Risk Assessment of Vessel Traffic on Endangered Blue and Humpback Whales in the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries

Summary of Research Results

Prepared by

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EXECUTIVE SUMMARY

The identification of cetacean habitat use associated with major feeding areas for endangered blue (*Balaenoptera musculus*) and humpback whales (*Megaptera novaeangliae*) within areas of high ship densities has become of greater conservation importance in the San Francisco Bay area due to the three endangered whales that died from ship strike injuries during July, September and October 2010. The objective of this study was to examine ship use in shipping lanes approaching San Francisco Bay in relation to temporal and spatial high use areas of blue and humpback whales to identify primary areas of overlap and assess potential risks. The study area extended from 35.5-38.5 °N Latitude and from 121-124°W Longitude and included Cordell Bank and Gulf of the Farallones National Marine Sanctuaries.

This study conducted by Oikonos Ecosystem Knowledge, Cascadia Research Collective, R.G. Ford Consulting Company, the Naval Post Graduate School Ocean Acoustics Laboratory, and Save The Whales was made possible through funding from Pacific Life Foundation.

To measure relative risk of impacts of vessel traffic and evaluate collision potentials to blue and humpback whales during seasonal foraging high use areas we did the following: 1) identified blue and humpback whale habitat use patterns; 2) identified vessel traffic patterns during Aug-Oct 2009-2010; and 3) identified overlap of humpback and blue whale distributions during seasonal high use feeding and transiting locations and vessel traffic densities near and in San Francisco shipping lanes. Aug-Oct was selected because historically, both blue and humpback whales tend to be more abundant during these months in the study area when their preferred prey (krill and small schooling fish) are most abundant.

Results of humpback and blue whale habitat use patterns indicated greatest densities occurred near the continental shelf edge, along the inner side of the shelf edge and along the shelf slope, at Cordell Bank, and west, north and south of the Farallon Islands, and also on the continental shelf in the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries. The observations made during whale watching cruises and other studies exhibited a similar pattern. Results of San Francisco approach vessel traffic patterns during Aug-Oct 2009-2010 indicated the greatest numbers of vessels were cargo ships (52%) and tankers (24%); 14% were 'Other' (passenger, pilot vessel, search and rescue, port tender, military ops, underwater ops, law enforcement, sailing, pleasure, fishing, unidentified); and 10% were towing or tugs. Overlap of whale density and vessel density results indicated the principal areas of relative risk were the western approach shipping lanes that intersect the shelf edge within the Gulf of the Farallones and in the Cordell Bank area where the (extended) north-west lanes pass through the shelf north of the Gulf of the Farallones.

Understanding distribution and occurrence patterns of these whales is an important pre-requisite for conservation and mitigation. Insight gained from our research, combined with the involvement of government agencies, environmental groups and the shipping industry, will be a critical contribution to help reduce the effects of this growing concern.

INTRODUCTION:

The threat of ship strikes from vessel traffic off central California has become a conservation issue due to the increase in numbers and sizes of ships traveling through endangered blue (*Balaenoptera musculus*) and humpback whale (*Megaptera novaeangliae*) feeding areas in the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries. The Marine Mammal Center and NOAA Fisheries Service/Southwest Region Marine Mammal Stranding Network record numbers of whale deaths along the California coast annually. Between 1988 and 2007 Berman-Kowalewski et al. (2010) reported 21 blue whale deaths along the California Coast, typically one or two cases annually. Fall strandings were observed 1988 (n = 3), 2002 (n = 2), and 2007 (n = 4), the latter of which were located in the shipping lanes off Southern California. In the San Francisco Bay area, during July, September and October 2010, three endangered whales were killed from ship strikes (pers. comm. F. Gulland 2010), including an 84 ft pregnant female blue whale that washed up on Bean Hollow State Beach with her 17 ft long fetus on 3 October 2010. A total of 14 large whale ship strikes were reported in 2009-2010. Dead whale strandings along the coast related to ship strikes may represent only a small portion of true ship strike mortality; most cetacean deaths are never recovered because they either sink or do not come ashore (John Calambokidis, personal communication). Actual deaths from ship strikes may be higher than beach strandings would indicate.

Comprehensive mapping is an important tool for identifying critical habitats for blue and humpback whales as it provides important details on the overlapping densities of endangered whales and ships. Understanding distribution patterns of these whales, measuring relative risk of impact of vessel traffic, and evaluating potential collisions are all important pre-requisites for their conservation and mitigation.

METHODS & RESULTS

SELECTION OF STUDY AREA AND SEASON

The original intent of the study was to analyze cetacean distribution and ship traffic patterns in the waters of the Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries. Because the ship traffic dataset did not reliably extend into the nearshore southern part of this study area, the final analysis was restricted to the area north of 37°15'. The August-October season was selected because historically, both blue and humpback whales tend to be more abundant during these months in the study area when their preferred prey (krill and small schooling fish; Calambokidis et al. 1991, Kieckhefer 1992) are most abundant. Cetacean data for this season span more than 30 years (Calambokidis et al. 2009), while data on ship traffic acquired for this study are for 2009 and 2010.

CETACEAN HABITAT USE PATTERNS RELATIVE TO SHIPPING LANES

Cetacean Data:

Historical whale sighting data were used to identify their primary habitats for seasonal foraging and transiting relative to shipping lanes. The whale analyses used archived research data collected for the past 30 years in systematic and photo-ID surveys, as well as opportunistic data collected on whale watching trips since 2001, to characterize the distribution of humpback and blue whales during the August-October season. Data from several studies were combined in order to determine overall patterns of occurrence over a span of years. One data set used in the present study included eight systematic survey programs conducted during 1980 – 2001 and summarized in NOAA (2007). A second data set consisted of Cascadia Research data on humpback and blue whales based on the sightings during annual photo-ID surveys conducted in summer and fall from 1991 to 2010. These were non-systematic surveys generally conducted with 5-6 RHIB launched from Bodega Bay, SF Bay, or Half Moon Bay aimed at encountering and obtaining photo-IDs of the target species. Surveys were conducted with support and in collaboration with SWFSC. Other data sets included California Department of Fish and Game Office of Spill Prevention and Response regular and spill response flight data (2001-2008); historical opportunistic photo identification research from Kieckhefer 1988-1990; and Keiper whale watching opportunistic data collected in 2001-2008, 2010 and 2011. Data sets are summarized in Table 1 below.

Table 1. Data sources for characterization of humpback and blue whale distribution in the August-October season. Only the Cascadia and CDFG-OSPR densities were used in the final traffic analysis. Parameters for density estimation [g(0) and ESW] were based on investigator approximation. Both linear km of effort and whale numbers are for the defined study area only.

Data Source	Type of Survey	Years	Linear Km of Effort	Estimated g(0) and ESW	Humpback Whales Sighted	Blue Whales Sighted	Use in This Analysis
Cascadia	Photo-ID	1991-2010	35,895	0.5 / 1 km	4,726	1,720	Densities
CDFG-OSPR	Aerial systematic and spill response	2001-2008	113,424	0.1 / 75 m	298	148	Densities
Keiper	Opportunistic	2001-2008; 2010-2011	~14,000	Not used	533	89	Illustrative
Kieckhefer	Photo-ID	1988-1990	TBD	Not used	923	N/A	Illustrative
NOAA 2007	Systematic	1980-2001	306,961	Various	1,629	Not used	Illustrative

Density Calculation for Cascadia and CDFG-OSPR data:

While all data sets were used to create mapped representations of humpback and blue whale distributions, some were used for illustrative purposes only. The Cascadia and CDFG-OSPR data were in a format that allowed the creation of density estimates in one minute latitude/longitude cells; these density estimates were later combined with vessel data to illustrate spatial patterns of the risk of vessel traffic to whales.

