Western Gray Whale Movement, Respiration, and Abundance during Pipeline Construction off Sakhalin Island, Summer 2006

Photo taken from shore at North Station. G. Gailey

Gailey, G.[1], T. McDonald[2], R. Racca[3], O. Sychenko[1], F. Hornsby[2], A. Rutenko[4], V. Vladimirov[5], and B. Würsig[1]

[1] Texas A&M University, 4700 Avenue U Bldg 303. Galveston, TX. 77551

[2] West, Inc. Western EcoSystems Technology, 2003 Central Avenue, Cheyenne, WY 82001.

[3] JASCO Research Ltd, Suite 2101-4464 Markham Street . Victoria, B.C., Canada. V8Z 7X8

[4] Pacific Oceanological Institute. Far East Branch, Academy of Sciences of Russia. Vladivostok, Russian Federation

[5] All-Russian Research Institute of Fisheries and Oceanography, Moscow, Russian Federation.

18 November 2010

Table of Contents

List of Figures

List of Tables

Introduction

During the summer of 2006, Sakhalin Energy Investment Company (SEIC) conducted inshore and offshore construction in proximity of the nearshore feeding habitat of the critically endangered population of western gray whales (*Eschrichtius robustus*). The construction activity consisted of dredging trenches and laying pipes from two oil platforms (PA-A and PA-B; 13-16 km from shore in 30 m water depth) to landfall. The route of the pipeline preceded south from the platforms to an area that was outside of the known nearshore feeding grounds of the western gray whale. Once the pipeline reached this area, the route preceded east to reach landfall (Figure 1). Pipeline construction consisted of multiple phases and mitigation and monitoring measures were employed to minimize sound levels within the known foraging habitat of western gray whales.

One of the primary concerns surrounding the construction activities was the potential disturbance and/or displacement of the whales during their feeding season. While western gray whales face several threats during their annual north-south migration along the west coast of Asia, a concern during their feeding season off northeast Sakhalin Island is potential effect from exposure to underwater sound produced by oil and gas development operations (vessel traffic, drilling, dredging, construction, seismic exploration, etc.). Since gray whales only forage during the summer and fall months of each year, this timing is critically important to provide sufficient energy reserves to sustain individuals for the rest of the year.

Anthropogenic sound can influence the behavior of a number of baleen whale species (see Richardson *et al.* (1995) for a summary) and monitoring changes in abundance and behavior can be used as leading indicators that could reveal effects that anthropogenic activity may have on the whales. For example, Tyack and Clark (1998) found that migrating eastern gray whales avoided a low frequency acoustic sound source when it was located directly in their migratory path. An experimental exposure of eastern gray whales on their feeding grounds in the Bering Sea to playback of continuous sounds revealed that whales changed swim direction at received levels (broadband SPL) ranging from 110 dB re µPa (10% of population) to 120 dB re µPa (50%) and 130 dB re µPa

(90%). Malme *et al.* (1986) found that ~10% of eastern gray whales stopped feeding and moved away from transient (seismic) sounds when received sound levels exceeded 163 dB re µPa (rms). This relationship was based on small sample sizes but was later supported by a larger dataset obtained from migrating eastern gray whales (Malme *et al.* 1988).

Western gray whales have also been observed to respond to sounds produced during geophysical seismic surveys (Gailey *et al.* 2007a, Johnson *et al.* 2007, Weller *et al.* 2002, Würsig *et al.* 1999, Yazvenko *et al.* 2007). One study found that whales traveled faster, changed directions of movement less, moved further from shore, and stayed under water longer between respirations when exposed to higher received sound levels (Gailey *et al.* 2007a). Similarly, Weller *et al.* (2005) found that whales traveled faster and more linearly with short respiration intervals during seismic operations that occurred near the western gray whale feeding grounds in 1997. During the installation of a Concrete Gravity Based Structure (CGBS), western gray whales were noted to move further from shore as sound levels increased (Gailey *et al.* 2007b). However, this study was confounded by two different sound sources (nearshore vessel and offshore construction activity) and therefore the potential impact could not be directly attributed to either sound source nor the combination of both sound sources.

Objectives

The primary objective of this study was to examine potential disturbance of sound exposure on western gray whale behavior and abundance during the pipeline construction activity in 2006. One aspect of this objective was to assess and quantify changes in abundance, movement and behavior of gray whale due to underwater sound levels produced by the dredging and pipeline laying activities. Another aspect was sounds associated with research vessel activity that occurred near and in the Piltun feeding area which could have contributed to the potential disturbance.

