BLUE WHALE (*BALAENOPTERA MUSCULUS*) BEHAVIOR & GROUP DYNAMICS AS OBSERVED FROM AN AIRCRAFT OFF SOUTHERN CALIFORNIA

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Blue whale mother/calf pair. Photographed 24 May 2013 by D. Steckler under NMFS permit 14451.

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Executive Summary

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Blue whales (*Balaenoptera musculus*), the largest known species to inhabit the earth, are currently endangered despite their global range and over 45 years of protection from whaling. There is growing evidence and concern that increasing anthropogenic activities may be inhibiting recovery of their populations. To identify effective management and conservation actions, it is critical to describe and quantify "natural behavior" and habitat-use patterns to understand how they may change in response to anthropogenic activities. While population numbers and distribution are well studied in some regions, virtually nothing is known about behavioral strategies and group dynamics of this species. Such information is essential for the management and conservation of the blue whale because understanding baseline behavior, such as group size and cohesion, spatio-temporal trends and habitat use allow for better recognition of potential changes in response to perceived or real threats. In this paper, I quantify and explore the relationships between blue whale behaviors; group dynamics and spatio-temporal variables of blue whales in the Southern California Bight (SCB) to provide previously undescribed baseline behavioral data on this species. The SCB is one of the rare places in the world where blue whales regularly occur close to shore and thus are readily accessible for study.

During 2008 – 2013, SmulteaSciences conducted 18 aerial surveys, flying 87,555 kilometers (km) within the Southern California Bight (SCB). Observations and data were collected from the unique bird's eye three-dimensional vantage point of a small plane following systematic line-transect protocol. After a sighting occurred, focal groups were circled at distances outside the hearing range of the animals so as not to disturb them and avoid potential confounding of observations. Response variables consisted of group type/size (GT), behavior state (BS) and cohesion index (minimum and maximum nearest neighbor in body lengths [BL]). Explanatory variables consisted of season, time of day (TOD), distance from shore (km), depth at sighting (m) and group heading (direction of travel). In addition, I conducted descriptive behavioral analyses of group dynamics and inter-whale associations as observed during focal follows and transcribed from video recordings.

A total of 70 groups (117 individuals) of blue whales were observed. Group size ranged from a single animal (*n* = 1) to a group of 6 individuals (*n* = 6), (mean = 1.67, SD = 1.2, *n* = 70). Sighting rates (number of individuals observed per 1,000 km flown) were highest during summer (4.54 individuals/1,000 km) followed by spring (0.56 individuals/1,000 km) and fall (0.12 individuals/1,000 km). Despite over 9,100 km of effort there were no sightings during winter.

Analyses indicated that GT differed significantly by season, behavior state, TOD, water depth and distance from shore. With respect to season, GT differed significantly between spring and summer among single animals (singles), pairs and groups (χ^2 = 31.18, df = 2, *n* = 66, $p < 0.001$). Groups were only observed during summer while pairs were observed during spring, summer and fall. BS also differed significantly by GT (G^2 = 100.4, df = 4, *n* = 107, $p < 0.001$). Groups of more than two blue whales were significantly more likely to engage in mill (M) and slow travel/rest (ST/R) than single animals and pairs. Only singles and pairs were observed in medium/fast travel (M/F Travel). GT also differed significantly by TOD (χ^2 = 17.58, df = 2, *n* =

67, $p < 0.001$), as did BS (χ^2 = 20.19, df = 2, n = 113, $p < 0.001$). Mom/calf pairs and singles were found in deeper water and further from shore than groups and pairs. In addition, there was a strong positive correlation between water depth and distance from shore (R^2 = 0.53).

Similar to GT, BS was significantly influenced by spatio-temporal factors. Mill decreased in late afternoon compared to morning and early afternoon, whereas ST/R increased in late afternoon compared to morning and early afternoon. BS also varied significantly by distance to shore and depth: M was observed in more shallow, coastal waters while ST/R and M/F Travel were seen most frequently in more offshore, deeper waters. Cohesion and group size were positively correlated (R^2 = 0.39) at a statistically significant level ($p<0.05$): as group size increased individual blue became less cohesive and more spread out within groups.

Results provide the first quantitative summary of inter-relationships between blue whale behavior/group dynamics and spatio-temporal variables. Data indicate that group type (single, pairs, mom/calf pairs, and groups of two or more whales) influences behavior state. In addition, group type and behavior are influenced by spatio-temporal variables. Detailed narratives of inter-whale associations from focal follows of two different blue whale groups provide additional insight into blue whale group behavior. In summary, these results indicate the importance of considering and differentiating the influences of group size and spatio-temporal factors when assessing potential impacts of anthropogenic activities. The latter approach is critical in order to separate “normal” behaviors from the effects of anthropogenic factors and to consider their potential interactions.

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1 Introduction

Blue whales (*Balaenoptera musculus*) are the largest, yet currently one of the most endangered whales worldwide due to historical intensive whaling that nearly decimated populations. Though protected by the International Whaling Commission since 1966, blue whale populations have not recovered and are currently threatened by increasing anthropogenic activities. Potential related threats include ship strikes, coastal development, pollution, military training activities, fishing, vessel traffic, etc. Like most baleen whales the blue whale migrates between high-latitude feeding grounds and low-latitude largely unidentified calving/breeding areas in both coastal and oceanic habitats. Due to its principally oceanic tendencies and low numbers, blue whales remain one of the least studied of the large baleen whales. This is especially evident with respect to basic natural history, including migratory routes as well as social, foraging, breeding, nursing and calving behaviors. Blue whale behavioral ecology and more specifically group composition characteristics are poorly studied and virtually unpublished.

To identify effective management and conservation actions to assist in recovery of the blue whale population, it is imperative to describe and quantify natural behavior and habitat-use patterns. Such information provides important insight as to how this species may alter behavioral ecology strategies in response to anthropogenic activities. Anthropogenic activities that alter behavioral strategies can adversely affect overall individual fitness and population recovery. Activities of concern to blue whales in the Southern California Bight (SCB) ~~SCB~~ study area include: ship strikes, fishing, and coastal and offshore development.

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Between 2008 and 2013 SmulteaSciences conducted 18 aerial surveys flying 87,555 km within the ~~Southern California Bight (~~SCB~~)~~. The SCB is the curved coastline of the Pacific Ocean in Southern California from Point Conception to San Diego, including the Channel Islands (Dailey et al. 1993). Surveys occurred during all months of the year except December (Smultea et al. 2011a, 2011b, 2011c, Smultea and Bacon 2012). The primary focus of the 2008-2013 aerial surveys was to collect recent baseline data on marine mammals inhabiting the SCB.

Observations and data were collected from a small plane during systematic aerial surveys. Upon making a sighting, a focal group was circled at distances outside the hearing range of the animals so as not to disturb them and avoid potential confounding of observations. The data collected during these surveys represent the most extensive record of systematic undisturbed behavior on this species in available published literature. This includes behavioral, social and spatial interactions not previously documented (Smultea et al. 2011, Smultea and Bacon 2012).

During the six years of the SCB aerial surveys I had the unique opportunity to work as a research assistant and aerial observer for SmulteaSciences. My role allowed me to dedicate extensive time to the observation of marine mammal behavior from an aerial platform. I was also able to be thoroughly involved in the development of data collection procedures and aerial survey protocol specific to marine mammal behavior. This opportunity allowed me to develop questions and hypotheses based on previously undocumented observations regarding large whale baseline behaviors. When given the opportunity to pursue an Independent Research Project (IRP) with Johns Hopkins University I chose to focus on the SCB aerial survey data and

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specifically the blue whale based on the lack of "natural" behavioral data available on an ESA-listed species. Natural blue whale behavioral information in the SCB is significant for policy, species management, and conservation as it provides insights to baseline habitat use against which to assess potential changes and threats due to anthropogenic activities.

In this paper interactions between blue whale behavior and group dynamics are quantified and assessed relative to the influence of spatio-temporal variables. Descriptive analyses of group dynamics and inter-whale associations as observed during focal follows and video recordings are also provided. The combined results represent the first quantitative summary of blue whale behavior and group characteristics, including detailed descriptive analyses of inter-whale associations.

1.1 Background

Many techniques and dedicated studies have increased our understanding of various aspects of blue whale biology. These include:

1) P~~1) p~~hotographic identification studies that have provided estimates of abundance and movements (Sears et al., 1987; Calambokidis et al., 1990; Sears and Larsen, 2002; Calambokidis and Barlow, 2004),

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2) ~~2) v~~Vessel-based line transect surveys to examine distribution and abundance (Barlow, 1994; Forney and Barlow, 1998; Gerrodette and Forcada, 2003; Calambokidis and Barlow, 2004),

3) ~~3) s~~Satellite tagging to examine continuous migratory movements (Mate et al., 1999), and

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4) ~~4) a~~Acoustic studies using detections of vocalizations to examine the distribution, seasonality, and vocalization (call) behavior of blue whales (Stafford et al., 1998, 1999; McDonald et al., 2001; Burtenshaw et al., 2004; Oleson et al. 2007).

Within the SCB study area in particular, numerous aerial surveys have been conducted over the last four decades to address various questions regarding marine mammals as funded by different agencies (Carretta et al. 2000, Barlow et al. 2009, DoN 2011). These surveys focused on the occurrence, distribution, abundance, habitat-use, and density of marine mammals, primarily from spring through fall, with minimal effort conducted during winter. None of these surveys focused on behavior.

Even with such extensive study efforts there is still little known about even basic behavioral ecology and group dynamics of blue whales. This is due, for the most part, to the species' typically inaccessible oceanic distribution. Blue whale calving, breeding and courting behaviors have never been described in the literature. Thus, calving and breeding grounds remain to be identified, should they occur. Some authors have postulated that this species does not aggregate for breeding and calving like other baleen species such as humpback and gray whales (e.g., Sears et al. 2013).

Baseline data on the natural, undisturbed behavior of blue whales are needed and critical for comparative purposes to understand and differentiate potential effects of anthropogenic activities as well as natural threats. There is increasing evidence that behavioral characteristics of marine mammals and other animals (e.g., mating, feeding, calf presence, migrating,

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socializing) affect the level of response [or lack thereof] to anthropogenic activities. Yet behavioral observations and studies are not always considered when assessing anthropogenic effects and proposed management decisions. Group size and inter-whale distance (i.e., cohesion) are important factors that provide insight into behavior and social dynamics. Such knowledge assists in identifying how habitat is used temporally and seasonally when compared by time of year and time of day. For example, areas that are used for nursing, feeding and/or breeding are considered higher priority for protection through management and conservation decisions, particular for endangered species such as the blue whale. Furthermore, it is important that group size and temporal-spatial influences on behavioral ecology be considered in order to separate “normal” behaviors from the effects of anthropogenic factors and to consider their potential interactions.

