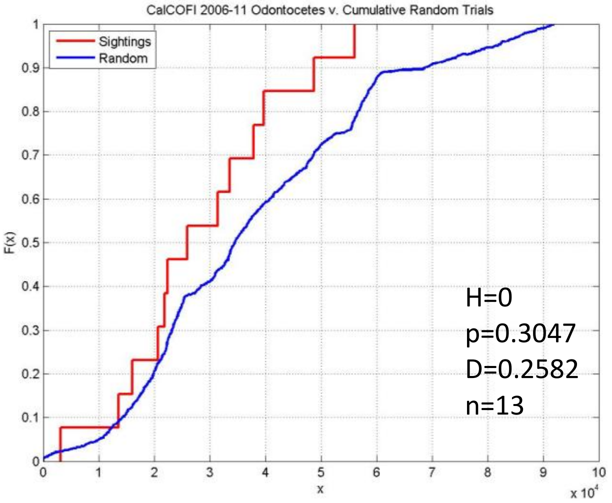

CalCOFI 2006-10 Odontocetes v. Cumulative Random Trials

H=1
p=0.0350
D=0.3432
n=16

2006


CalCOFI 2006-11 Mysticetes v. Cumulative Random Trials

H=1
p=<0.01
D=0.8919
n=4


CalCOFI 2006-11 Odontocetes v. Cumulative Random Trials

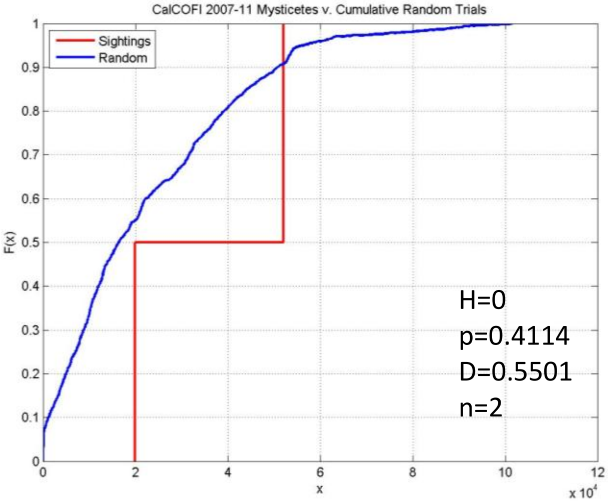
H=0
p=0.3047
D=0.2582
n=13

Figure 14 cont.