We sought to accomplish these objectives using an analysis that accounted for sources of natural variation as well as assessment of research and industrial effects. A multivariate approach was needed to incorporate non-industrial environmental factors, temporal factors, spatial variables, sound levels, and vessel effects (number and distance to vessels). Both research and construction related sound levels were used to examine impacts that industrial operations and other sources of anthropogenic activities. These analyses expands upon our previous analytical framework (Gailey *et al.* 2007b) by taking into account recommendations and comments by previous reviewers (WGWAP 1/INF2, WGWAP2 report).

Methods

This report provides supplemental analyses to those reported in Gailey *et al.* (2007c), Rutenko (2007), and Vladimirov *et al.* (2007). These analyses combines acoustics, abundance, and behavioral data to investigate disturbance effects during pipeline construction activity that occurred in the proximity of the nearshore feeding habitat of western gray whales. Details of data collection methods for acoustics, abundance and distribution, and behavioral research were outlined in Rutenko (2007), Vladimirov *et al.* (2007), and Gailey *et al.* (2007c), respectively, and are not repeated in this report. Relevant information on sound level estimation, datasets, and analytical approach are described below.

Relative Abundance and Behavioral monitoring

During the dredging and pipeline laying and backfill, western gray whale abundance, behaviors, respiration, and movement patterns were monitored from shore. For this report, we used scan sampling, theodolite tracking, and focal follow methodologies to collect data on gray whale abundance, movements, and respiration activities (see Gailey *et al.* 2007c and Vladimirov *et al.*2007). These methodologies were used to monitor whales near and outside of pipeline construction activity. For distribution and abundance surveys, two teams conducted one scan sample at 13 stations (stations 1-13) along the nearshore feeding per good weather day (Figure 1). Movement, respiration, and abundance data were collected by three behavioral teams (Gailey *et al.* 2007c). Two behavioral teams collected data at two stations per good weather day on the northern spit region (North Station to South Station, Figure 1). An additional behavioral team conducted observations near a region of pipeline construction activity where the pipeline reached landfall and thus was particularly close to shore (albeit outside of the known primary feeding grounds). This observation team collected data at one station per good weather day from the Campsite to Chaivo shore-based platforms (Figure 1).