It is difficult to observe inter-individual spatial relationships with large whale species given the inherent challenges with their remote and often widely dispersed, typically offshore habitat use. Most observations have been conducted from vessels, through passive acoustic monitoring, or tagging studies (see above). These platforms are limited or biased by confounding factors (e.g., a boat following a whale can disturb its behavior) and/or do not provide information on social contextual factors (e.g., tagging information) that are known to influence habitat use, behavior, and sensitivity to disturbance among both marine and terrestrial mammals. Group composition behaviors as observed from an aerial platform have previously been recorded and described in published literature for other large whale species (e.g., Wursig et al. 2003) but never for blue whales. Observations from an aerial platform in

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clear waters allow a "bird's eye" view through the water of three-dimensional behavioral interactions of large whales and in this study, blue whales in the SCB.

The study described herein is part of an overall six-year study conducted from a fixed-wing small plane to quantify and describe the baseline occurrence, abundance, habitat-use, and behavior of marine mammals in the SCB. These surveys were conducted to address the U.S. Navy's marine mammal monitoring requirements relative to military readiness training activities involving mid-frequency active sonar and underwater detonations, as specified by the National Marine Fisheries Service under the U.S. Marine Mammal Protection Act and the U.S. Endangered Species Act.

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The primary focus of the 2008-2013 aerial surveys was to collect recent baseline data on marine mammals inhabiting the SOCAL Range Complex study area (**Error! Reference source not found.**). The data collected during the SCB aerial surveys represent the most extensive record of systematic undisturbed behavior on this species in the SCB and include behavioral, social and spatial interactions not previously documented in this region for marine mammals, including ESA listed blue whale (Smultea et al. 2011, Smultea and Bacon 2012).

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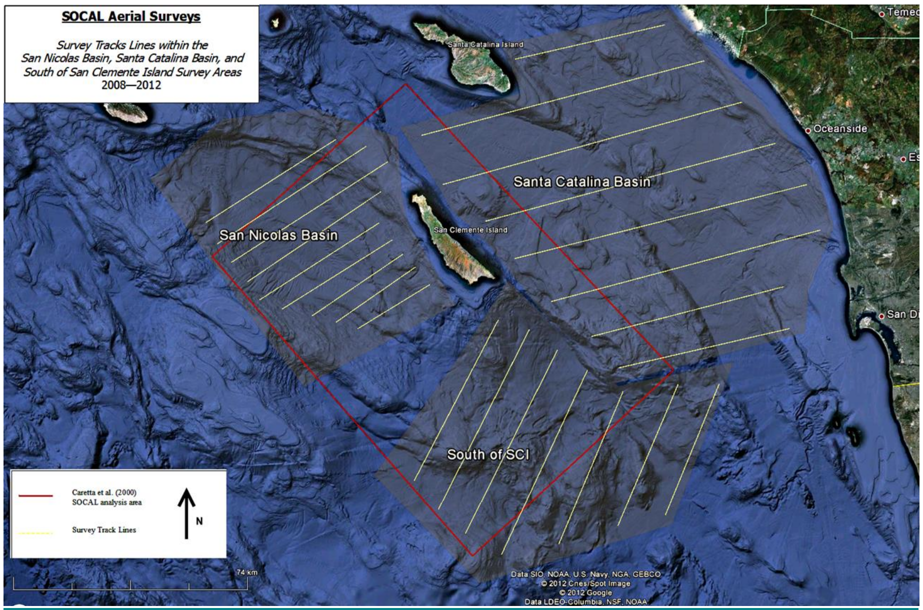

Figure 1~~11~~. 2008 – 2013 SCB aerial survey area developed based on priority areas selected by the U.S. Navy for marine mammal monitoring within the Southern California Range Complex: (1) San Nicolas Basin, (2) Santa Catalina Basin, (3) south of San Clemente Island/San Clemente Basin.

1.2 Study Objectives, Questions and Predictions specific to IRP

The overall goal of my IRP is to quantify and describe natural behavior and group dynamics of blue whales in the SCB. This information is of interest for management of an endangered species and more specifically to understand how this species uses the SCB. My results provide a baseline against which to assess potential changes due to anthropogenic activities. My objectives are to:

1) ~~(1) p~~Provide a baseline description of what constitutes natural blue whale behavior and group dynamics,

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2) ~~(2) q~~Quantify how blue whale behaviors vary by group types (i.e. single, pair, mom/calf pair and groups) and spatio-temporally, and

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3) ~~(3)~~ I~~i~~dentify behavioral indicators that can potentially be used as indices of changes in behavior due to anthropogenic activities.

To address these objectives I developed a series of questions and predictions focused on my primary variables of interest. I selected dependent variables that would reflect components of behavior and group dynamics, address my questions, and evaluate the validity of my predictions. My primary variables of interest were: group type (size and composition), behavior state, cohesion (i.e. inter-individual spacing within groups), and heading (direction of travel). I selected the independent and spatio-temporal variables to include season, time of day (TOD), distance from shore (km), and water depth (m). Table 1~~Table 1~~ provides a summary of study variables, questions and predictions. Presentation of Methods, Results and Discussion are organized by the four primary dependent variables: Group Type (GT), Behavior State (BS), Cohesion, and Heading.

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Table 1. Variables, Questions and Predictions

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Dependent Variables	Questions		Predictions
Group Type (GT)	Does GT vary by…	Season?	GT varies spatio-temporally
		TOD?	
		Distance?	
		Depth?	
Behavior State (BS)	Does BS vary by…	GT?	GT varies by BS
		Season?	BS varies spatio-temporally
		TOD?	
		Distance?	
		Depth?	
Cohesion	Does Cohesion vary by…	GT?	Cohesion varies by GT - As group size increases cohesion decreases (i.e. larger distance between neighbors for larger groups) and groups are less cohesive than pairs.
Heading	Does Heading vary by…	Season?	Heading varies by season. Blue whales migrate N in spring and S in fall thus we would expect dominant to correspond.
		TOD?	Heading does not vary by TOD

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~~**Figure 1. 2008 – 2013 SCB aerial survey area developed based on priority areas selected by the U.S. Navy for marine mammal monitoring within the Southern California Range Complex: (1) San Nicolas Basin, (2) Santa Catalina Basin, (3) south of San Clemente Island/San Clemente Basin.**~~

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2 Literature Review

The blue whale's large body size, ranging up to 33 m and 172 metric tons (Yochem and Leatherwood, 1985), made them prime targets during the modern era of commercial whaling when faster vessels and explosive harpoons became common whaling practice. Stocks in the North Pacific, North Atlantic, and Southern Ocean were severely depleted in the first half of the 20th century. The North Pacific stock was subjected to increasing whaling effort as the Southern Ocean stocks declined (Rice, 1974), until 1966 when the International Whaling Commission (IWC) listed the blue whale as a protected species and commercial hunting ceased (Ellis, 1991).. Worldwide populations were depleted from approximately 300,000 to approximately 10,000 blue whales globally from the early 1900's to 1966 (Gambell, 1979). Despite protection, their numbers remain very low and show an overall lack of recovery.

Blue whales are found in all oceans of the world, from sub-polar to sub-tropical latitudes. Movements and migrations towards polar areas in the spring allow for blue whales to feed on high productivity areas in summer months and migrate towards warmer waters during winter months (Jefferson et al. 2008; Mate et al. 1994). Found in offshore oceanic waters, blue whales also inhabit more coastal zones along the shelf.

The largest known population is found in the North Pacific and estimated between 2,000 and 3,000 animals. The North Pacific population was estimated (pre-whaling) at almost 5,000 animals (Barlow 1994; Carretta et al. 2009, Calambokidis et al. 2004). There are thought to be two separate populations or stocks: 1) the Eastern North Pacific and 2) the Western North Pacific. Knowledge of these two separate stocks is based on differences in call types (Stafford

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and Fox 1996; Stafford et al. 1999, 2001). For the purposes of this paper I will be focusing in the Eastern North Pacific stock. The eastern stock is known to migrate annually between ~~summer~~ feeding areas in summer months, ranging from California to the Gulf of Alaska, and tropical winter breeding areas off Mexico and Gulf of California (GoC) (Sears et al 2001, 2008, 2013) (Calambokidis et al. 1990; Reilly & Thayer 1990) and Central America (Costa Rica and Nicaragua (Mate et al. 1999)). In California waters during summer months, blue whales are in their feeding grounds and typically forage in dense, subsurface layers of euphasiids (krill) on both the shelf and extending off the shelf edge (Fiedler et al. 1998). Blue whale feeding aggregations are often found at the continental shelf edge where upwelling produces larger concentrations of krill (Fiedler et al. 1998; Schoenherr 1991; Kieckhefer et al. 1995). The main sources of prey for blue whales in the North Pacific include *Euphausia pacifica* and *Thysanoessa spinifera* (NOAA 2014). They are selective consumers and feed in rates of up to 2 metric tons per day (Rice, 1978). Blue whales are typically found alone or in pairs (Jefferson et al. 2008). Social associations and aggregations are not thought to be long-term (Sears 2008). There are records of concentrations of 50 or more animals spread out in foraging areas of high productivity, however these events are rare and not well published (Sears 2008). Little is known about the mating behavior or social dynamics of this species. Female–male pairings have been noted with regularity in Eastern Canada from summer into fall, and the approach of the winter breeding season with some pairings lasting upwards of 5 weeks (Sears 2008; 2013). Sears et al. (2013) noted that on occasion a second male joins pairs, which initiates surface-active behaviors associated with competitive breeding such as one animal pursuing another and breaching by all 3 individuals. Physical contact between the males, using head, body and tail swipes has been recorded. These

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observations support the hypothesis that the blue whale mating strategy is polygynous with antagonistic male–male competition (Sears et. al 2013). Information on the reproductive system of blue whales is still largely based on Southern Ocean whaling data. As in most balaenopterids, female give birth to a single calf after a gestation period of 10 to 11 months. The calf remains with the lactating mother and nurses for 6 to 7 months before weaning (Ottestad 1950, Yochem & Leatherwood 1985). First parturition is thought to be >10 years. (Sears et al. 2013). Sears et al. 2001 estimated calf size at one to three months to be between 10-14 m based on GoC data (Sears et al. 2001). Some females have shown site fidelity to nursing grounds, such as the GoC, however the lack of documented births in the GoC may indicate that female blue whales choose open, pelagic water for calving and move to GoC and coastal waters when calves are older (Sears et. al 2013).