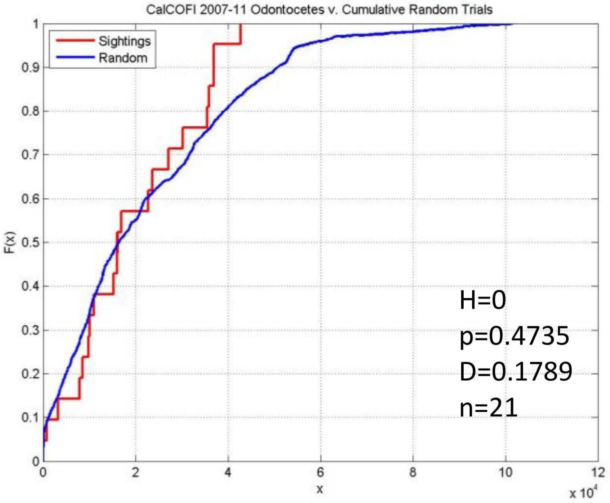
## Fall Cruises – Mysticetes

## Fall Cruises – Odontocetes

2007



H=0
p=0.4114
D=0.5501
n=2



H=0
p=0.4735
D=0.1789
n=21

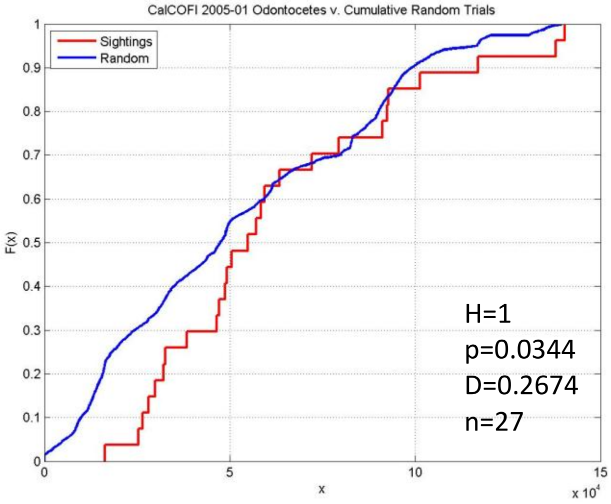
Figure 15

## Winter Cruises – Mysticetes

## Winter Cruises - Odontocetes

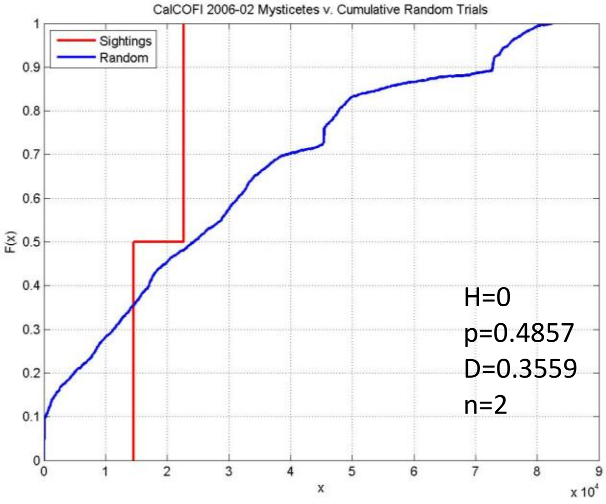
2005

**N/A**

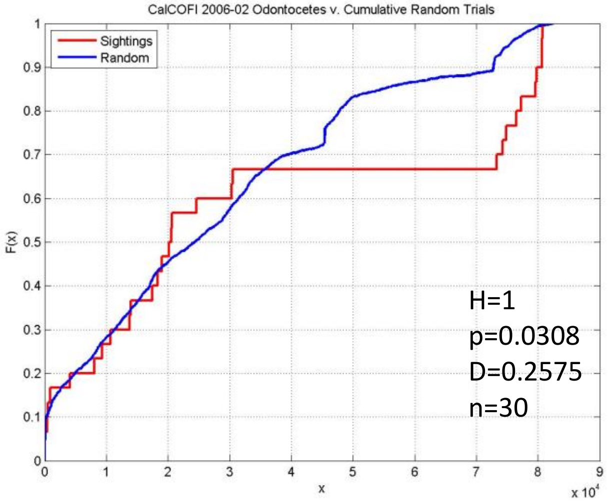


H=1
p=0.0344
D=0.2674
n=27

2006

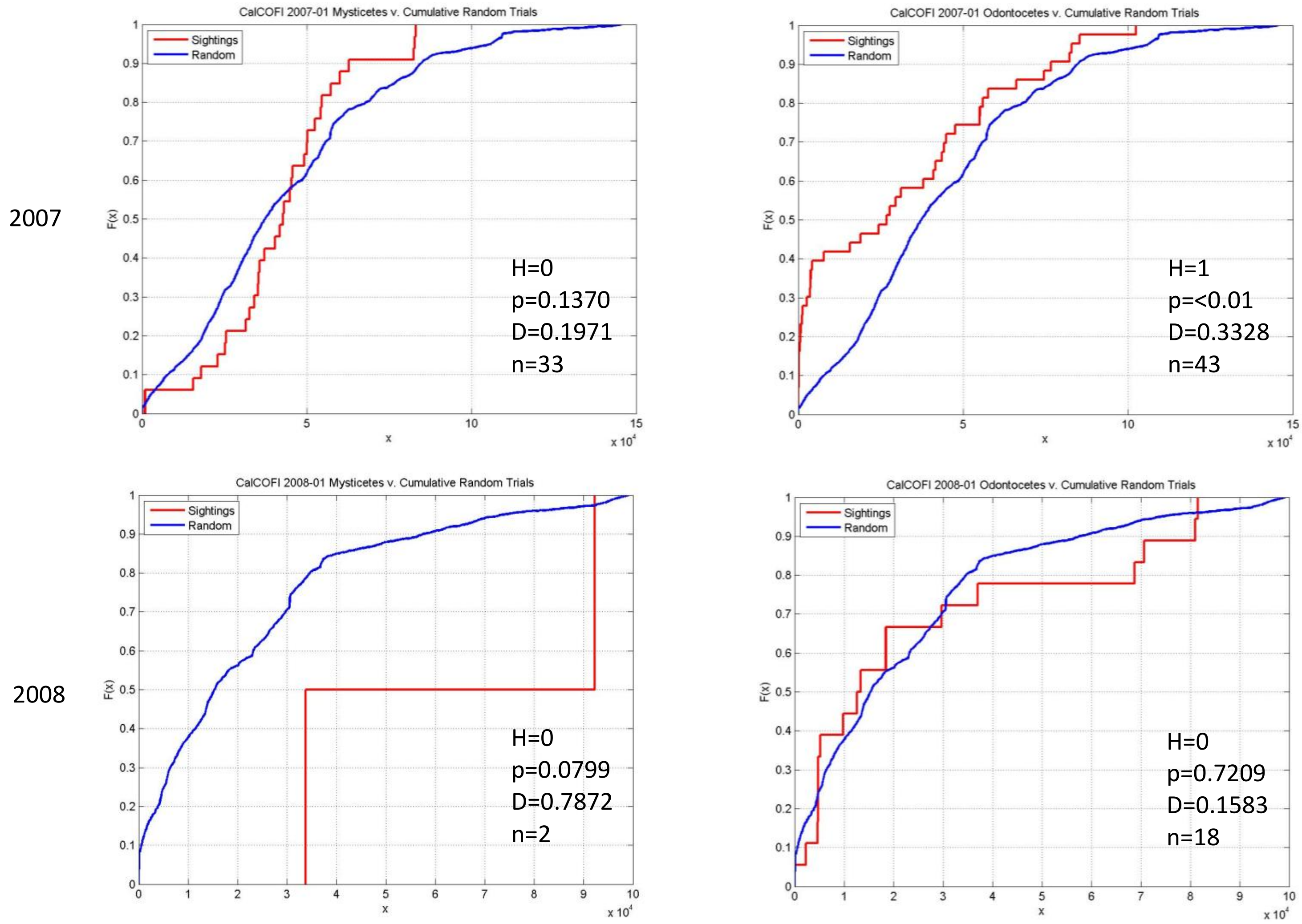


H=0
p=0.4857
D=0.3559
n=2



H=1
p=0.0308
D=0.2575
n=30

Figure 15 cont. **Winter Cruises – Mysticetes** **Winter Cruises - Odontocetes**



## **Discussion**

Results suggest the most active thermal front region within the CalCOFI study area is along the continental shelf, near the 2000m depth contour. The Southern California Bight (SCB) has a varied bathymetry; a combination of seamounts, island slopes surrounding the Channel Islands and a shelf break south of south of Point Conception. As the California Current travels toward the equator it interacts with all of these features enhancing turbulence and mixing, which is visible through the front detection process. The result is enhanced surface nutrients which supports primary and secondary production (Fiedler et al. 1998; Burtenshaw 2004). Upwelling is also caused by the convergence of smaller scale currents, which result in eddies, like the Southern California Eddy. Small and meso-scale eddies help to entrain the nutrients and productivity within the SCB.

Southern California is rich in euphausiid larvae, and their growth coincides with seasonal upwelling. As upwelling proceeds northward along the California coast it is followed by larval euphausiid recruitment. Cohort analysis of *E. Pacifica* has shown the summer and early-fall seasons are peak biomass periods (Brinton 1976; Burtenshaw 2004). This peak in abundance may be the source of mysticetes' link to frontal zones in the summer and fall.

Although odontocetes showed less association with front activity in comparison to mysticetes, this may be related to their trophic placement. Odontocetes prey on fish, squid and other marine mammals. Therefore, they may opportunistically associate with frontal zones when these higher order organisms are attracted to fronts. Previous studies have correlated aggregations of cephalopod populations with frontal zones (Rodhouse et al. 1992; Ichii et al. 2002; Garrier et al. 2007). In many cases odontocete species, such as sperm whales, rissos' dolphins and beaked whales were sighted favoring fronts in order to forage upon these aggregations (Davis et al 2002; Garrier et al. 2007).