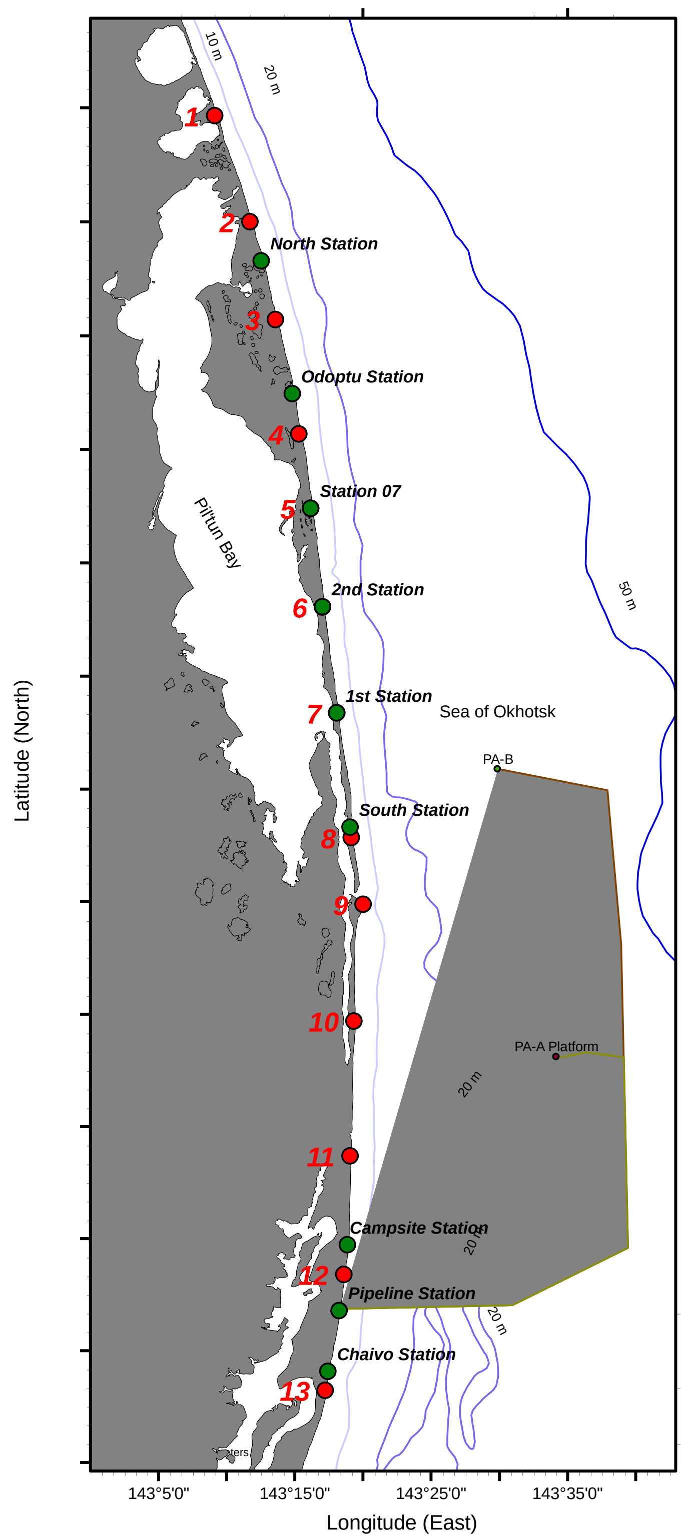


Figure 1. Abundance and behavioral observation platforms in relation to pipeline construction activity.

Data Processing, Response, and Explanatory Variables

Three abundance, eight movement, and seven respiration variables were derived from scan sampling, trackline, and focal animal observations (

Table 1). Collectively, we term these 18 abundance and behavioral variables “the response variables”. To standardize units for analysis, the behavioral response variables were calculated for every 10.5 minute interval (hereafter referred to as a ‘bin’) of continuous observation. Since many response variables (such as linearity and reorientation rate) are not instantaneous measurements, some time was required to derive the response variables. We arbitrarily chose bins of 10.5 minutes in length as a compromise between allowing adequate time to acquire data upon which responses could be measured and the need to assess short-term behavioral responses. Similar length bins have been used in the past (Gailey *et al.* 2007 a, b) and proved adequate for meaningful analyses. Prior to computing responses for each bin, all movement data were resampled every 90 seconds to avoid under- or over-sampling issues and to standardize step lengths of movement (see Gailey *et al.* 2007b, Turchin 1998). This resampling allowed for standardized responses by connecting all observations of an individual through time, and then placing a point on this interpolated path every 90 seconds. If several observations were recorded within, as an example, 20 seconds of each other during a single resurfacing event, the resampling scheme used those observations to establish a path progressing through those observations, but placed points along the path at 90 second intervals. A 90 second resampling interval was chosen based on an autocorrelation analysis of the movement data that indicated that correlation initially died out on average around 90 seconds (Würsig *et al.* 2002). This resampling procedure produced seven spatial points per bin. Bins that did not yield adequate data for the entire 10.5 min. duration (i.e. the last bin in a sequence of bins of a single trackline) were removed from the dataset. For each these bins, several response variables were calculated (Table 1).

Relative abundance data were calculated per scan observation (see Gailey *et al.* 2007c and Vladimirov *et al.* 2007 for data collection methods). The total number of whales, number of pods, and mean distance from shore were calculated for each complete scan conducted during the 2006 field season (Table 1). If no whales were seen during a scan, that scan was not included in for the distance from shore analysis. Relative abundance data were collected by two different sampling approaches: 1) broad scale - one scan was conducted for each observation station per good weather day (see Vladimirov *et al.* 2007) and 2) fine scale - multiple scans were conducted throughout the day at three out of nine observation stations per good weather day (see Gailey *et al.* 2007c). These datasets were termed broad and fine since one dataset has one sample at one time of day with one acoustic exposure level, while the fine scale has multiple samples per day with multiple exposure levels. Therefore, analyzing changes in abundance could be assessed on different levels. As such, data were partitioned to analyze the fine scale observations separately to further explore gray whale abundance and distance from shore as it relates to sound. The rationale for the separate analyses is that the explanatory may be related differently based on sampling approach and the fine scale sampling protocol may contain more data on a particularly events. For example, if there was a particularly loud period during the day whales may have moved out and returned within that day. The fine scale approach would prove more likely to detect these changes verses the broad scale approach.

Table 1. Description of the response variables derived from abundance, movement, and respiration observations. Movement variables were derived from track lines. Respiration variables were derived from focal follow observations. Abundance data were derived from scan sampling.

	Variable	Definition
Movement	Leg Speed	Distance traveled between two sequential fixed points within a trackline divided by the time interval between the two points
	Acceleration	Changes within leg speed to determine if an animal is generally increasing or decreasing speeds within a trackline
	Linearity	An index of deviation from a straight line, calculated by dividing the net geographic distance between the first and last fix of a trackline by the cumulative distances along the track
	Mean Vector Length	A directionality index r (Cain 1989) dependent on angular changes - range from 0 (great scatter) to 1 (all movements in the same direction)