Blue whales have been recorded reaching speeds of 32 to 36 km/hr, however they most often cruise at 2 to 8 km/hr while feeding and traveling (Yochem and Leatherwood 1985). Blue whales generally dive for 5 to 15 minutes (min) however dives of as long as 36 min have been recorded in the St. Lawrence, although these are considered rare. Off California and in the GoC, 231 dives from seven tagged blue whales lasted up to ~15 min and went to a maximum depth of 204 m (Croll et al. 2001). During surfacing bouts blue whales typically breathe between 6 and 20 times for 1 to 5 min in duration.

Although aerial platforms do now allow for behavioral observations when animals are at depth, shallow sub surface behaviors can still be recorded, especially with blue whales off SCB due to the clarity of the water and animal's large size. Observations from an aerial platform in clear waters allow a unique view through the water of three-dimensional behavioral interactions and

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allow for continual monitoring when animals are not deep diving. Calambokidis et al. (2003) examined the underwater behavior of blue whales off California and GoC using CRITTERCAM, a suction-cup-attached video-imaging instrument. From the 13 successful deployments (a total of 19 hour [hr] of video recordings) observations indicated that inter-whale associations seen at the surface also continue underwater. The lead and follow orientations noted at the surface were consistent with the positioning seen underwater in the video. This suggests that what is observed for inter-whale associations from the aerial platform could be representative of underwater associations and related behaviors.

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3 Methods

3.1 Survey methods

From 2008 through 2013 behavioral data for blue whales were collected during line-transect and focal-follow effort during 18 aerial surveys (Table 4~~Table 4~~~~Table xx~~). First observed behavior state, heading, and minimum and maximum inter-individual dispersal distance were recorded during line-transect sampling. Blue whales were in view typically for 30 seconds (sec) during line transects. If behavior state, group composition, or species were not confirmed, the plane circled the sighting to confirm these data. 55% percent of all blue whale sightings were subsequently circled to conduct focal observations. Focal groups were circled for 10-60+ min and videotaped (when applicable) from outside Snell's sound cone to avoid disturbance (Richardson et al. 1994).

Surveys were conducted primarily (*n* =17; 94%) from a high-winged, twin-engine Partenavia aircraft; the remaining survey (*n* = 1; 6%) was conducted from an Aero Commander aircraft. Survey personnel consisted of two observers, one recorder/photographer/videographer, and one or two pilots. The three effort types for these analyses included:

1) ~~1.~~ Systematic line-transect "search" effort along east-to-west oriented lines located east and west of San Clemente Island (SCI) (flown at 244-305 m altitude and 100 knots [kt])
2) ~~2.~~ "Verify" involving breaking from line transect effort to circle and photograph sightings to verify species, numbers and behavior with photographs

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3) ~~3.~~ "Focal follow" involving circling (at 365 to 457 m altitude and 0.5 to 1.0 km radial distance) of high priority species to video and collect focal behavior (i.e. "focal follow") data for periods of 5 to 60 min (typically 15 to 20 min).

3.2 IRP Methods

I developed methods for data extraction and analyses specific to my IRP and initial questions proposed (see ~~above~~Section 1.2). Methods included extracting all blue whale sightings and associated data and blue whale focal follow data. I divided my analyses into:

1) ~~1)~~ First Observed Analyses (Section 3.2.1) based on behavior variables recorded from existing data set collected during the 2008-2013 aerial surveys, and

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2) ~~2)~~ Descriptive Analyses from Video Focal Follows (Section 3.2.2) which included descriptive explanations of focal follows of blue whales where there are three or more individuals based on available video footage.

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~~3.2.1~~3.3 First Observed Analyses

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First-observed data parameters collected for sightings included group size and type (i.e. composition), number of calves, behavior state, heading, and minimum and maximum distance (i.e., cohesion index) between neighbors within a group (estimated in adult body lengths [BL]). The purpose of first-observed behavior analyses was to describe and quantify typical baseline behavioral parameters of blue whales relative to selected environmental and other explanatory variables including time of day (TOD), season, heading, distance to shore (km) and water depth at sighting (m).

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~~3.2.1.1~~3.3.1 Dependent Variables

~~1.~~3.3.1.1 *Group Type (GT)*

Group Type, including group size and composition (when applicable i.e. mom/calf) was divided into four categories (Table 2).

Table 22~~2~~. Definition of Group Type (GT) categories observed.

Group Size	Code	Composition	Definition
n = 1	S	Single animal	Animal observed alone or >50 BL from other animals
n = 2	M/C	Mom/calf pair	Adult animal with smaller (~½ size of adult) swimming alongside adult
n = 2	P	Pair	Any two animals within 50 BL of each other
n > 2	G	Group	Any group of animals where n>2 and all are within 50 BL of each other

~~2.~~3.3.1.2 *Behavior State (BS)*

Table 33~~3~~. Definition of B~~b~~ehavior S~~s~~tates observed.

Behavior State*	Code	Definition (e.g., per Encyclopedia of Marine Mammals)
Slow Travel/Rest	ST/R	>50% of group exhibiting little or no forward movement (<1 km/hr) remaining at the surface in the same location or drifting/traveling slowly with no wake
Travel (medium/fast)	TR	>50% of group swimming with an obvious consistent orientation (directional) and speed, no surface activity. Medium travel = 1-3 km/hr wake no white water; Fast travel = >3 km/hr with white water
Mill	MI	>50% of group swimming with no obvious consistent orientation (non-directional) characterized by asynchronous headings, circling, changes in speed, and no surface activity. Includes feeding.
Unknown	UN	Not able to determine behavior state. (e.g., animals out of sight, too far to determine, on a dive, etc.)

~~3.~~3.3.1.3 *Cohesion (Nearest Neighbor)*

We followed the techniques used to measure social association and group dynamics by measuring nearest neighbor, where the single closest individual to a focal animal is noted (e.g., Boinski & Mitchel, 1994 (monkeys); Dwyer & Lawrence, 1999 (sheep); Freeberg, 1999 (birds)).

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~~4.~~3.3.1.4 Heading

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We assessed cardinal heading (i.e. direction of movement and orientation in degrees magnetic) while traveling. Heading was determined using aircraft compass and WAAS-enabled Global ~~Positiioning~~Positioning System (GPS). Heading was not applicable to milling animals and only collected on groups observed in the ST/R and TR behavior states.

- NorthEast (NE) 0 - 90
- SouthEast (SE) 91 - 180
- SouthWest (SW) 181 - 270
- NorthWest (NW) 271 - 360

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~~3.2.1.2~~3.3.2 Spatio-temporal V~~v~~ariables

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The following independent variables are considered for spatio-temporal trends:

1) ~~1) d~~Distance from shore (km),

2) ~~2) W~~W~~w~~ater depth at sighting (m),

3) ~~3) s~~Season, where seasons are defined as the following: Spring (1 March - 31 May), Summer (1 June – 31 August), Fall (1 September – 30 November), and Winter (1 December – 29 February) ~~and~~

4) ~~4)~~ Time of Day (TOD) where TOD is defined as “morning” (0801 – 1159), “early afternoon” (1200 – 1559), and “late afternoon” (1600 – 1959).

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~~3.2.2~~3.3.3 Descriptive Analyses from Video Focal Follows

Descriptive analyses included case studies on two of the large groups (n = 6 and n = 3), presented in descriptive form (i.e. written observations of the focal follow). Descriptive

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analyses of behavior from aerial platforms have been published for other large whales such as the bowhead whale in the Beaufort Sea (Wursig et. al 1985).

4 Results

A total of 18 surveys (97 days) were conducted over six years with surveys occurring in every season. During the 18 surveys (87,555 km flown; Table 4~~Table 4Table xx~~), 70 groups comprised of a total of 117 individuals of blue whales were observed (Table 5~~Table 5Table xx~~, Figure 2~~Figure 2Figure xx~~). Group size ranged from a single animal (*n* = 1) to a group of 6 individuals (n = 6) with the overall mean group size of 1.67. (SD = 1.2, *n* = 70). Of the 70 groups 61% were single animals (*n* = 43 groups), 23% were pairs (*n* = 16 groups), 4% were mom/calf pairs (*n* = 3 groups) and 11% were groups (n = 8 groups). The groups consisted of three groups of n=3, one group of *n* = 4, one group of *n* = 5 and three groups of *n* = 6. Of the three-mom/calf pairs recorded, two occurred during May and one during August. One group (*n* = 6) included a fourth mom/calf pair and occurred during July, for the purpose of analyses this mom/calf pair is included in the "groups" rather than the "mom/calf pairs". Sighting rates (Table 5~~Table 5Table xx~~; Figure 3~~Figure 3Figure xx~~) were calculated based on number of individuals observed per 1,000 km flown. Sighting rates were highest during summer (4.54 individuals/1,000 km) followed by spring (0.56 individuals/1,000 km) and fall (0.12 individuals/1,000 km). Despite over 9,100 km of effort there were no sightings during winter.

Table 444. Summary of surveys and flight effort.

Survey Dates	No. Days Flown	Aircraft	Total Observation Effort (km)
17-21 Oct 2008	5	Partenavia P68-C	4,563
15-18 Nov 2008	4	Partenavia P68-C	3,838
5-11 Jun 2009	6	Partenavia P68-C	6,140
20-29 Jul 2009	9	Partenavia P68-C	6,500
18-23 Nov 2009	6	Partenavia P68-C	4,823
13-18 May 2010	6	Partenavia OBS	4,891

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Survey Dates	No. Days Flown	Aircraft	Total Observation Effort (km)
27-3 Aug 2010	7	Partenavia P68-C	3,125
23-28 Sep 2010	6	Partenavia OBS & Bell 206 Helicopter	3,918
14-19 Feb 2011	4	Partenavia OBS	3,193
29-3 Apr 2011	3	Partenavia P68-C	1,865
12-20 Apr 2011	9	Aero Commander 685	10,976
9-14 May 2011	6	Partenavia P68-C	4,902
30 Jan - 5 Feb 2012	7	Partenavia P68-C	5,973
13-15 Mar 2012	3	Partenavia P68-C	3,233
28 Mar - 1 Apr 2012	5	Partenavia P68-C	4,527
21-30 Mar 2013	6	Partenavia OBS	4,923
22-26 May 2013	5	Partenavia P68-C	5,645
24-29 July 2013	6	Partenavia P68-C	4,521
Total	**97**		**87,555**

Table ~~55~~5. Summary of groups, individuals, total observation effort (km) and sighting rates by season.