For each survey on each day, the trackline of the vessel or aircraft was plotted and the length of that trackline in each one minute latitude/longitude cell was calculated. The effective area surveyed was calculated as the product of the length of the trackline, the estimated strip width, and the sightability estimate [g(0)]. Each sighting was also assigned to the one minute cell in which it occurred. The values for each survey in each cell were summed and overall densities for each cell were calculated. Densities are given in individuals per square kilometer, calculated as numbers of individuals observed divided by effective area surveyed in each cell.

Cetacean Habitat Use Patterns:
All datasets show a similar pattern of whale distribution in the August-October season. Highest densities of humpback and blue whales during summer and fall feeding seasons occurred near the continental shelf edge, along the inner side of the shelf edge and along the shelf slope, at Cordell Bank, and west, north and south of the Farallon Islands, and also on the continental shelf in the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries (Figures 1-3). GIS analysis of historical data indicates a clear overlap of humpback and blue whale distributions during seasonal high use feeding and transiting locations and San Francisco shipping lanes.

Opportunistic Whale Watching Cruise Patterns and Other Studies:
Whale watching trips provide an important platform of opportunity to fill data gaps in year round temporal and spatial occurrence patterns and habitat use of humpback and blue whales. Koslovsky (2008) reported that data from these platforms are widely used for scientific studies to identify their abundance, encounter rates and distribution (Ingram et al. 2007; MacIeod et al. 2004; Weinrich et al. 1997). Due to fundamental differences in data collection techniques between structured scientific surveys and opportunistic whale watching data collection it was not possible to integrate these data into the historical database. Because whale watching trips are conducted on a regular basis throughout the year, data collected on these trips (date, time, location, species, number, behavior) has provided (and will continue to provide) a large source of information regarding the temporal and spatial distribution of the whales.

Although data collection in 2001-2006 on whale watching trips was sporadic and not equal each year, data collection has been more regular in 2007-2008, and 2011. Whale watching trips to the Farallon Islands depart from Sausalito and San Francisco and typically travel directly to the Farallones (Southeast Farallon Island) or head north along the coast to Duxbury Reef or Pt

Reyes and then head to the Farallones. After spending some time at the Farallones, most trips (depending on wind and sea conditions) travel out to the edge of the continental shelf and venture into the continental slope and deeper waters to the north and/or south of the Farallones. Although GPS data was not collected historically, examples of tracklines were created to document whale watching trips that range from 115-142 km (average 125 km) that take 7-8 hours. Vessels leave the dock at 08:00 and return between 15:00 and 16:00 (Figure 4).

Habitat use analysis of blue and humpback whales during the summer and fall feeding seasons during 2001 – 2008, 2010, and 2011 on opportunistic whale watching cruises indicated the highest numbers of humpback and blue whale opportunistic sightings occurred during these feeding seasons near the continental shelf edge and slope, along the inner side of the shelf edge, west and north of the Farallon Islands and also on the continental shelf in the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries (Figure 5). In order to minimize bias from the uneven allocation of survey effort in both time and space, we used the sightings-per-unit-effort (SPUE) algorithm (#whales/km). This method produced number of individual cetaceans per unit length of track line within user defined temporal and spatial units. SPUE: humpback whales = 0.039 and blue whales = 0.0071.

Also included in mapping results are data from Kieckhefer's study (Kieckhefer 1992) on daytime feeding behavior of humpback whales in the Gulf of the Farallones and adjacent waters during autumn of 1988-1990. Feeding was the most common behavior observer (52%) and less frequently traveling (23%), milling (21%) and resting (4%). Vessel survey effort is illustrated in Figure 6 and sightings from these surveys along with Keiper data are included in Figure 7.

Summary of Cetacean Habitat Use Patterns

Greatest humpback and blue whale concentrations occurred during seasonal feeding in summer and fall. Greatest densities occurred along and near the continental shelf edge and west, north and south of the Farallon Islands, generally concentrated along the inner side of the shelf edge and also on the continental shelf in the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries. The observations made during whale watching cruises and other studies exhibit a similar pattern. These high-use areas include waters in close proximity to and within the shipping lanes approaching San Francisco.

SAN FRANCISCO APPROACH VESSEL TRAFFIC PATTERNS

Numbers and Types of Vessels:

Automatic Identification Systems (AIS) ship data within 37°-38.5° N Latitude and 122.5° - 124° W Longitude in selected time-periods (Aug-Oct 2009-2010) were collected from a shore station located at the Bodega Marine Laboratory north of San Francisco and were used to identify types and numbers of vessels that transit the shipping lanes in the vicinity of the large cetaceans foraging and transiting areas. Aug-Oct 2009-2010 were selected because historically, both blue and humpback whales tend to be more abundant during these months in these waters due to more abundant prey resources (krill and small schooling fish).

To quantify vessel traffic, daily totals of all vessels within 37°-38.5° N Latitude and 122.5° - 124° W Longitude were calculated for Aug-Oct 2009-2010. The daily totals were then tallied for monthly traffic**.** These data are based on available AIS message data from coastal receivers and is not a comprehensive total of all shipping entering San Francisco Bay. These receivers have poor coverage close to shore at the San Francisco Bay entrance due to topographic obstruction of the radio signals. These data are also based on daily totals, so any vessel transiting about 00:00 GMT will be counted twice, in each day in which it appeared. The greatest numbers of vessels were cargo ships (52%) and tankers (24%); 14% were 'Other' (passenger, pilot vessel, search and rescue, port tender, military ops, underwater ops, law enforcement, sailing, pleasure, fishing, unidentified); 10% were towing or tug (Figure 8). Summary of vessel totals: Aug-Oct 2009 n = 2,550 and Aug-Oct 2010 n = 2,443.

Vessel Tracks:
Automatic Identification Systems (AIS) ship data were plotted and summarized using the Geographic Information System (GIS). The area affected was calculated as the product of vessel beam and length of vessel track within a grid cell. The areas affected by all vessels within a cell were then summed to indicate relative risk. The GIS analyses based on five minute latitude/longitude cells indicated the highest grid cells are found in the vessel traffic lanes of the western approaches, south of the Farallon Islands and within the Gulf of the Farallones National Marine Sanctuary (Figure 9).

In the finer scale analysis, based on one minute latitude/longitude cells, the highest risk cells were those of the outbound westbound lane (Figure 10). An average of five vessels per day transited each of these cells. The average beam of the vessels in this analysis is approximately 27 meters. Up to 9% of the surface area of these high-risk cells was affected directly by vessel passage on any given day in this season. Overall, average vessel speed was 13 kt (the range was 0-39 kt).

COMBINING WHALE & SHIP DATA TO IDENTIFY AREAS OF CONCERN

Methods
Data for whale distribution and ship traffic were used to estimate vessel traffic risk using methods similar to those described by Nichols and Kite-Powell (2005) and David et al. (2011) for other cetacean species and regions. We derived blue and humpback whale densities for the August-October season using data spanning 20 years, resulting in a composite representation of the species' use of the study area during this time of year. All whale data were summarized into 1' latitude/longitude blocks. In order to provide a clearer view of the pattern of whale distributions, we smoothed the whale densities by recalculating the density of each 1' cell as the average of the raw density values of that cell and the 8 adjacent cells. Vessel traffic data for this season for 2009 and 2010 were summarized into the same grid to create a representation of recent vessel traffic. Vessel traffic data were used to estimate the total area swept by each ship (the product of vessel beam and distance traveled), summed over all vessels within each

block. The product of area swept and whale density within each block provides a relative measure of the number of whale/ship encounters per season within each cell.