The results of this analysis suggest that frontal areas serve as a proxy for food availability and possibly as attractive foraging locations for mysticetes, while odontocetes exhibited little association to frontal zones. Upon further examination of the mysticetes the difference in species distance to SST front could reflect species-specific feeding strategies. Doiol-Valcroze et al. (2007) suggested that upwelling temperature gradients can along their edges have a herding affect on krill and fishes. Krill may become more concentrated as they fight the forces of upwelling to remain out of the light. Similarly, fishes, such as capelin, have been discovered concentrating within narrow temperature zones to avoid cold water. The species specific differences in the baleen whales distributions to front activity are possibly a result of partitioning the frontal zones to reduce competition. Regardless, these animals show a relationship to the SST fronts that are not explained under a random scenario. Potentially these animals are actively exploiting areas which maintain regular front activity to minimize time spent traveling and foraging.

No link can be drawn between species richness and front activity from this study. The inability to capture any clear linkage may be a result of cetacean's high level of mobility and the scale at which the analysis occurred. It may be of value to revisit this issue by expanding the size of the sampling unit.

## Conclusion

This study indicates that a relationship exists between SST fronts and cetacean distributions. However, it would be useful to incorporate additional habitat variables to obtain a more nuanced understanding of their behavior. Valuable environmental variables to incorporate into this analysis are bathymetry, chlorophyll-a levels, and distance to shore. Identifying whether these animals are grouping along specific temperature gradients may also be of interest. It may offer insight into their foraging strategies and the species they may be preying upon. The applications of such analyses should be incorporated into habitat models and applied to management and policy decisions. A critical requirement of ecosystem-based management is the ability to define and identify valuable biological areas from the organism's point of view. Enhancing our predictive capacity for where and how cetaceans will be distributed allows for the easing of anthropogenic impacts. For instance, theses models could be applied towards the mitigation of ship strikes through speed reduction zones for vessel traffic, defining optimal time windows and locations for performing naval training exercises, as well as aiding the development of Marine Protected Areas (MPA) or seasonal time closures with cetaceans as the focal species. Ultimately the goal is to attain the ability to perform predictions on a real time basis. The ability to do so will require an enhanced understanding of what preferred cetacean habitat is.

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