Season	No. Groups	No. Indiv.	Avg. Group Size	Stand. Dev.	Range of Group Size	Total Observational Effort (km)	Sighting Rate by Season (indiv per 1000 km flown)
Fall	1	2	2	_	2	17,142	0.12
Spring	18	23	1.28	0.46	1 to 2	40,961.3	0.56
Summer	51	92	1.8	1.36	1 to 6	20,286	4.54
Winter	0	0	0	_	_	9,166	0
All Seasons	**70**	**117**	**1.67**	**1.2**	**1**	**87,555.3**	**1.34**

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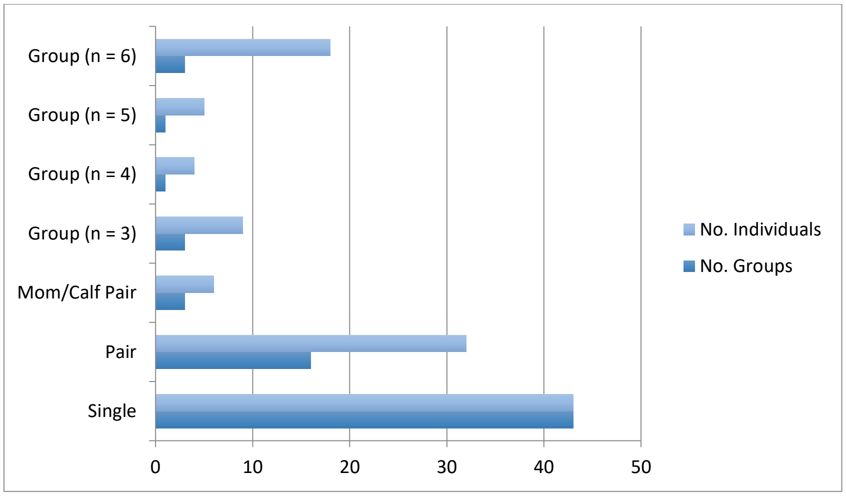

Figure 2~~2~~. Number of groups and individuals by group size.

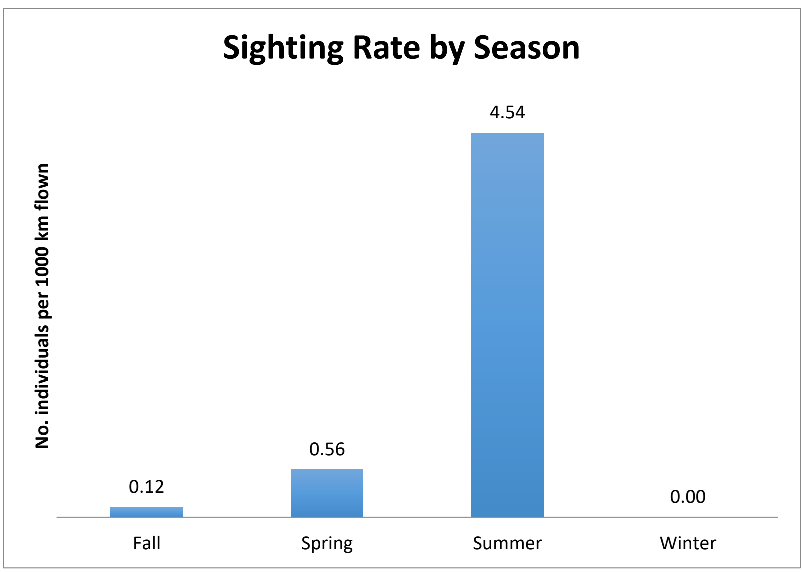

Figure 3~~3~~. Sighting rates (number of individuals per 1,000 km flown) by season.

~~Table 5. Summary of groups, individuals, total observation effort (km) and sighting rates by season.~~

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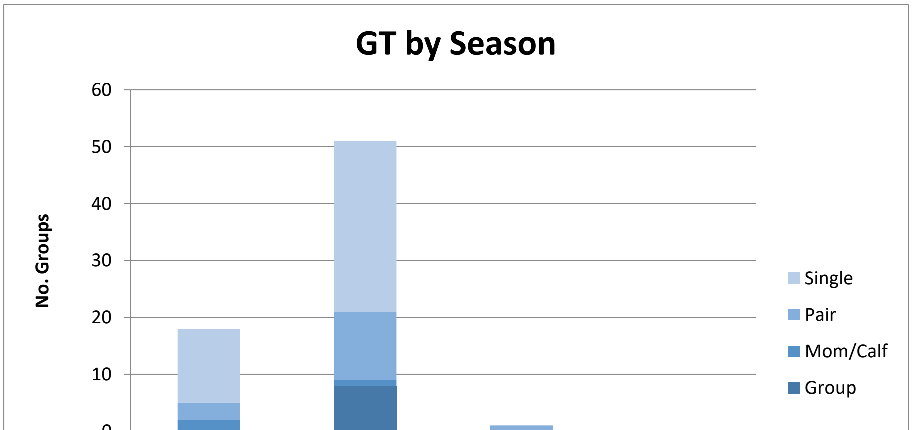
~~4.56.1~~4.1.1 GT by Season

I assessed GT by season for the 70 groups observed (Figure 4~~Figure 4~~~~Figure xx~~). GT differed significantly between spring and summer among singles, pairs, and groups of blue whales (χ^2 = 31.18, df = 2, *n* = 66, p <0.001; the sample size of three mom/calf pairs was too small to include in the analyses). This difference was due primarily to groups found only during summer and not spring (Freeman-Tukey Deviate, z = -1.96). During spring singles were more common than pairs or mom/calf pairs and in summer singles were most common. Only one pair was observed during fall and there were no blue whale sightings during winter. Groups were only observed during summer and mom/calf pairs and singles only observed during spring and summer. Pairs were seen during all seasons except winter.



	Spring	Summer	Fall	Winter
Single	13	30		
Pair	3	12	1	
Mom/Calf	2	1		
Group		8		

Figure 44. GT (number of groups) by Season

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~~4.56.2~~4.1.2 GT by TOD

I assessed GT by TOD for all 70 groups (**Error! Reference source not found.**~~Figure 5~~~~Figure xx~~) and found a significant difference in the frequency of GTs observed by TOD (χ^2 = 17.58, df = 2, n = 67, p < 0.001; the sample size of three mom/calf pairs was too small to include in the analyses). Singles tended to be the most commonly observed GT across the day (i.e., during all three TOD periods). Mom/calf pairs were only seen during “morning” and “early afternoon”, but the sample size was small (n = 3).

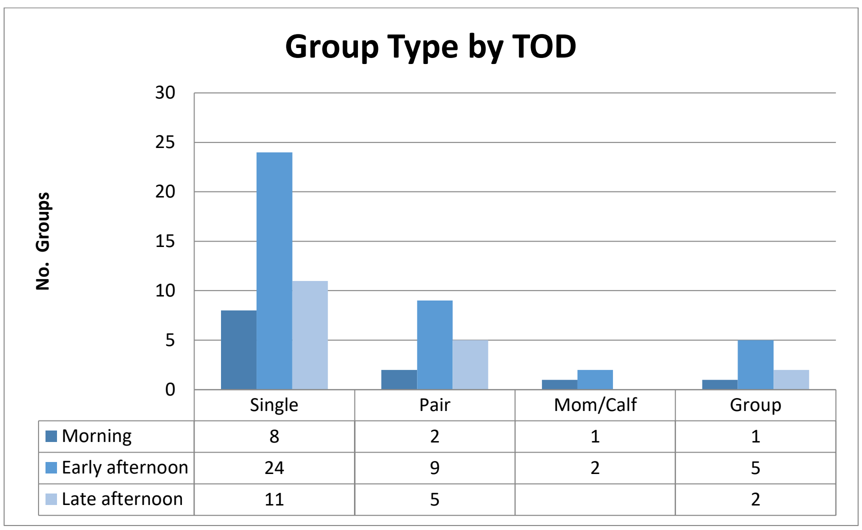

Figure ~~5~~5. Group Type by TOD.

~~4.56.3~~4.1.3 GT by Distance & Depth

Table 6. Summary of GT by average distance to shore (km) and depth (m)

	Group	Mom/Calf	Pair	Single	All
Avg. d~~D~~istance to shore (km)	9.9	18.1	9	13.2	12.1
Avg. d~~D~~epth at sighting (m)	285.6	419.2	380.9	477.6	431

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I assessed variations in GT by distance from shore (km) and water depth (m) at the sighting. Results show that mom/calf pairs were found farther from shore than other GTs. Groups and pairs were found closer shore at approximately the same distance from shore and in shallower water. Mom/calf pairs and singles were found in deeper water than pairs and groups. Results show that distance and depth had a positive correlation ($R^2 = 0.53$; Figure 6~~Figure xx~~), which was statistically significant ($p<0.0005$) a indicating that as distance from shore increased depth based on sighting locations of the blue whales observe increased as well.

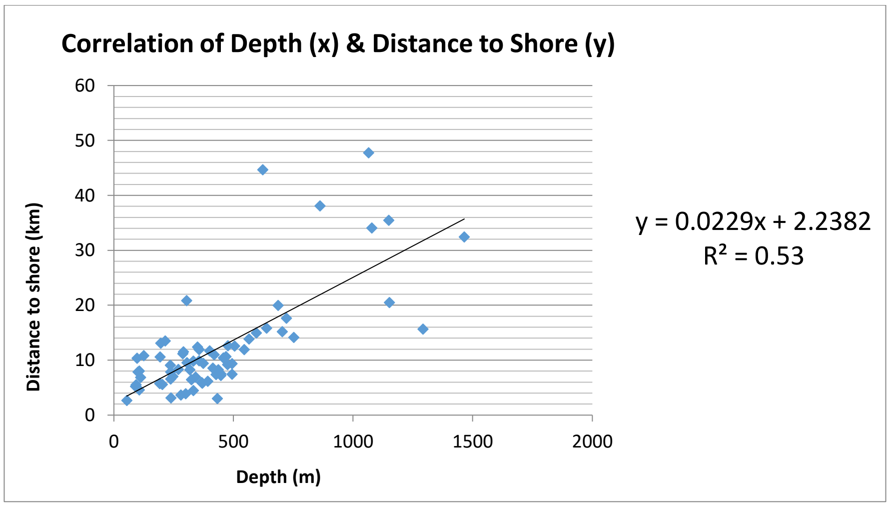

Figure 6. Correlation of depth and distance.