Results of identification of areas of relative risk and concern:
As would be expected, the areas with the greatest ship traffic are concentrated within the lanes of the Traffic Separate Scheme (TSS), especially the western approach shipping lanes. Many ships appear to continue on the same heading after exiting the TSS, or to set their headings so that they are aimed toward the entry to the TSS. As a result, the positioning of the traffic lanes affects the intensity of ship traffic well beyond the end of the lanes.

The distribution of risk is a function of both the distribution of vessel traffic and whales, and the greatest risk occurs where the two are both abundant. The principal areas of relative risk are therefore where the (extended) western approach shipping lanes intersect the shelf edge within the Gulf of the Farallones, or in the Cordell Bank area where the (extended) north-west lanes pass through the shelf north of the Gulf of the Farallones (Figures 11- 12).

CONCLUSIONS & FUTURE WORK

Habitat Use Patterns of Blue and Humpback whales: Greatest densities of humpback and blue whale concentrations occurred during seasonal high use feeding areas in summer and fall near the continental shelf edge, along the inner side of the shelf edge and along the shelf slope at Cordell Bank and west, north and south of the Farallon Islands, and also on the continental shelf in the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries.

Vessel Traffic: During Aug-Oct 2009-2010 greatest numbers of vessels were cargo ships and tankers with an average beam of 27 meters and average vessel speed was 13 kts (minimum 0 kts, maximum 39 kts).

Primary Areas of Overlap and Relative Risk Areas: The principal areas of risk were the western approach lanes which intersect the shelf edge within the Gulf of the Farallones and the lanes that pass through the Cordell Bank area. Collision potential was highest in the western approach shipping lanes due to the required fuel switching 24 nm miles from the coast that was implemented in July 2009 and resulted in a significant increase in the use of these lanes.

Greatest Concern of Ship Strikes: Eastern North Pacific stock of blue whales due to no evidence that this stock is currently growing (2,842; Stock Assessment Report 10/15/2009); this is in contrast to the humpback whale populations that appears to be more robust with a best with estimate of 18,000-20,000 in the entire Pacific Basin (Calambokids et al.2008) and the best estimate of 2,043 for the CA/OR Stock (Calambokidis et al.2009).

Education Outreach: Results have been presented to resource managers, and will be presented to the shipping industry. Participation in mitigating solutions of vessel traffic with the Cordell

Bank and Gulf of the Farallones National Marine Sanctuary Joint Working Group (CB/GFNMSJTWG) on Vessel Traffic is currently taking plan and will continue through May 2012.

Opportunistic Whale Sighting Data: To document the seasonal and inter-annual variability of blue and humpback whales we will continue with on-going opportunistic data collection on whale watching cruises and plan to expand these 'platforms of opportunity' to fill data gaps in year round temporal and spatial habitat use in support of the importance of long term monitoring.

Databases: Will be shared with the North Central California Pelagic Ecosystem Application (NCCPEA)SEF12 Project to be used on Applied California Current Ecosystem Studies (ACCESS) and Ocean Biogeographic Information System (OBIS) that will be updated in 2012.

Future Research: Spatial modeling to incorporate the underlying variability in both process and estimation into the analysis of strike risk (Garrison 2005); plan further research to understand the behavior of large ships and humpback and blue whales and their varied speed of travel as a factor of reduction of ship strike threats. Create predictive scientific model of presence and absence of the whales in critical foraging areas to inform vessel traffic advisories. Continuous monitoring is critical for the blue and humpback whales due to the significant spatial and temporal variability in habitat use both seasonally and inter annually. We will pursue future funding needed for 1) 'citizen scientist' training for continuous monitoring and opportunistic data collection and 2) manuscript writing and publication of our results.

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- Capt. Jim Roberts, Outer Limits
- Capt. Mick Menigoz, Superfish

Pacific Life Foundation for funding

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FIGURES

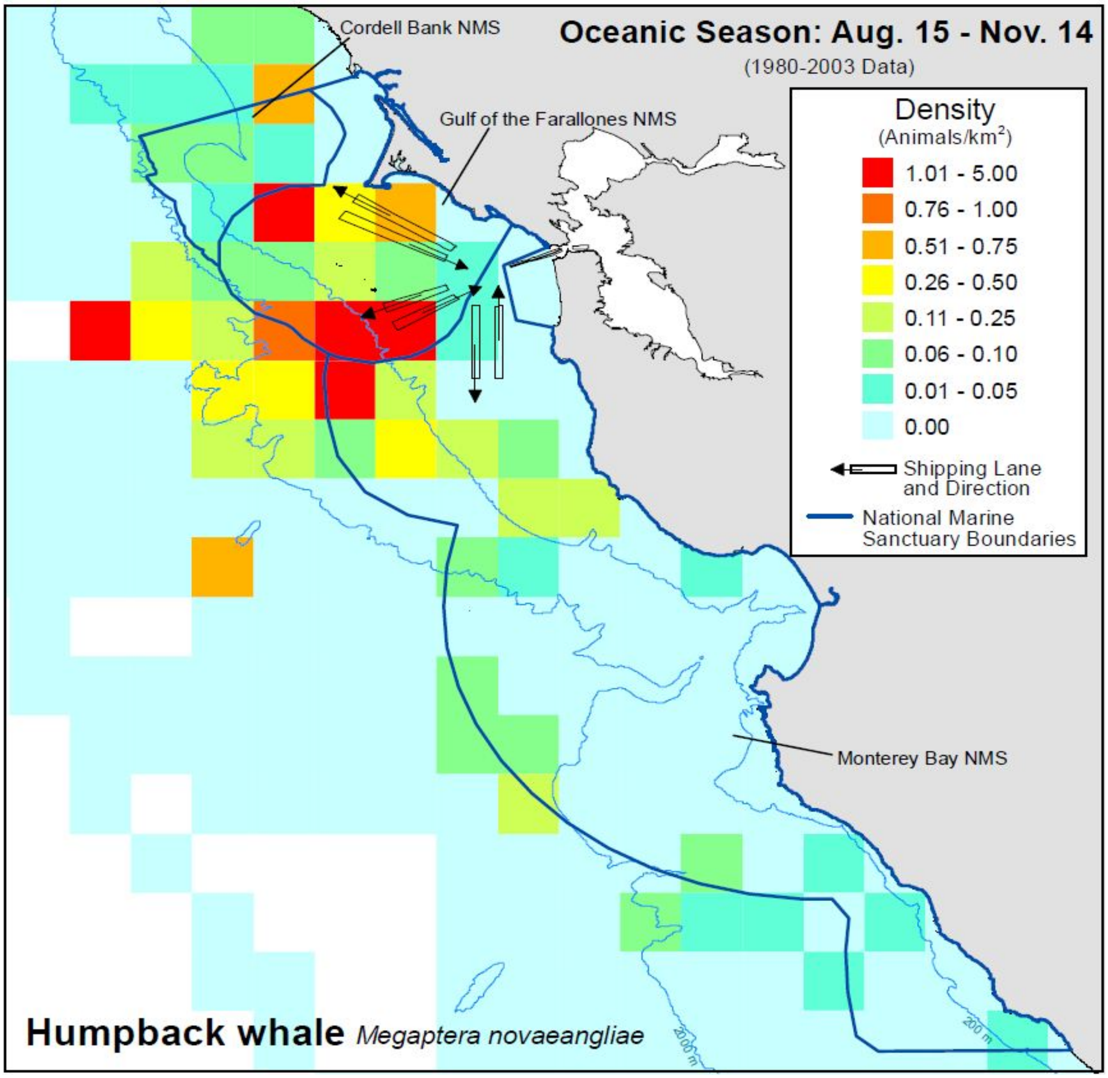

Figure 1. Humpback whale densities during August-October season (adapted from NOAA 2007) showing habitat use relative to shipping lanes in the Gulf of the Farallones, Cordell Bank, and Monterey Bay National Marine Sanctuaries. Average densities are shown in 5 minute latitude/longitude cells.