	Reorientation Rate	Magnitude of bearing changes, calculated by the summation of absolute values of all bearing changes along a trackline divided by the entire duration of the trackline in minutes
	Direction of Movement	A mean geographic bearing of the general movement for the trackline. Sine(direction) was an indicator of whale movement inshore-offshore and cosine(direction) indicated whale movement along shore.
	Distance-from-Shore	Distance of animal from the closest perpendicular distance from the nearby coastline
	Ranging Index	Measure of the minimal diagonal area of the whale's track incorporating its course and track duration (Jahoda *et al.* 2003)
Respiration	Respiration Interval	Duration less than 60 s between subsequent exhalations per surfacing
	Dive Time	Any interval where exhalation period is greater than 60 s
	Surface Time	Duration the animal remains at or near the surface
	Number Blows/Surfacing	Total number of exhalations per surfacing
	Time at Surface	Percent of time animal was observed at the surface without diving
	Surface Blow Rate	Mean number of exhalations per minute during a surfacing
	Dive-Surface Blow rate	Number of exhalations per minute averaged over the duration of a surfacing-dive cycle, using the dive previous to the surfacing
Abundance	# Whales/Scan	Total number of western gray whales observed during a scan sample
	# Pods/Scan	Total number of western gray whale pods observed during a scan sample
	Distance-from-Shore	The average distance of western gray whales distance from shore during a scan sample

Independent Variables

Independent variables, used to explain variation in abundance, movement, and respiration activities, were categorized into two classes: 1) natural variables, and 2) impact variables (Table 2-Table 3). The class with natural variables consisted of environmental, temporal, spatial, and the behavioral state of the animal (i.e. feeding, traveling, feeding/traveling, or mixed). Environmental variables included the observation station, date, time of day, Beaufort sea state, visibility, distance to station, water depth at the animal's location, tide height, wind speed, wind direction, estimated swell height, atmospheric temperature, and atmospheric pressure for each observation bin. Behavioral variables consisted of the behavioral state of the animal and the subject (adult, mom-calf, yearling, etc.). Station, behavioral state, subject, and wind direction were categorical (discrete) variables and were included as factors. Factors were coded as a set of 0-1 indicator variables (i.e. either have a value of 0 or 1) that measured effects of changing from one category to another relative to an arbitrary reference. For example, observations were recorded from nine stations in the movement and respiration dataset. The factor effect for these data was coded as a set of three indicator variables, the first being 1 if an observation was from Station07, 0 otherwise, the second being 1 if an observation was from 2nd Station, 0 otherwise, and so on. No indicator variable was constructed for 1st Station because it was the reference level. In other words, the effects of 1st Station were included in the intercept of the model, and the effects of other stations were measured relative to those of 1st Station. That is, a coefficient of β for Station07 implied that the predicted response value at Station07 was β units different from the predicted value at 1st Station, assuming all other variables were the same at both.

Levels of the Beaufort scale factor were grouped differently during analysis of the scan, respiration, and movement data. The scan dataset contained Beaufort values of 0, 1, 2, and 3. The fine scale subset of abundance data had few scans with Beaufort scale values of zero; and therefore, a separate effect for the zero level could not be estimated and Beaufort scale values for this analysis was grouped into less than or equal to 1, equal to 2, and equal to 3. For the respiration and movement analyses, Beaufort scale was not grouped and consisted of individual values.

The behavioral state of gray whales was associated with each bin and classified as one of the following four levels: Feeding, Feeding/Traveling, Traveling, and Mixed. Classification of behavior into one of these four categories was based on field observations regarding a whale's predominant behavioral state at the time. Feeding behavior was characterized by non-directional movement where whale(s) generally remain in one localized area with consistent periods of diving. Traveling behavior was characterized as swimming in one general direction and often remaining at the surface without consistent dives. Feeding/Traveling behavior consisted of whale(s) swimming at relatively slow speeds with consistent periods of diving and having directional persistence in movement. Mixed behavior was any combination of unknown, transitional behaviors, or unrecognized behaviors comprising a substantial portion of the bin.

The class of impact variables included both anthropogenic sound variables and variables associated with vessels. The impact variables were 1) approach distance of the closest vessel of any type, 2) number of vessels within 5 km of the whale, 3) vessel type of the closest vessel approach, 4) underwater sound level received by nearshore vessel activity, 5) underwater sound level received by offshore construction activity, and 6) the time since the onset of construction activity to represent potential auditory fatigue (Table 2-Table 3).

Distance of closest approach by any vessel was coded as a factor containing the following five levels: 0 km to 0.5 km, 0.5 km to 1.0 km, 1.0 km to 2.0 km, 2 km to 5 km, and greater than 5 km. We treated distance of closest research vessel approach as a factor, rather than a single continuous variable, because distance measurements to vessels greater than 5 km were not available for all vessels operating in the area. This lack of vessel positional data beyond 5 km in distance is relatively inconsequential for the results because its factor coding provided a flexible fit to response variables, and any impact vessel proximity may have had on gray whales were expected to be higher as the vessel approached the whale and relatively low beyond 5 km. However, not all vessels recorded positional information and therefore some vessels may have been within a certain distance but were not included in the dataset. Zodiac research vessels and the nearshore dredging vessels tended to be the most prominent vessel activity within a relatively close distance, < 2 km, of a whale.