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~~4.56.4~~4.1.4 Group Type (GT) by Behavior State (BS)

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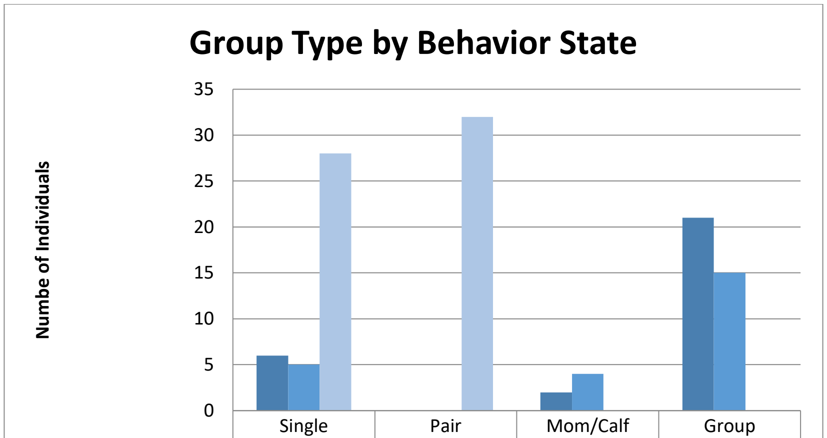

	Single	Pair	Mom/Calf	Group
Mill	6	0	2	21
Slow Travel/Rest	5	0	4	15
Medium/Fast Travel	28	32	0	0

Figure 7~~76~~. GT by BS state for number of individuals.

~~4.57~~4.2 Behavior State (BS)

~~4.57.1~~4.2.1 Behavior by TOD

Blue whale behavior for all periods was most frequently (51%) TR followed by MI (25%) and ST/R (21%). BS differed significantly by TOD (χ^2 = 20.19, df = 2, n = 113, $p < 0.001$). MI decreased in “late afternoon” compared to “morning” and “early afternoon” and ST/R increased in “late afternoon” compared to “morning” and “early afternoon”.

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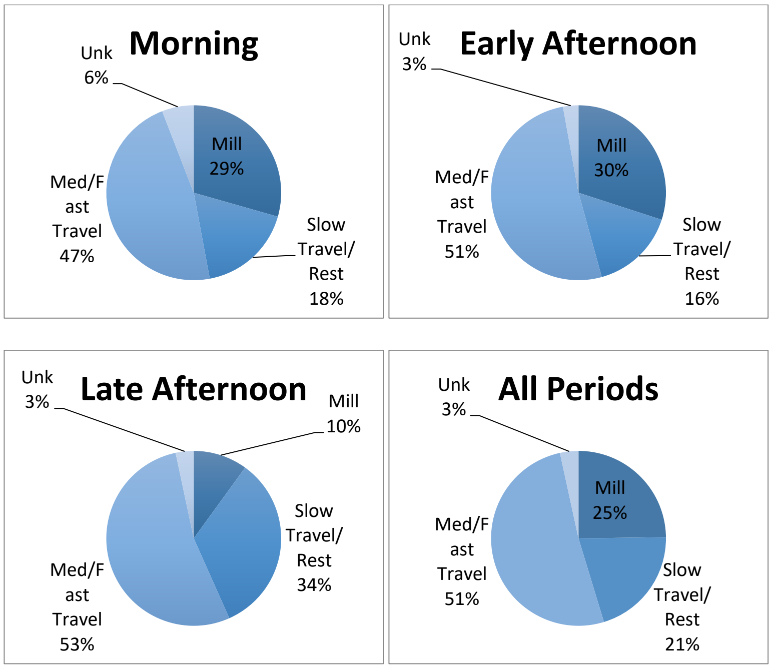

Figure 8. Behavior State by TOD

~~4.57.2~~4.2.2 BS by Season

BS differed significantly between spring and summer (χ^2 = 40.44 df =2, n = 111, p <0.001). There was only one pair observed during fall and no sightings during winter thus BS was limited to the spring and summer seasons. During both spring and summer, TR was the dominant BS (52% and 50% respectively) followed by MI (31% and 24% respectively) and ST/R (13% and 23% respectively). MI was observed more during spring than summer where ST/R was observed more during summer.

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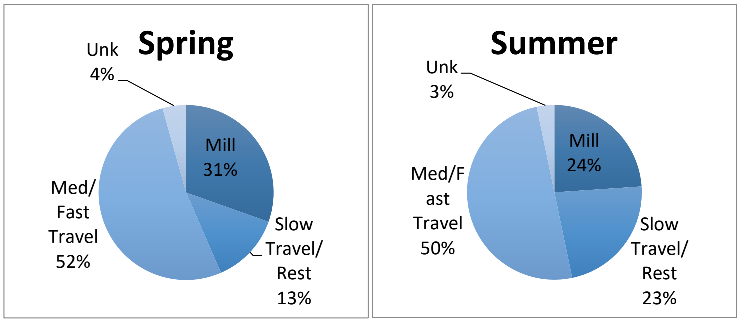

Figure 9. Behavior State by season.

4.2.3 BS by Distance to Shore (km) & Depth (m)

~~4.57.3~~ Table 7. BS by distance to shore and depth.

	Mill	Slow Travel/Rest	Medium/Fast Travel
Average d~~D~~istance to shore (km)	8.42	15.53	12.6
Average depth at sighting (m)	250.16	436.5	443.3

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Mom/calf pairs and single animals, on average, were found in deeper water (~ 419 m and ~478 m, respectively) where groups were found in more shallow waters (~286 m). Overall the average depth at sightings was in ~431 m of water. Mom/calf pairs were found further offshore than all other group categories (18.1 km).

~~4.58~~4.3 *Cohesion*

Cohesion for pairs (excluding mom/calf pairs due on small sample size) and for groups was collected for 16 pairs (32 individuals) and 8 groups (36 individuals). Cohesion in pairs ranged from 1 to 20 BL with over 90% observed at 1 to 2 BL. Average distance to nearest neighbor was 1.3 BL. Note that for pairs the average, minimum, and maximum distance between nearest neighbor is the same because there are only two individuals. Cohesion in groups was more variable, ranging from 1 to 50 BL with the average minimum distance 2.8 BL, the average maximum distance 25 BL and overall average 13.9 BL. Results show that cohesion by group size had a positive correlation ($R^2 = 0.39$; Figure 10~~Figure 10~~~~Figure xx~~), which was statistically significant ($p<0.05$). These results show that groups were more spread out than pairs and thus exhibited less cohesive behavior.

Table 8~~87~~. Average, minimum and maximum cohesion for pairs and groups.

Cohesion Index	Pairs (n = 14 pairs, 28 individuals)	Groups (n = 8 groups, 36 individuals)
Average minimum distance to nearest neighbor (BL)		2.8
Average maximum distance to nearest neighbor (BL)		25
Average distance to nearest neighbor (BL)	1.3	13.9

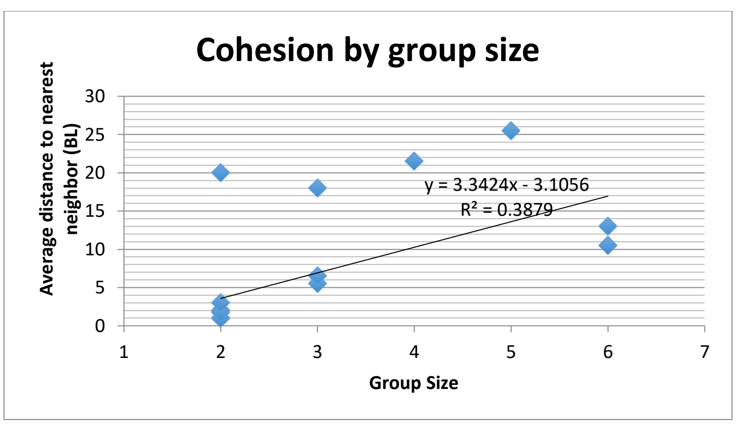

Figure 10~~107~~. Cohesion by Group Size

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~~4.59~~4.4 *Heading*

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We assessed heading by season and TOD. Our results found that there was no clear pattern between heading and season or TOD.

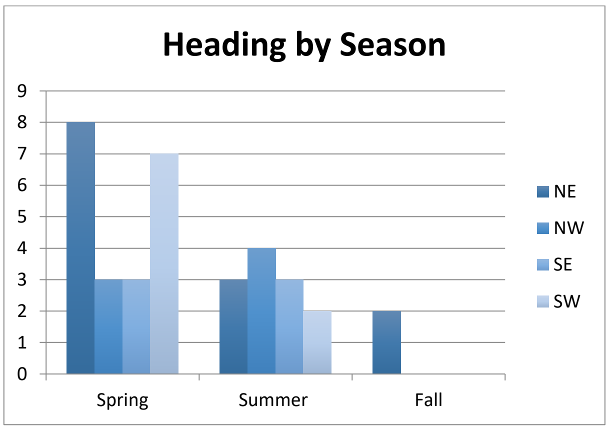

Figure 11~~118~~. Heading by season

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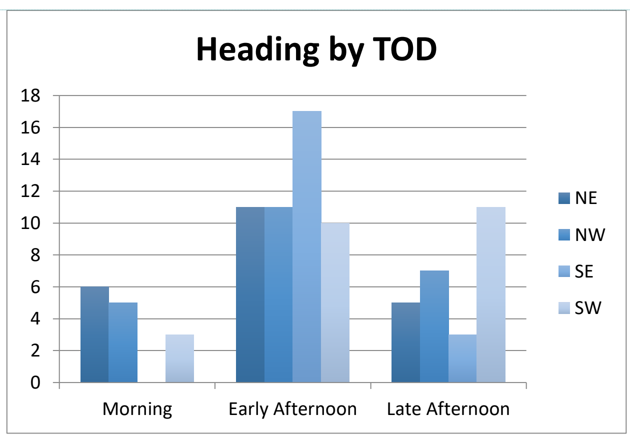