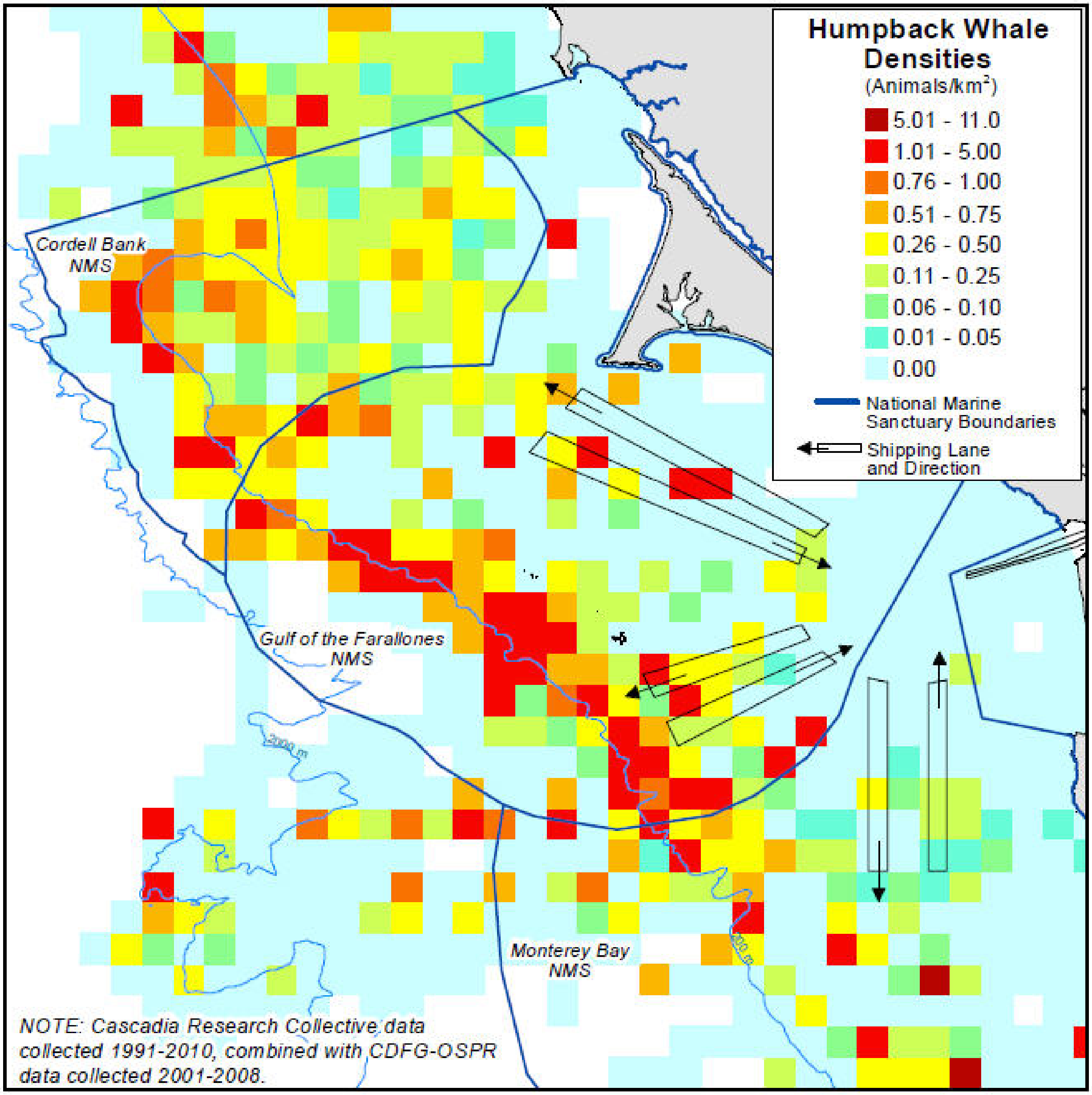

Figure 2. Humpback whale densities during the August-October feeding season. Data are from Cascadia Research Collective (1991-2010) , combined with data from the California Department of Fish and Game Office of Spill Prevention and Response flights (2001-2008) , and show habitat use relative to shipping lanes in the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries. Average densities are shown in 2 minute latitude/longitude cells.

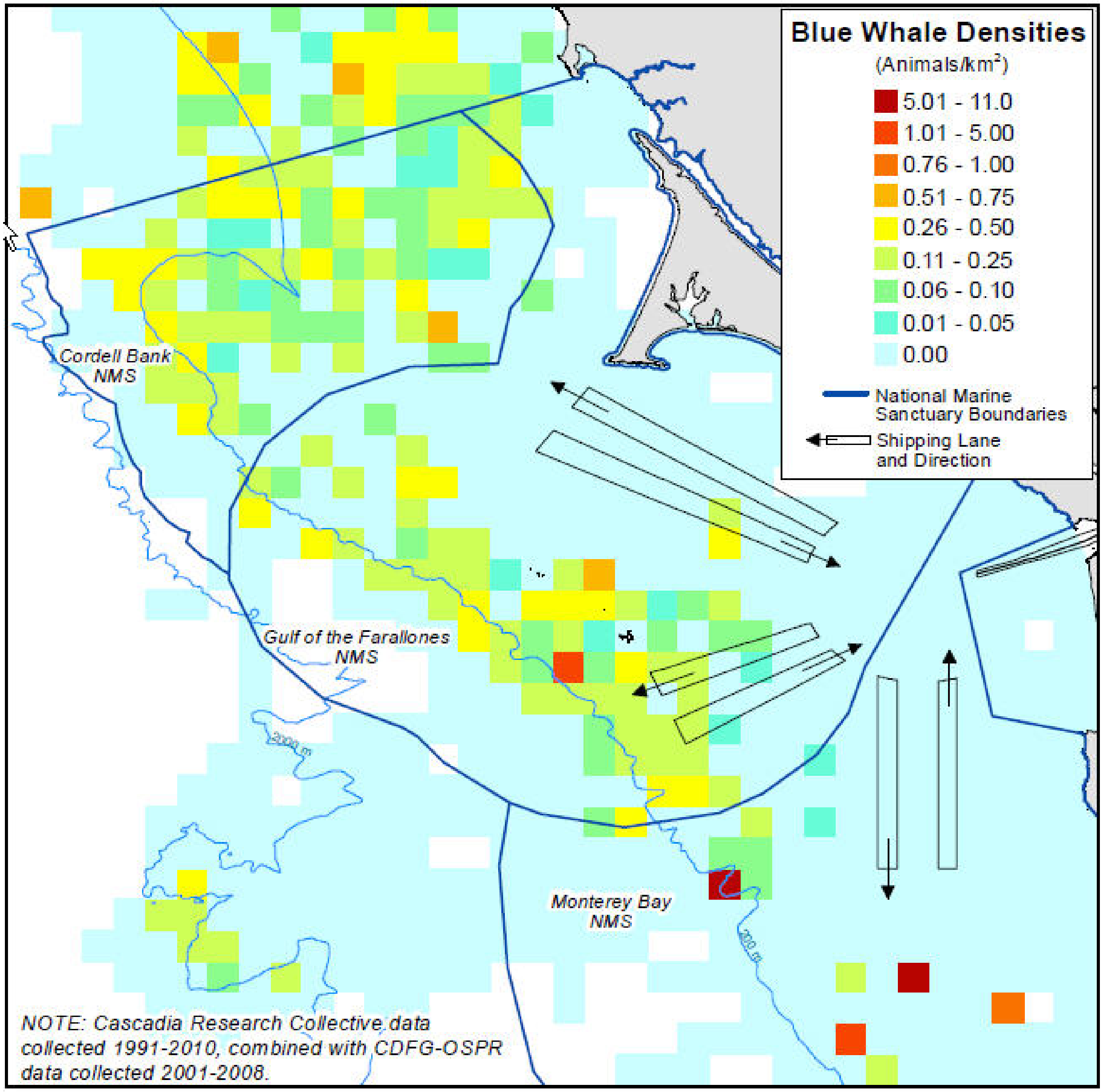

Figure 3. Blue whale densities during the August-October feeding season. Data are from Cascadia Research Collective (1991-2010), combined with data from the California Department of Fish and Game Office of Spill Prevention and Response flights (2001-2008), and show habitat use relative to shipping lanes in the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries. Average densities are shown in 2 minute latitude/longitude cells.