Abundance model responses used a slightly different set of covariates depending on the model that combined or separated the fine and broad scale datasets. When both datasets were included, swell height and visibility were excluded among the pool of potential covariates since these variables were not measured or compatibly recorded between the different research teams. Although the combination of the two datasets reduced the number of potential explanatory variables in this model, it provided the maximum sample size to be used for the analysis.

Table 2. Environmental and impact variables used to explain variation in movement and respiration activity of western gray whales.

Variable type	Variable	Description	Coding
Natural	Station	Name of observation station where whale was observed	Factor with nine levels: 1st station 2nd station South Station Station 07 Odoptu station

		North station Chaivo station Campsite station Pipeline station 1st station is the reference level.
Day	Number of days from the start of the survey.	
Time of day	Time of the observation	Time of the observation, coded as hours after 00:00:00 of the same day. E.g., an observation at 3:41:15pm on any day is coded as 15.6875.
Behavior	Animal's behavioral state during observation bin	Factor with four levels: Feeding Feeding/Traveling Traveling Mixed (other) Feeding is the reference level.
Subject	Type of Individual(s) being observed	Factor with four levels: Mom-Calf Yearling Adult Unknown Adult is the reference level.
Beaufort	Sea state measured on Beaufort scale	Factor with six levels: [0] [1] [2] [3] [4] [5] [0] is the reference level.
Visibility	Visibility conditions estimated at the time	Factor with five levels: [1] [2] [3] [4] [5] [1] is the reference level.
Distance to Station	Distance from whale location to the onshore observation station (km)	
Depth	Water depth at whale location (m)	
Tide	Predicted tide height at time of observation (m)	
Wind direction	Direction of the wind	Factor with four levels: South = “S”, “SE”, “SES”, “SSE”, “SSW”, “SW”, “SWS” West = “W”, “WNW”, “WSW”, “NWW” East = “E”, “ENE”, “ESE”, “NEE”

			North = “N”, “NE”, “NNE”, “NNW”, “NW” South is the reference level.
	Wind speed	Speed of the wind (km/h) during observation	
	Swell Height	Field estimated swell height (m) during observation	
Impact	Closest vessel	Distance from whale to closest vessel (km)	Factor with five levels: [0,0.5] : distance 0 to 0.5 km (0.5,1] : distance >0.5 to 1.0 km (1,2] : distance >1.0 to 2.0 km (2,5] : distance >2.0 to 5.0 km (5+] : distance >5.0 km [0.0.5] is the reference level. No vessels in the vicinity will be coded as (5+].
	Number of vessels	Total number of vessels within 5 km of the whale (range 0 to 3)	Fitted as a linear (1 coefficient) effect.
	Vessel Type	Type of vessel closest to animal's location	Factor with three levels: Construction Nearshore Zodiac Construction is the reference level.
	Time Since	Number of weeks since the onset of construction.	
	Sound level (nearshore)	Average sound level (dB re 1 m Pa) of nearshore vessels at the mid-point location of the 10.5 minute interval.	
	Sound level (offshore)	Average sound level (dB re 1 m Pa) of offshore construction activity at the mid-point location of the 10.5 minute interval..	

Table 3. Environmental and impact variables used to explain variation in abundance of western gray whales.

Variable type	Variable	Description	Coding
Natural	Station	Name of observation station where whale was observed	Factor with nineteen levels: Station 1 Station 2 Station 3

		Station 4 Station 8 Station 9 Station 10 Station 11 Station 12 Station 13 1st station 2nd station South station Station 07 Odoptu station North station Chaivo station Campsite station Pipeline station Station 1 is the reference level.
Day	Number of days since the start of the field season	
Time of day	Time of the observation	Time of the observation, coded as hours after 00:00:00 of the same day. E.g., an observation at 3:41:15pm on any day is coded as 15.6875.
Beaufort*	Sea state measured on Beaufort scale	Factor with four levels: [0] [1] [2] [3] [0, 1] is the reference level.
Glare Present	Glare presence during a scan sampling survey	Factor with two levels: [0] — no [1] — yes [0] is the reference level.
Week Since	Number of weeks since the onset of pipeline construction	
Swell Height°	Field estimated swell height (m) during observation	
Tide Height	Predicted tide height at time of observation (m)	
Visibility°	Visibility conditions estimated at the time	Factor with five levels: [1] [2] [3] [1] is the reference level.
Wind direction	Direction of the wind	Factor with four levels: South = “S”, “SE”, “SES”, “SSE”, “SSW”, “SW”, “SWS” West = “W”, “WNW”, “WSW”, “NWW” East = “E”, “ENE”, “ESE”, “NEE” North = “N”, “NE”,