Figure 12~~129~~. Heading b~~m~~y TOD

~~4.60~~4.5 *Summary of Results*

Dependent Variables	Questions		Predictions	Results
Group Type (GT)	Does GT vary by…	Season?	GT varies spatio-temporally	• GT differed significantly between spring and summer among singles, pairs and groups of blue whales (χ^2 = 31.18, df = 2, *n* = 66, p <0.001) • Groups (n>2) only found during summer and not spring (Freeman-Tukey Deviate, z = -1.96) • Pairs observed during spring, summer and fall • No blue whales observed during winter
		TOD?		• GT differed significantly by TOD (χ^2 = 17.58, df = 2, *n* = 67, p < 0.001)
		Distance?		• Mom/calves (18.1 km) and singles (13.2 km) were found farther from shore than groups (9.9 km) and pairs (9 km)

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Dependent Variables	**Questions**		**Predictions**	**Results**
Behavior State (BS)		Depth?		• Mom/calves (419.2 m) and singles 477.6 m) were found in deeper water than groups (285.6 m) and pairs (380.9)
	Does BS vary by…	GT?	GT varies by BS	• BS differed significantly by GT (g2 = 100.4,df =4, *n* = 107, p < 0.001) • Groups engaged in MI and ST/R more than single animals and pairs • Only singles and pairs were observed in TR, groups were not
		Season?	BS varies spatio-temporally	• BS differed significantly between spring and summer χ^2 = 40.44 df =2, *n* = 111, p <0.001). • MI was observed more during spring (31%) than summer (24%) where ST/R was observed more during summer (23%) than spring (13%).

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Dependent Variables	Questions		Predictions	Results
		TOD?		• BS differed significantly by TOD (χ^2 = 20.19, df = 2, n = 113, $p < 0.001$) • MI decreased in “late afternoon” compared to “morning” and “early afternoon” • ST/R increased in “late afternoon” compared to “morning” and “early afternoon”
		Distance?		• BS varied by distance to shore where MI was observed in water closest to shore (8.42 km) followed by TR (12.6 km) and ST/R (15.53 km)
		Depth?		• BS varied by depth - MI behavior was observed in more shallow water (250.16 m) followed by ST/R (436.5 m) and TR (443.3 m).

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Dependent Variables	Questions		Predictions	Results
Cohesion	Does Cohesion vary by…	Group size?	Cohesion varies by group size - As group size increases cohesion decreases (i.e. larger distance between neighbors for larger groups) and groups are less cohesive than pairs.	• Cohesion by group size had a positive correlation (R^2 = 0.39), which was statistically significant ($p<0.05$. n = 24). • Groups were more spread out than pairs and thus exhibited less cohesive behavior • As group size increased so did average distance between nearest neighbor
Heading	Does Heading vary by…	Season?	Heading varies by season. Blue whales migrate N in spring and S in fall thus we would expect dominant to correspond.	No clear pattern between heading and season
		TOD?	Heading does not vary by TOD	No clear pattern between heading TOD

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~~4.61~~4.6 *Descriptive Analyses of Focal Sessions*

~~4.61.1~~4.6.1 27 July 2010 - Group of Six

On 27 July 2010 at 15:24 we encountered a group of ~~6~~ six blue whales. The group composition consisted of ~~4~~ four adults and one mom/calf pair. A focal follow of ~20 minutes was conducted and 10:08 minutes of video footage was recorded. The following table and associated photos provide descriptive analyses of the event. The calf was over ½ the length of the mom and was swimming less than 0.25 BL from the mother. The pairs were separated by 8 -14 BL.

Table 9~~98~~. Descriptive Analyses of blue whale group on 27 July 2010 from video analyses.

Video timestamp	Pair	Composition	Cohesion (BL)	Details of observation	Photos
00:00 - 04:08	Pair 1	Adults (n=2)	1.5	Two adults within 1.5 BL, slow movement in the same direction. Surfacing synchronously. Observed at or subsurface throughout the ~4 min observational period.	1 & 2
5:21	Pair 1 & 2	Adults (n=4)		Four adults (Pair 1 and Pair 2) at surface and all visible in video frame. All animals heading same direction.	3
04:29 - 06:05	Pair 2	Adults (n=2)	1	Pair 2 observed ~14 BL from Pair 1. Two adults within 1 BL, slow movement in same direction. Surfacing synchronously. Observed at the surface or subsurface for the ~1.5 min observational period. Both animals fluke up dive at 06:05	4
6:10	Pair 2 & 3	Adults and mom/calf (n=4)	0.25	Pair 3 surfaces 8 BL from visible fluke print of Pair 2, heading opposite direction from last visible heading of Pair 2	5

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Video timestamp	Pair	Composition	Cohesion (BL)	Details of observation	Photos
06:10 - 08:48	Pair 3	Mom/calf (n=2)	0.25	Mom/calf pair, slow movement in same direction, less than 0.25 BL, possible contact and touching. Calf on right side of mom. Observed at the surface or subsurface for the ~2.5 min observational period.	6 & 7
08:49 - 09:24	Pair 3	Mom/calf (n=2)	0.25	Calf subsurface under mom's belly.	8
09:25 - 09:28	Pair 3	Mom/calf (n=2)	0.25	Dive and no longer visible subsurface, end focal session at 10:08	

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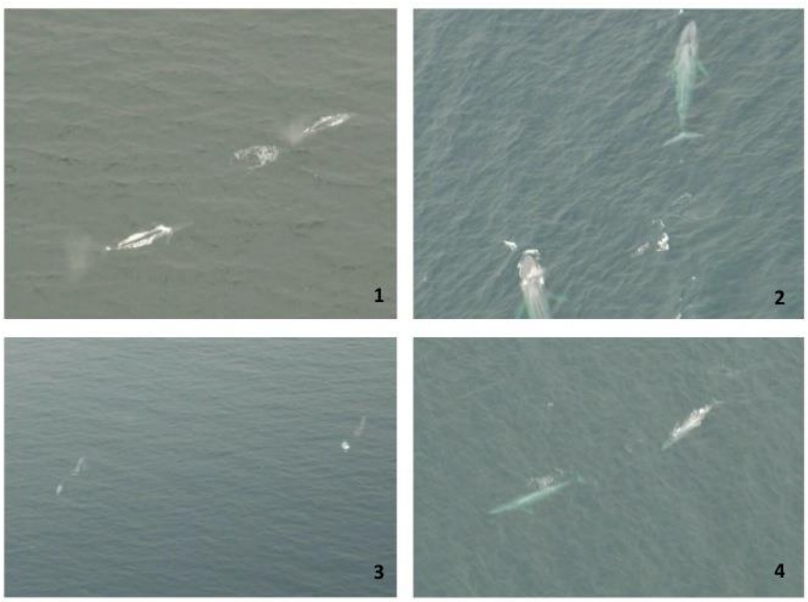

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Figure 1313~~10~~. Photos 1 – 4 from blue whale group 27 July 2010.

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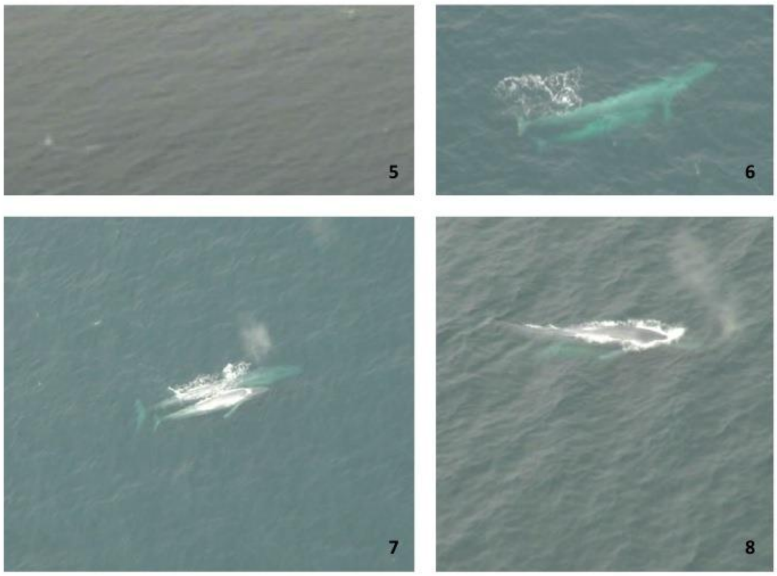

Figure 14~~1411~~. Photos 5 – 8 from blue whale group 27 July 2010.

~~4.61.2~~4.6.2 29 July 2010 Group of Three

On 29 July 2010 at 16:19 we encountered a group of ~~3~~ three blue whales traveling slowly in a SE direction (120) approximately 7 km from shore, in 341 m of water. The group composition consisted of ~~3~~ three adults. A focal follow of ~30 min was conducted and 16.5 min of video footage was recorded. The following table and associated photos provide descriptive analyses of the event.

Table 10~~109~~. Descriptive Analyses of blue whale group on 29 July 2010

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Video timestamp	Pair	Composition	Cohesion (BL)	Details of observation	Photos
00:00 – 01:04	Animal (A) 1, 2 & 3	Adults (n=3)	12-Feb	Two adults within 2.5 BL, slow travel SW heading. A1 directly in front of A2 and separated by 2 BL. Surfacing synchronously. Single adult surfacing ~12 BL behind A1 & A2, traveling in the same SE heading. A3 Surfacing at different intervals than A1 & A2 (i.e. not surfacing in synchronously) A1 & A2 conduct fluke up dive at 1:04. A3 dive not observed.	9
1:04 – 10:00	A3	Adults (n=3)	NA	A1, A2 & A3 sub surface and not visible for video observation.	
10:00 – 11:06	Animal 1 & 2	Adults (n=2)	12-Jan	A1 & A2 surfacing synchronously, 1 BL. A1 in lead and A2 directly behind.	10
11:06	Animal 2	Adults (n=2)	0.5	A2 increased speed and changed orientation slightly to left rear side of Animal 1, BL distance decreased from 2.5 to 0.5	11 & 12
11:06 – 13:55	Animal 1, 2 & 3	Adults (n=3)	0.5 – 12	A1 & A2 conduct fluke up dive at ~13:55. A3 ~12 BL behind Animal 1&2.	
13:55 – 16:29	Animal 3	Adults (n=3)	NA	A3 at surface alone. Continuing same slow travel SE heading.	