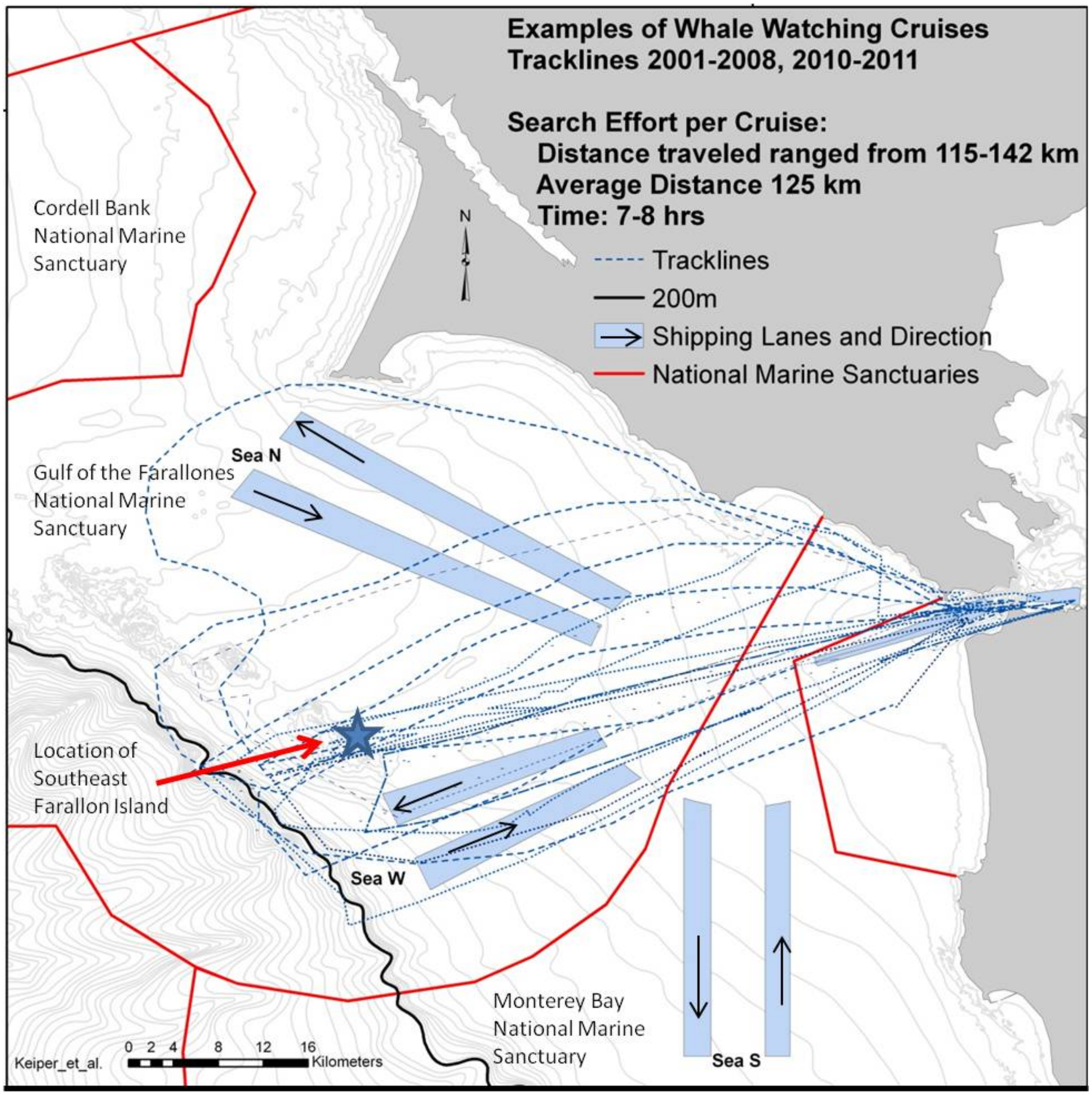

Figure 4. Although GPS data was not collected historically, examples of tracklines were created to document whale watching trips that range from 115-142 km (average 125 km) that take 7-8 hours. Vessels leave the dock at 08:00 and return between 15:00 and 16:00; the route is a round trip to the Farallon Islands and north, south, and west of the Farallones and to the shelf break and slope, depending on sea and wind conditions.