			“NNE”, “NNW”, “NW” South is the reference level.
	Wind speed	Speed of the wind (km/h) during observation	
Impact	Closest vessel	Distance from whale to closest vessel (km)	Factor with four levels: (0.5,1] : distance >0.5 to 1.0 km (1,2] : distance >1.0 to 2.0 km (2,5] : distance >2.0 to 5.0 km (5+] : distance >5.0 km [0.5.1] is the reference level. No vessels in the vicinity will be coded as (5+].
	Vessel Type	Type of vessel closest to animal's location	Factor with three levels: Construction Nearshore Zodiac Construction is the reference level.
	2 hours	Cumulative underwater sound levels associated with 1) nearshore research vessel activity and 2) offshore pipeline construction activity during the preceding two hours from the time of the scan survey. Sound levels were estimated at a“virtual” whale location, summarized over 2 hours prior to an observation. Measurements were RMS levels in dB re 1 μPa.	
	8 hours	Cumulative underwater sound levels associated with 1) nearshore research vessel activity and 2) offshore pipleline construction activity during the preceding two hours from the time of the scan survey. Sound levels were estimated at a“virtual” whale location, summarized over 8 hours prior to an observation. Measurements were RMS levels in dB re 1 μPa.	
	1 day	Cumulative underwater sound levels associated with 1) nearshore research vessel activity and 2) offshore pipleline construction activity during the preceding two hours from the time of the scan survey. Sound levels were estimated at a“virtual” whale location, summarized over 1 day prior to an observation. Measurements were RMS levels in dB re 1 μPa.	

	3 days	Cumulative underwater sound levels associated with 1) nearshore research vessel activity and 2) offshore pipleline construction activity during the preceding two hours from the time of the scan survey. Sound levels were estimated at a“virtual” whale location, summarized over 3 days prior to an observation. Measurements were RMS levels in dB re 1 μPa.

* [0] and [1] were grouped together in the behavior team dataset due to a limited number of [0] for modeling.
° Visibility and Swell Height were not considered when both teams were being modeled.

Sound-Level Estimation

To examine potential impact related to underwater noise, sound level variables were estimated for each data set. A hybrid estimation approach was implemented that combined sound level measurements at a sparse set of underwater acoustic recording stations with numerical modeling of sound distribution based on the knowledge of offshore construction activities and of the movements of research ships “Academik Oparin” and “Professor Bogorov”, the only large vessels routinely dwelling in the nearshore distribution area of the whales. The method, a detailed description of which is provided in Appendix A along with an analysis of its accuracy, made use of acoustic data collected at up to fourteen underwater stations distributed along the littoral waters to ground truth corresponding model estimates and thereby generate time dependent correction terms. These terms were then used to adjust correspondingly the model estimates at locations of interest, always using the nearest recording station as reference. The numerical estimates consisted of two additive components: precisely modeled noise footprints from notional scenarios of multi-vessel offshore activities, computationally intensive but only updated every several days of operation as the construction phases evolved, and simple distance-rule calculations of local noise levels from the research vessels that constantly changed with the ships’ position. At every location of interest the measurement based correction term was applied independently to each of the two components to yield separate sound level estimates for near-shore research vessels and offshore construction activity, which were used as distinct impact variables in the multivariate analysis.

Sound levels were estimated at the animal’s location for the analysis of the movement and respiration datasets. For analysis of relative abundance, on the other hand, sound levels were estimated at a point 2 km directly offshore of the observation platform (called the “virtual” whale location). Cumulative sound levels were assessed on a 2h, 8h, 1 day, and 3 day interval prior to the scan to examine potential shifts in animal abundance on different temporal scales (Table 3). In other words, a response in abundance was assessed on different temporal scales in relation to the sound levels to examine any association with the number of whales to the previous sound level exposures.

Analytical Dataset

The analytical dataset consisted of 139 focal animal follow observations collected between 30-Jun-2006 and 26-Sep-2006. The 139 tracklines consisted of 775 bins, and the 76 focal animal observations contained 389 bins. In some bins, certain variables could not be measured, primarily because focal animals did not dive during the observation period or acoustic data were unavailable; consequently, the actual number of bins used for estimation varied depending on the response variable being analyzed. Available acoustic information overlapped with 91% (353 bins) of the focal data and 93% (724) of the movement dataset. Bins that contained no sound levels (i.e. 36 bins ranging over 17 focal-follow sessions and 51 bins ranging over 6 tracklines) were removed from the datasets. Absence of acoustic information during these periods either was the result of missing positional information for near-shore scientific vessels operating in the area (required to adjust model estimates of the noise field) or was caused by a gap in the sound level recordings (due to AUAR maintenance) at any station sufficiently close to the whale's position to allow reliable estimation.