Figure 1515~~12~~. Photos 9 – 12 from blue whale group on 29 July 2010

~~4.62~~4.7 Maps

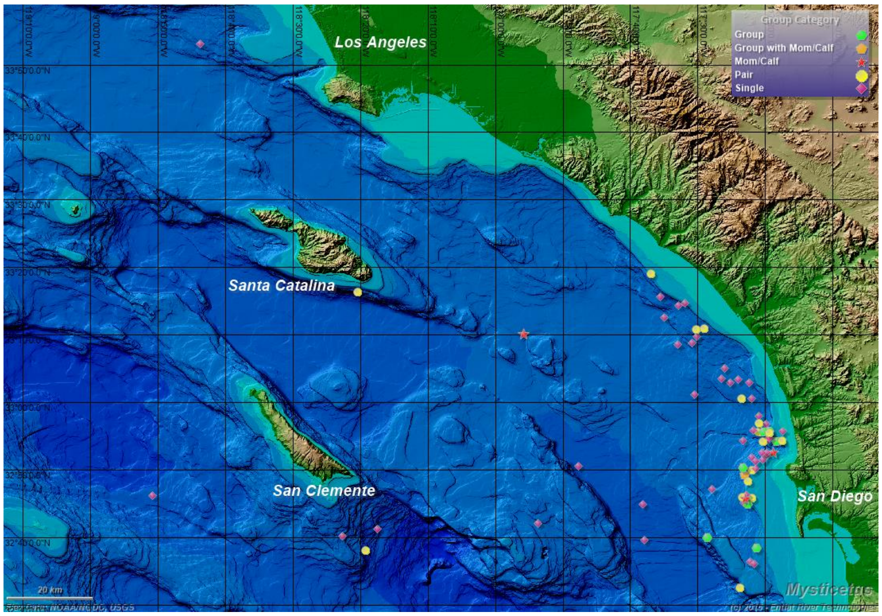

Figure 16~~1613~~. Map of all blue whale sightings during all months 2008 - 2013.

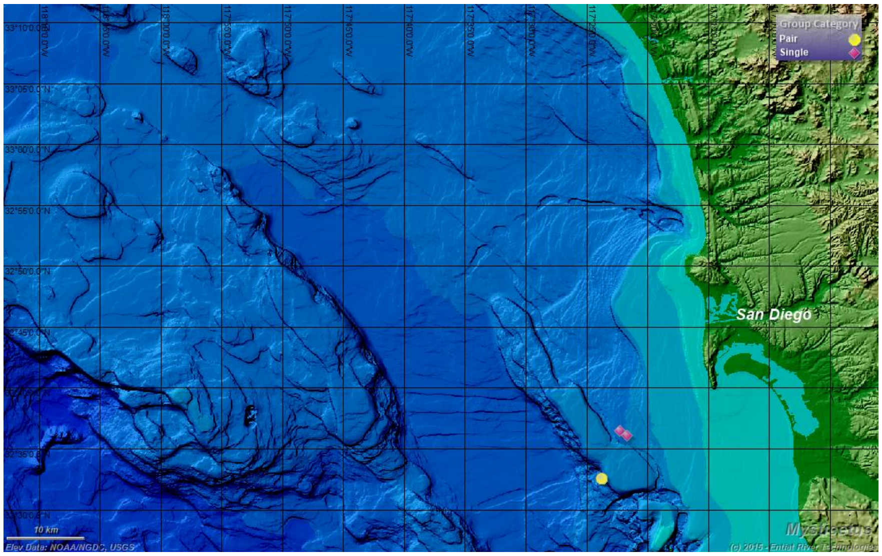

Figure ~~17~~. Map of all blue whale sightings during the month of April 2008 – 2013.

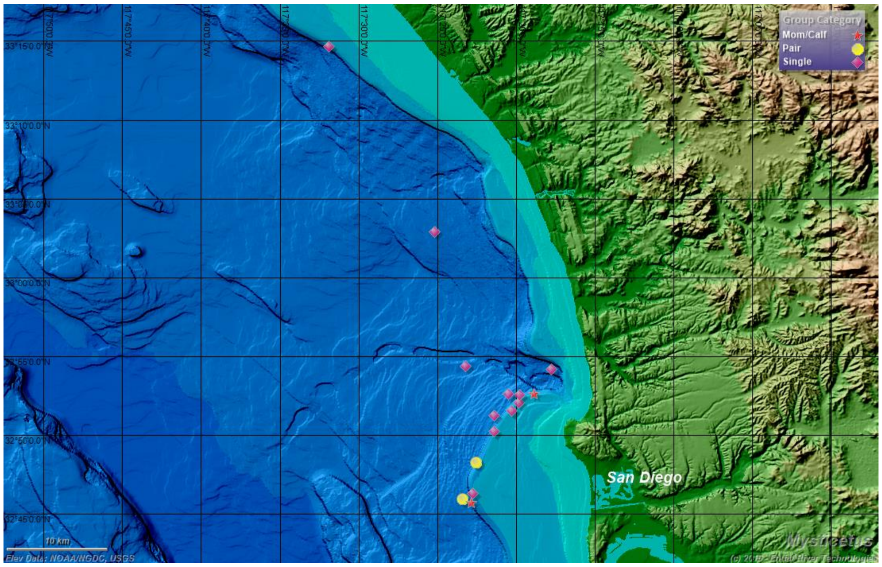

Figure 1818~~15~~. Map of all blue whale sightings during the month of May 2008 - 2013.

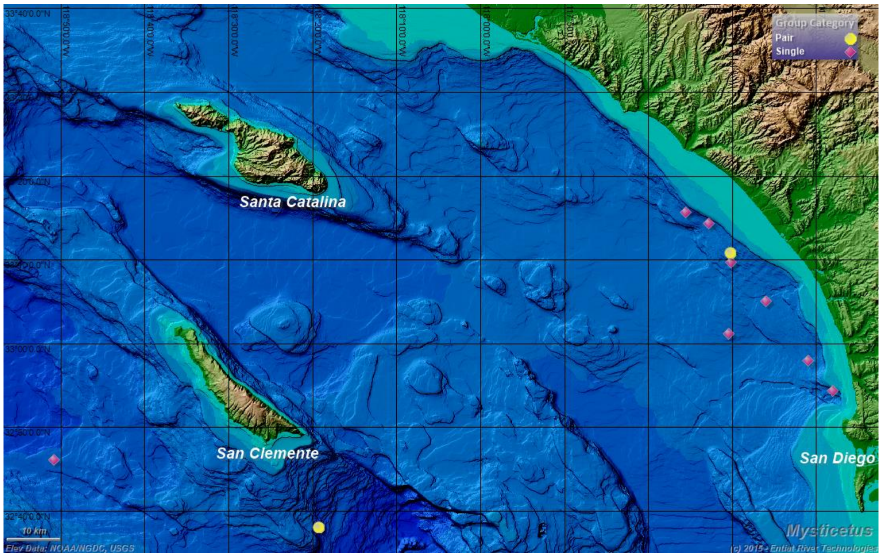

Figure 19~~1916~~. Map of all blue whale sightings during the month of June 2008 – 2013.

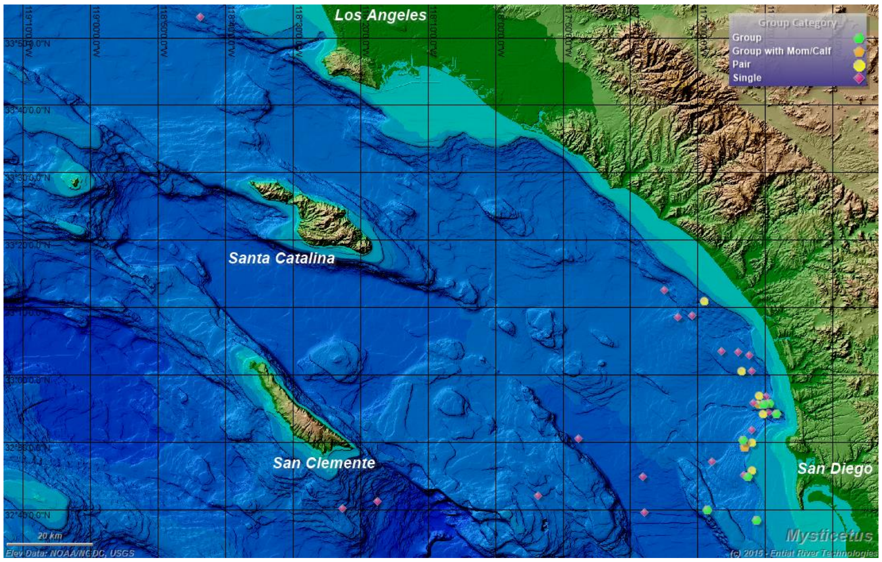

Figure 20~~17~~. Map of all blue whale sightings during the month of July 2008 – 2013.

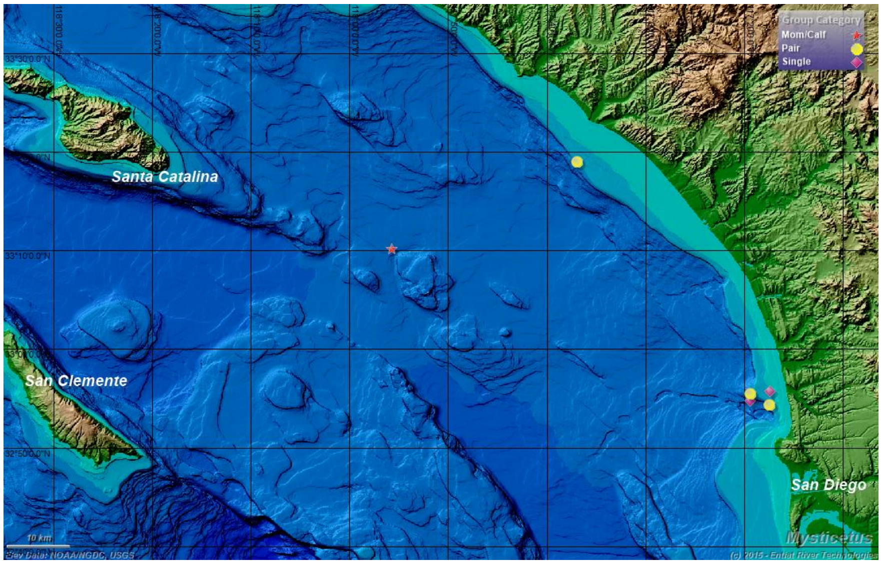

Figure 212118. Map of all blue whale sightings during the month of August 2008 – 2013.