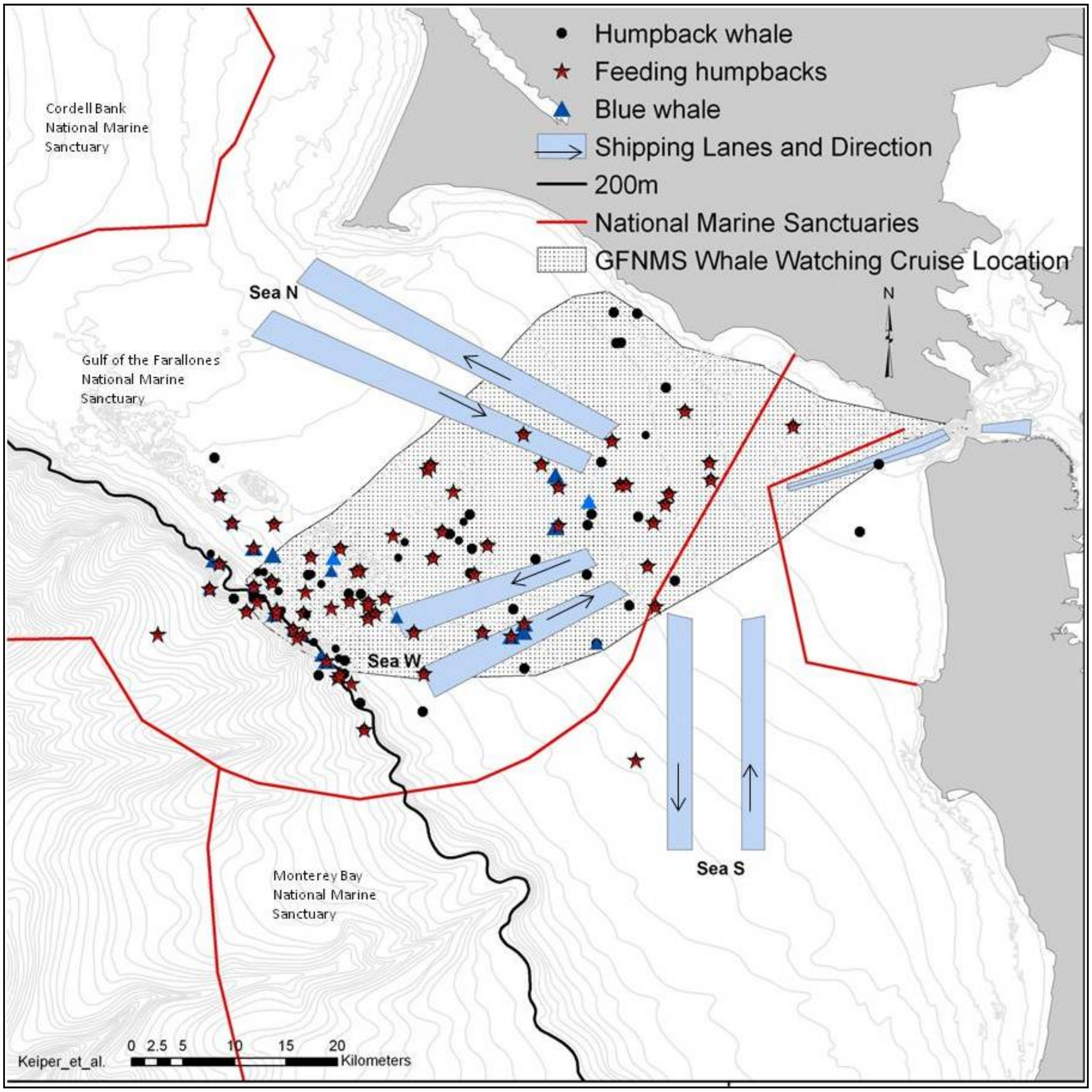

Figure 5. Opportunistic sighting locations of blue and humpback whales relative to shipping lanes during whale watching cruises in the GFNMS enroute to the Farallon Islands in 2001-2008 and 2011 (n = 112 data trips; ~125 km per trip). The shaded area is the primary search and cruising area that was not sampled equally and represents most of the trips in this area. Active surface feeding and milling behaviors were observed in 95% of the blue whale sightings and 76% of the humpback whale sightings. Numbers of humpback whales at sighting locations ranged from 1 to 30 and blue whales 1 to 15.

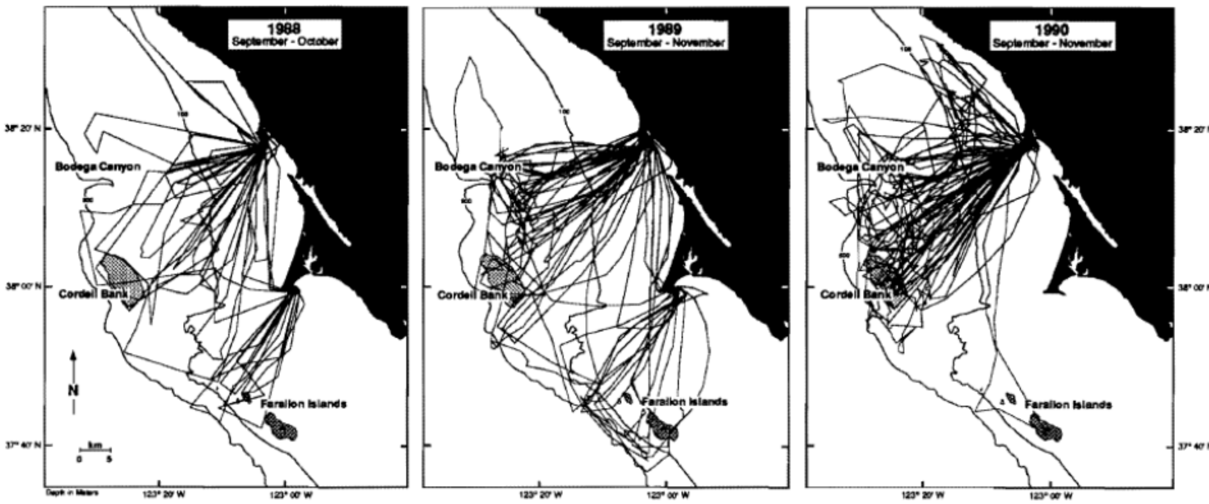

Figure 6. Tracklines from vessel surveys conducted from September to October 1988, and from September to December 1989 and 1990, by Kieckhefer.

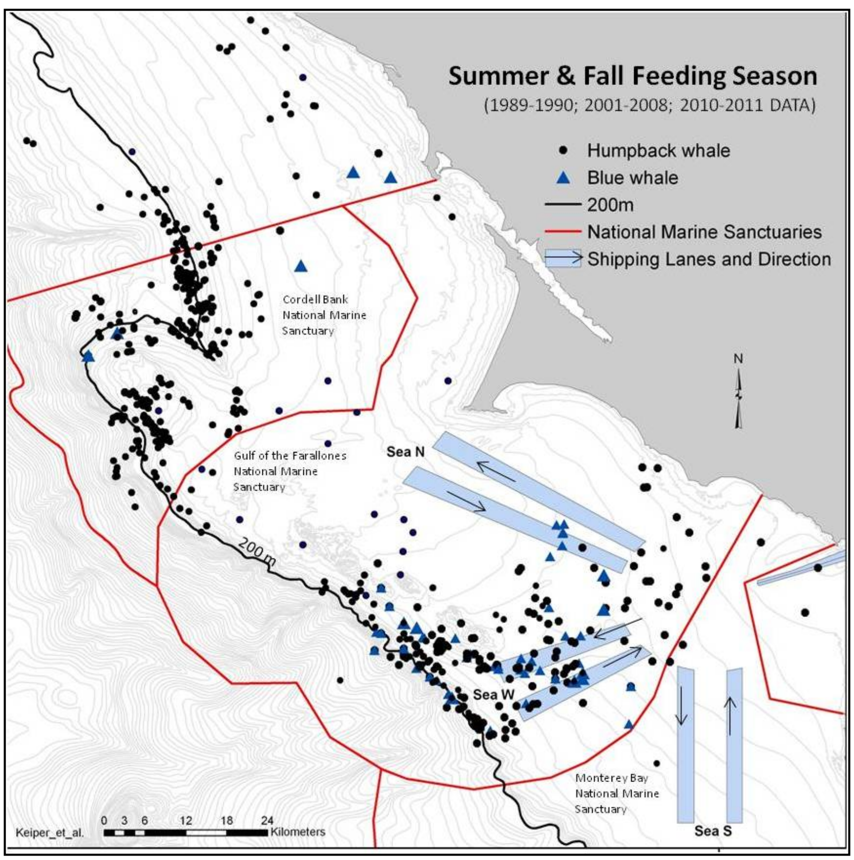

Figure 7. Sighting locations of humpback and blue whales during summer and fall feeding season during 1989-1990 (Kieckhefer humpback whale data) and 2001-2008; 2010-2011 (Keiper data for blue and humpback whales).

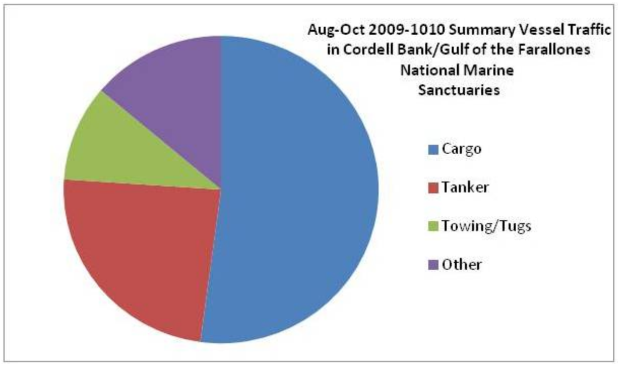

Figure 8. Summary of San Francisco approach vessel traffic during August-October 2009-2010.