A total of 663 scans were conducted along the nearshore feeding habitat of western gray whales from 23 June 2006 to 15 October 2006. A total of 3081 gray whale sightings were observed during this period for all shore-based teams. The fine scale dataset consisted of 376 scans. Acoustic information was not recorded after 25-September-2006. Available acoustic information overlapped with 71% (472) and 85% (562) for the distance from shore dataset and individual dataset when both teams were included. When only the fine scale data were considered, acoustic information overlapped with78% (293) and 95% (358) for the distance from shore model and the individual model, respectively. On average, scan observations yielded 4.6 whales (± 4.40) per scan for the entire observation area. Further general details on abundance and distribution data can be found in Gailey *et al.* 2007c and Vladimirov *et al.* 2007.

Sampling Unit/Pseudo-Replication

One of the fundamental analytical difficulties associated with the behavioral datasets were the potential biases due to pseudo-replication and autocorrelation. The bins observed for each individual were consecutive (i.e. potentially autocorrelated) within one track/focal session and varied in number among tracking/focal sessions. Movement responses were recorded on tracklines consisting of 1 to 51 consecutive bins (51 bins = 8.9 hrs). Focal animal follow data consisted of responses measured from 1 to 25 consecutive bins (25 bins = 4.4 hrs). The number of bins observed per animal was influenced by the ability to continuously track or follow whales for extended periods of time. The ability to continuously follow whales was a function of limited or decreased visibility due to fog, high sea state, rain, or other inclement weather in combination with the distance of the whale from the shore-based observation platform. Animals initially closer to the observation station were more likely to be chosen to be tracked / followed, and had a higher probability to be observed for longer periods than animals further from the station, suggesting distance-based inclusion bias. These factors caused observations from whales close to station to have higher probability of being included and contributed more bins (on average), than animals further from the observation platform. This implied sampling bias in the behavioral observations as a function of distance. In this case, the bias was toward including too many observations of whales that were closer and therefore "easier" to track or that were sighted during good weather close to shore and station. Conversely, fewer observations of whales further from shore/station that were more "difficult" to follow were included. Therefore, the probability that we obtained a bin from a whale was strongly correlated with the number of bins that were actually observed. If the probability of obtaining an observation was high, we tended to observe more bins. If probability of obtaining an observation was low, we observed fewer bins.

Furthermore, the number of bins likely to be observed was different for different behavioral classifications. For example, whales that were feeding (animals remaining in a localized area) were more likely to have more representative bins than a traveling whale (animals traversing across the study area). If inclusion probabilities were not correlated with the observed number of bins, researchers would have obtained approximately equal numbers of bins for whales displaying similar behaviors (i.e., feeding, traveling, etc.) and at different offshore distances, which was clearly not the case.

To adjust for this bias, we weighted each observation in the analysis by a value inversely proportional to the probability of obtaining that observation. The use of weighting was justified by the Horvitz-Thompson theorem (Horvitz and Thompson 1952, Overton and Stehman 1995), which states that weighted averages provide unbiased estimates of population means when weights are inversely proportional to probability of including the observation. Based on this theory, each behavioral observation (bin) was weighted by the inverse of the total number of bins observed from the whale. In other words, all observations in the analyses were weighted by $1/ n_i$, where n_i equaled the number of bins observed from animal *i*. As a result, each animal in the analyses had a total weight of 1.0.

Alternatively, resampling techniques could be applied to each track or focal session to increase the number of bins to the maximum number of bins observed for the entire dataset. The weighted and resampling approaches should yield similar results, but estimating variance for coefficients would be more difficult under the resampling approach.

Response Variable Treatment

The modeling approach taken here (see Model section below) assumes the response variables being analyzed have an approximately normal distribution. Therefore, we inspected the distribution of each response variable and sought response distributions that were unimodal, symmetrical, and contained as few outliers as possible. When the distribution did not fit an approximate normal distribution, we determined an appropriate transformation for each response by visually inspecting box-plots categorized by a whale's behavioral state (feeding, traveling, feeding/traveling, or mixed). Transformation procedures applied to each response variable are listed in Table 4. Two variables (linearity and mean vector length) were transformed using the logistic transformation even though these variables were not strictly binomial. Because some of the raw values were 1.0, a small constant was added to all values of these variables to compute the logit values. This constant was 0.5 (1-[largest value < 1]), which was small enough to have an inconsequential effect on results. The effect of all transformations on response variable distributions was assessed using box-plots.

The Direction of Movement response variable was a bearing value ranging from 0 to 360. We used the sine and cosine of the bearing to examine inshore-offshore movement as well as north and south alongshore movement patterns in relation to the explanatory variables.