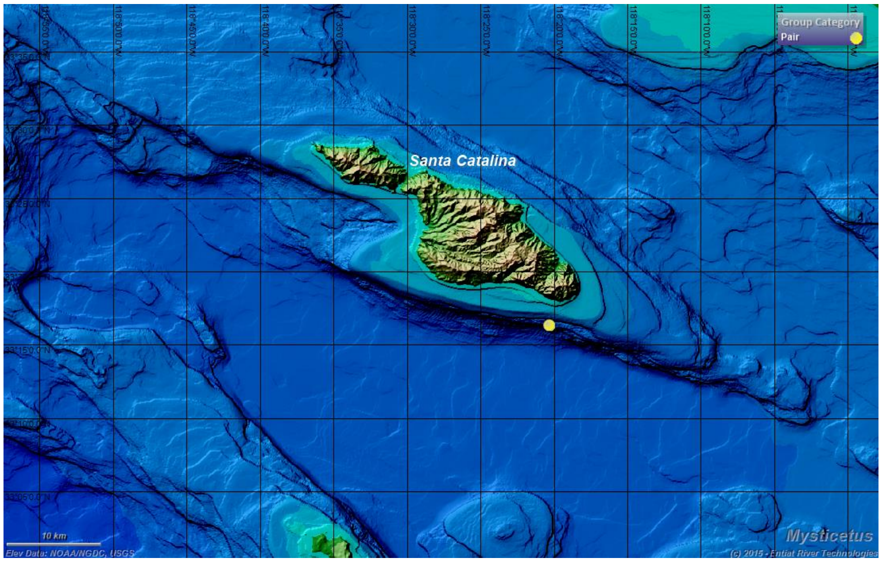

Figure 22~~2219~~. Map of all blue whale sightings during the month of October 2008 – 2013.

5 Discussion

Commented [KL6]: Needs work

In this paper I attempt to provide a baseline understanding of natural blue whale behavior and group dynamics in the SCB. Documenting and comparing patterns and frequencies of group dynamics and baseline behaviors among animals in groups can offer insights into levels of biological organization more so than those available at an individual level (Hinde, 1976; West-Eberhard, 1983; Whitehead & Dufault, 1999). Group size/composition, cohesion, and behavior are important factors that provide better understanding of habitat use and potentially social, mating and feeding dynamics. To identify effective management and conservation strategies, it is imperative to describe and quantify "natural" or baseline behavior and habitat-use patterns to understand how they may change in response to anthropogenic activities.

5.1 Group Type and Season/TOD

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Blue whales are thought to be more solitary animals that aggregate in small numbers specific to foraging and breeding. In the SCB they are known to feed during summer months and depart for a northward migration during fall, returning again the following spring. There is little information on group dynamics and associated behaviors when found within the SCB. When assessing group type seasonal trends, I found that in spring single animals were more common than pairs and mom/calf pairs and no groups were observed. During summer single animals were most common, however mom/calf pairs were recorded and groups were found exclusively during this season (i.e. no groups were observed during spring, fall or winter). These results suggest that animals are arriving from their southern migration to the SCB alone or in pairs and forming short-term social associations. Aggregations of three or more animals are specific to the feeding season. Pairs were recorded during all seasons except winter adding to the evidence that blue whales can form social associations during both foraging and migratory periods. Only a single pair was observed during fall, and no animals were observed during winter months, supporting the knowledge that blue whales migrate to the SCB for the summer feeding season and depart in the fall to spend the winter months in more northward, warmer waters. When assessing patterns of group types associations with time of day, I found that single animals were the most common group type during all periods ("morning", "early afternoon" and "late afternoon"). Mom/calf pairs were only observed during the "morning" and "early afternoon".

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5.2 Distance from Shore & Depth

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Blue whales are found in both offshore oceanic waters and more coastal zones along the shelf. My results found that blue whales in SCB occur in depths ranging from 54 m – 1,465 m and areas 2.7 km to 47.7 km from shore, supporting the understanding that these pelagic species can be found in both offshore and near-coastal waters. Results found that behavior varied by distance from shore and depth. Milling occurred in shallow, more coastal waters where medium/fast travel occurred in deeper offshore waters. Since feeding and foraging behavioral events are associated with mill behavior states this trend is a possible indicator that blue whales are moving inshore to forage and offshore to migrate or travel between foraging areas. Fiedler et al. 1988 reported that blue whales in Southern California were found in cold, well-mixed and productive upwelling zones, feeding on dense sub-surface layers of prey both on and extending off the shelf edge. They found blue whales to feed primarily on euphausiids;

Thysanoessa spinifer and *Euphausia pacifica* with a preference for the larger species found in more coastal waters (Fiedler et al. 1998). Also supporting this, my results showed that groups were found in more nearshore waters. Both the group type and behavior state recorded in shallow waters support the idea that groups of blue whales may aggregate in nearshore waters to feed, and disperse to pairs or single animals to travel between foraging areas and for resting periods.

Mom/calf pairs were found further from shore than singles, pairs and groups. The mom/calf pairs were found in an average water depth of 419.2 m and 18.1 km from shore. Although the mom/calf pairs represent a small sample size (n = 3) this group type was found in the deepest and furthest offshore waters. Hucke-Gaete et al. (2004) conducted aerial surveys off southern Chile in fjords and inter-island protected waters. Their study found mom/calf pairs (n = 11) between 0.8 and 16 km from shore in water depths ranging from 45 and 219 m. During this survey they observed mom/calf pairs exhibiting feeding and defecation behaviors, suggesting that blue whales used the area for both foraging and nursing young (Hucke-Gaete et al. 2004). A potential reason for mom/calf pairs using offshore, deeper waters in the SCB could be due to predator avoidance or evasion of other whales and associated potential danger for the calf. It is also possible that the mom/calf pairs are using deeper, offshore waters to migrate between protected foraging and nursing areas. With a small sample size further investigation is necessary to understand reasoning ~~fro~~ for mom/calf habitat use of offshore waters.

5.3 Behavior State

Within groups the predominant behavior state was mill followed by slow travel/rest. Behavior state for pairs was exclusively medium/fast travel with no other behavior states recorded.

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Single animals were predominantly observed in medium/fast travel with a small percentage in mill and slow travel/rest. This significant difference in behavior states observed between group types could indicate that single animals and pairs are traveling between foraging areas and congregating in larger groups in inshore waters where more milling occurs.

Blue whales were found to engage in slow travel/rest in groups in late afternoon and single or pair animals engaging in mill and medium/fast travel behaviors in the morning and early afternoon with mill decreasing in late afternoon. This possibly could be correlated to ~~diel~~ diet patterns (organisms and prey migrating vertically ~~migration~~ upward to shallow water during night and downward to deeper water during the day) associated with feeding, which have been previously reported. Surface feeding has been observed during the day, however it is thought that blue whales are conducting deeper dives (100 m) into layers of euphausiid concentrations during daylight hours and rise to feed near the surface in the evening, following the ascent of their prey in the water column (Sears et al. 2008).

As group size increased so did distance between nearest neighbor indicating that smaller groups and pairs were more cohesive than larger groups. Gowans et al. (2008) explains "animals form groups when survival and reproductive success of an individual is enhanced by group living" (Gowans et al. 2008). Although blue whales are not considered group animals and thought to be more solitary, my results showed that groups are both common and correlated to time of year, location, and behavior state. Benefits to groups for blue whales could include enhanced detection of prey and foraging techniques, enhanced reproductive strategies, social

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interaction and learning, and reduced predation. I found my prediction of cohesion to be true that as group size increases cohesion decreases, signifying that pairs are more closely associated or cohesive and larger groups more spread or less cohesive.

Focal follows and descriptive analyses from video show that within groups, pairs or sub groups exist where animals are remaining in close association, surfacing at the same intervals and moving in the same direction or pace for short durations of time. It is possible that these are short-term associations specific to feeding or migratory patterns however it is not clear if these associations continue for extended periods of time. Sub-groups within groups have been documented for multiple other species including primates (Lehmann and Dunbar 2009).

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Overall results did not show any clear trends with travel direction or heading. It appears as though direction of movement was random. This is possibly due to the fact that blue whales are moving between high productivity foraging areas specific to prey availability during the spring and summer seasons. Mate et al. 1999 found that 10 tagged blue whales in the SCB either clumped or zigzagged in pattern, suggesting feeding or searching for prey. My results similarly indicate that blue whales are moving between near coastal and offshore waters with no apparent direction of travel indicated.

Blue whales in the SCB are found in group types that include single, pair, mom/calf pair, and groups (3 or more animals). As group size increases animals are less cohesive and more spread out. It is unclear whether associations and pairs are short or long term, however I hypothesize that pair associations are more long-term than group associations. It is possible

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that pairs are traveling between foraging areas and associating within a group but remaining in the pair association as was observed during the focal follows.

Behavior state varied by group type where pairs and single animals were found almost exclusively traveling, and groups and mom/calf pairs were found milling and slow travel/rest. Groups were found in shallow, coastal waters, as were pairs however single animals and mom/calf pairs were found in deeper, offshore waters. These variations in behavior state and location by group type are possibly associated with foraging behaviors as would be expected in the SCB where groups are aggregating in shallow, coastal waters to feed, pairs and single animals are traveling between high productivity foraging areas, and mom/calf pairs are found in offshore, deeper waters. Groups were only found during summer months, singles and mom/calf pairs were found in spring and summer and pairs ~~are~~ were occurring during all seasons with the exception of winter.

6 Conclusion

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Results provide the first quantitative summary of inter-relationships between blue whale behavior/group dynamics and spatio-temporal variables. Data indicate that group type (single, pairs, mom/calf pairs, and groups of two or more whales) influences behavior state. In addition, group type and behavior are influenced by spatio-temporal variables. Detailed narratives of inter-whale associations from focal follows of two different blue whale groups provide additional insight into blue whale group behavior. In summary, these results indicate the importance of considering and differentiating the influences of group size and spatio-temporal factors when assessing potential impacts of anthropogenic activities. The latter approach is critical in order to separate "normal" behaviors from the effects of anthropogenic factors and to consider their potential interactions.

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