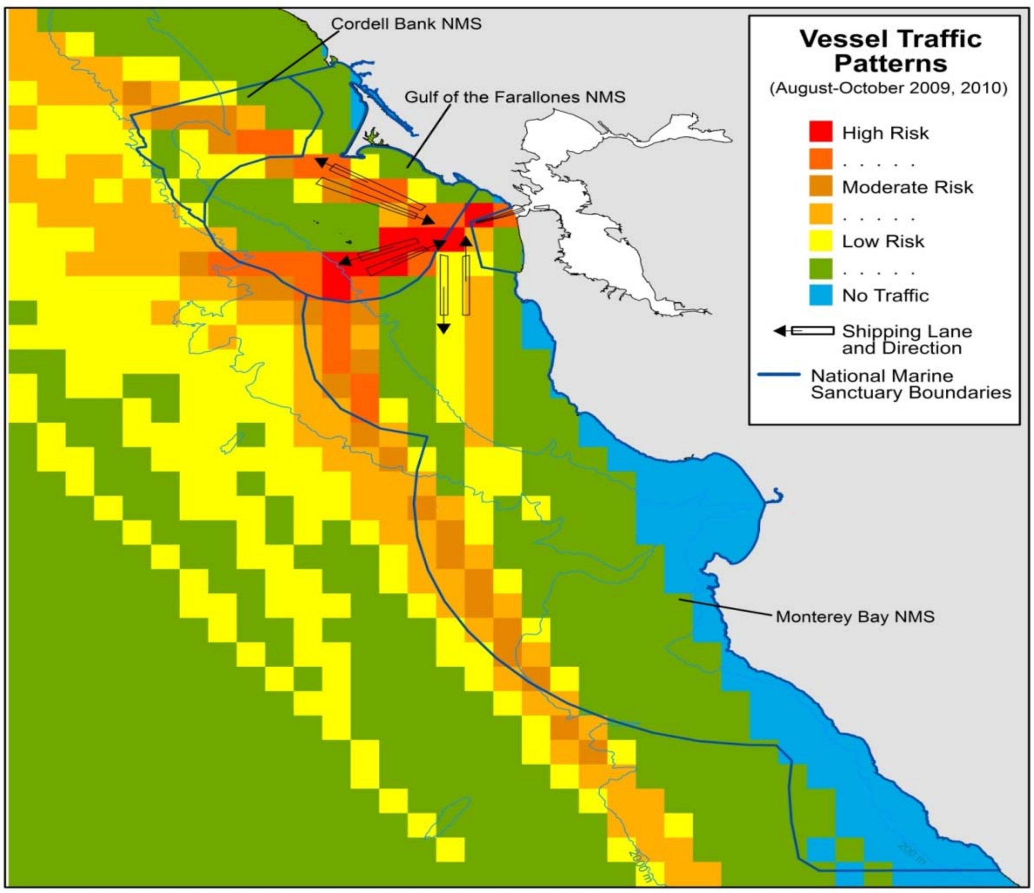

Figure 9. Vessel traffic data from Aug-Oct 2009 & 2010 combined. The area affected was calculated as the product of vessel beam and length of vessel track within a 5 minute latitude-longitude grid cell. The areas affected by all vessels within a cell were then summed to indicate relative risk.

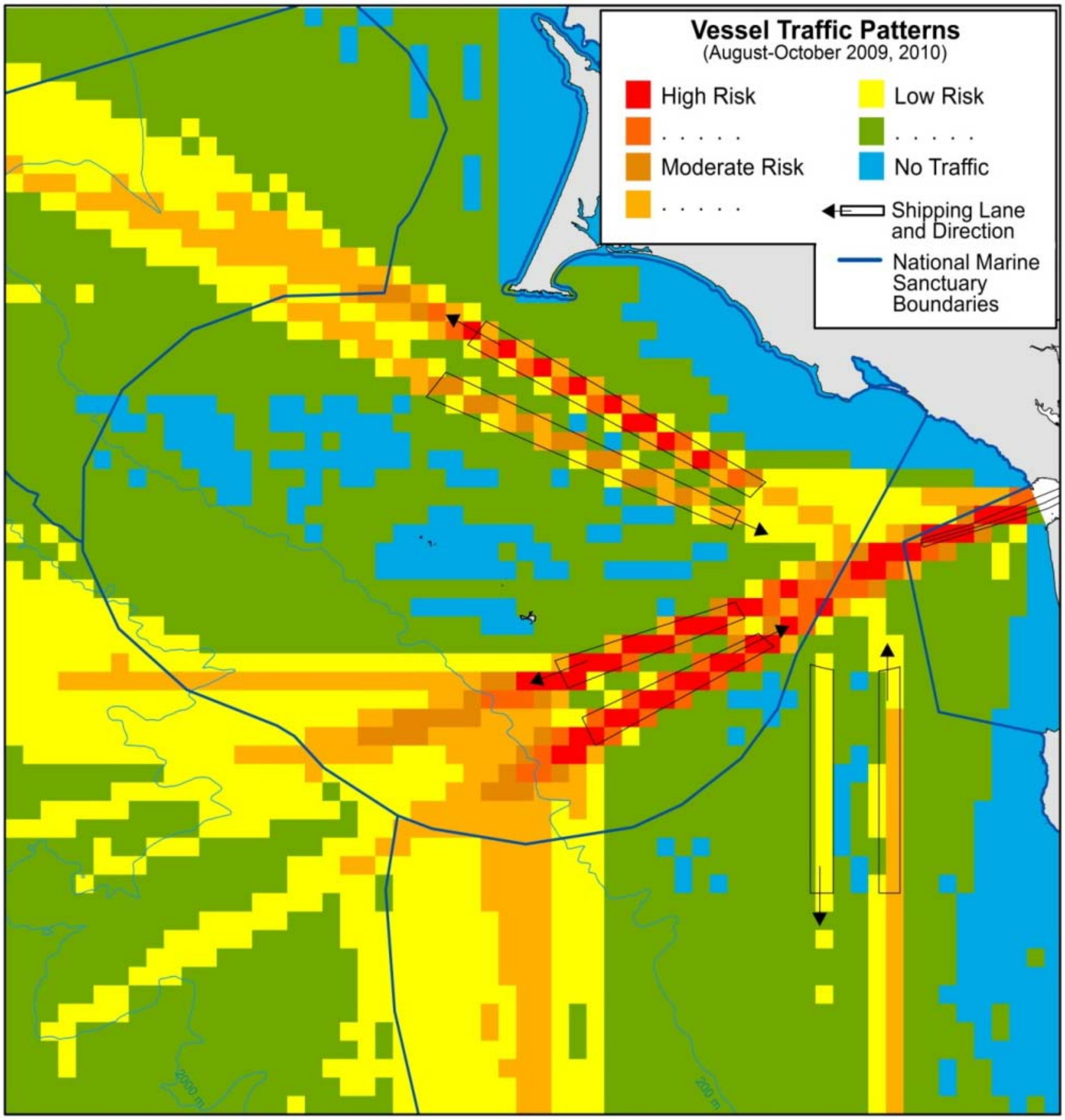

***Figure 10*.** Vessel traffic data from Aug-Oct 2009-2010 combined. The area affected was calculated as the product of vessel beam and length of vessel track within a 1 minute latitude-longitude grid cell. The areas affected by all vessels with a cell were then summed to indicate relative risk.

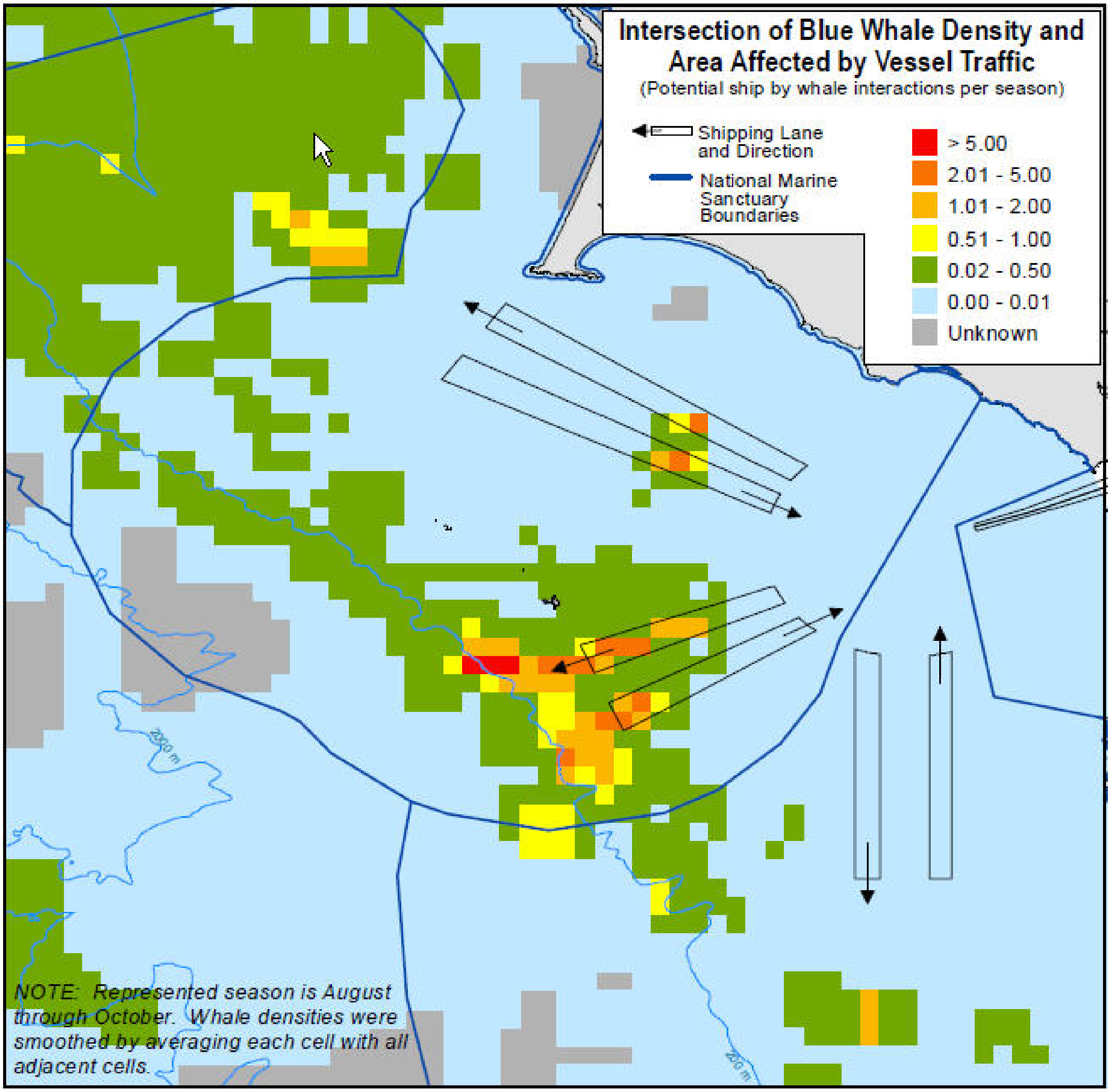

Figure 11. Intersection of smoothed blue whale data and traffic, showing areas of greatest concern. To reduce stochastic variation, whale densities were smoothed using a three point running average. The color of each one minute cell is the product of blue whale density and the area 'swept' by vessel traffic in the course of a season. This metric provides a measure of the relative risk of whale and ship collisions.

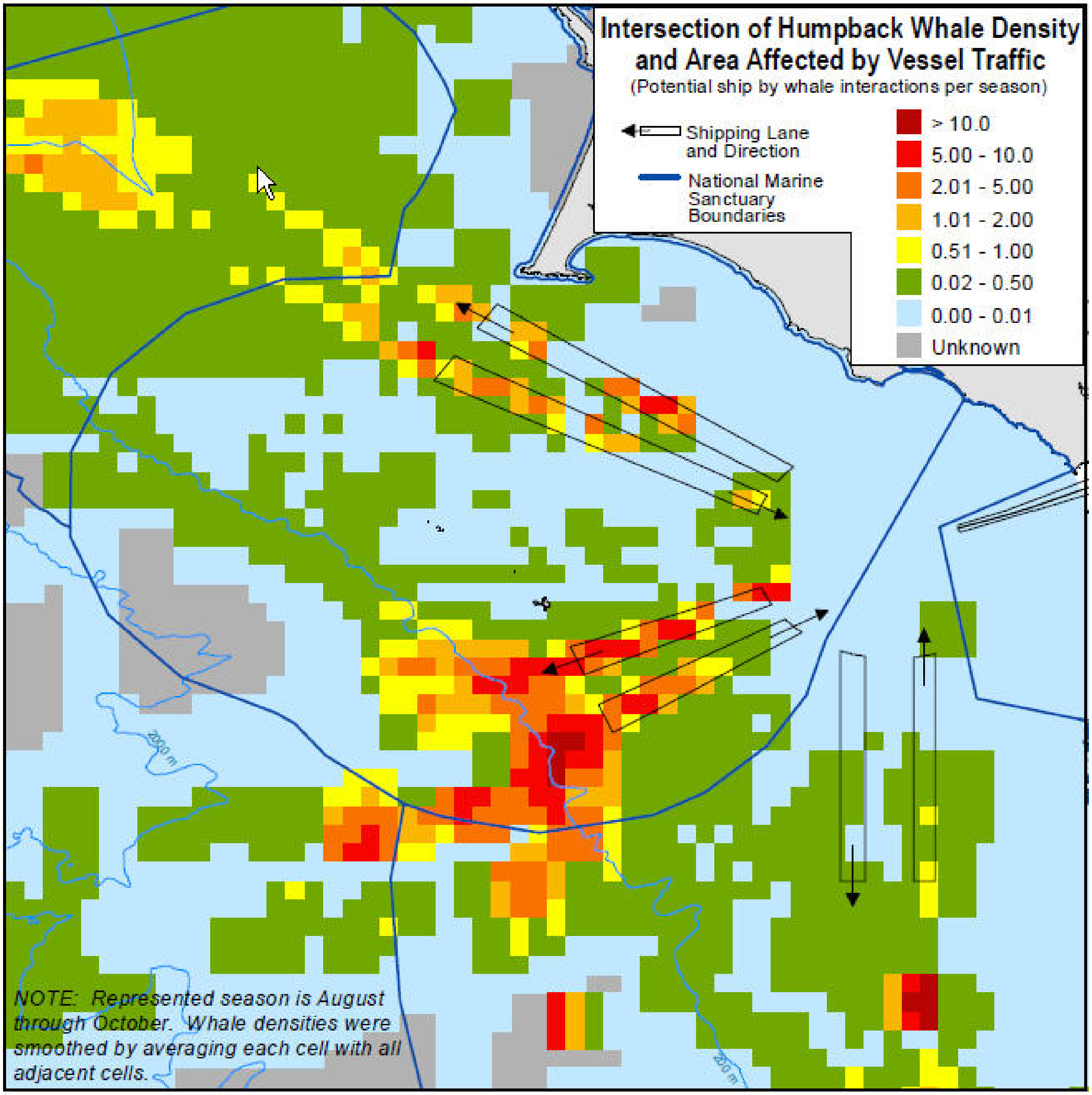

Figure 12. Intersection of smoothed humpback whale data and traffic, showing areas of greatest concern. To reduce stochastic variation, whale densities were smoothed using a three point running average. The color of each one minute cell is the product of humpback whale density and the area 'swept' by vessel traffic in the course of a season. This metric provides a measure of the relative risk of whale and ship collisions.