To examine potential colinearity among covariates, pair-wise Pearson correlation coefficients (Table C. 1 - Table C. 3 *in* Appendix C) were computed between all continuous natural and continuous impact covariates. Box plots were computed between non-continuous (i.e., factors) natural covariates and continuous impact covariates, and *vice versa*. Contingency tables were computed between pairs of non-continuous variables. For all continuous variables within the respiration and movement data, none of the correlation coefficients were sufficiently large enough (> 0.60) to warrant concerns that natural variables were masking impact effects, or *vice versa*, in the models. However, within the abundance data, there was high correlation between nearshore sound and offshore sound variables. Therefore, only one offshore sound variable and only one nearshore sound variable was allowed to enter the abundance models.

Table 4. Transformations applied to response variables. Transformations were chosen to yield approximate symmetric distributions with as few outliers as possible. All logarithms were natural logarithms (i.e., base *e*).

Response Type	Response Variable	Transformation
Track line	Speed	Square root: sqrt.speed = $\sqrt{speed}$
	Acceleration	No transformation
	Linearity	Logit: logit.linearity = log[(linearity – c) / (1 – (linearity – c))], where c = 0.0001722 was used to prevent division by 0. Constant c equaled ½ difference between largest linearity <1.0 and 1.0.
	Mean Vector Length	Logit: logit.mvl = log[(mvl – c) / (1 – (mvl – c))], where c = 0.00005 was used to prevent division by 0. Constant c equaled ½ difference between largest mvl <1.0 and 1.0.
	Reorientation rate	No transformation
	Direction of Movement	No transformation
	Range	Log: log.range = log(range)
	Distance from shore	No transformation
Focal-follow	Respiratoin Interval	No transformation
	Surface time	Log: log.stime = log(stime)
	Dive time	Log: log.divetime = log(dive.time)
	Time At Surface	Log: log.timesurf = log(timesurf)
	Blows per surfacings	Log: log.bps = log(bps)
	Surface blow rate	Log: log.srate = log(srate)
	Dive-Surface blow rate	No transformation

Relationship of the Response Variables

In addition to the individual response variables, an approach was taken to combine the response variables into fewer predictors to evaluate if a combined response of speed, directionality, and range indicators could provide a better predictor of western gray whale movement and respiration as opposed to analyzing each response separately. This allowed us to investigate anthropogenic impacts by two modeling approaches: 1) models of individual movement, respiration, and scan response variables and 2) models of the combined responses of movement and respiration. We believe evaluating these data by both approaches increases the robustness and reliability of the results and the conclusions derived from the analyses.

Several of the movement and respiration variables were, however, correlated with one another and presented colinearity and other analytical challenges to incorporate into a multivariate model (i.e. $Y_1 + Y_2 + Y_{...} = X_1 + X_2 + X_{...}$). Therefore, Principal Component Analyses (PCA) were used in the respiration and movement models to reduce the dimensionality of all response variables taken together to one or two synthetic variables that capture the salient features of whale responses. PCA is a useful technique that identifies associations in the data that account for the largest amount of variation encapsulated by a (linear) combination of the individual response variables, and constructs a small set of uncorrelated variables (i.e. the principal component scores) which were then used as a response variable in the analysis. PCA analyses were conducted separately on the movement and respiration variables. Pearson's correlation matrices were computed for both the movement and respiration response variables to assist interpretation of the principal component loadings.

Multivariate Analyses of WGW Abundance and Behavior

The objective of the multivariate analyses was to evaluate associations between western gray whale abundance and behavioral responses and anthropogenic activities in the area. The primary focus was on the impact variables associated with sounds produced during the dredging and pipelay activity, but we also investigated the impacts of research vessels operating in or close to the feeding area. To accurately identify impacts, it was necessary to include for natural variation in behavior while assessing sources of impact. The modeling techniques were chosen due to the nature of the objectives and because autocorrelation was present in the response variables. The analytical approach deviated from past analyses of western gray whale behavior (Gailey *et al.* 2007b) by:

- using general mixed linear models as opposed to multivariate regression techniques
- simplifying the model from a two phase to a one phase modeling approach
- accounting for potential autocorrelation in the response variables
- including abundance of western gray whales as a response variable
- incorporating additional explanatory and impact variables (subject, vessel type, etc.)

Movement and Respirations – Table 1 outlines the eight response variables for movement and seven response variables for respiration. For the movement response variables, range and mean vector length were excluded from the analyses since those variables were highly correlated with speed (Pearsons = 0.99) and reorientation rate (Pearsons = -0.92), respectively. The number of blows per surfacing was excluded from the respiration models due to high correlation (Pearsons = 0.91) with surface time. All other individual responses were modeled using a mixed or generalized mixed linear models described below. In addition to individual response variables, the scores of bins along the principal components for movement and respiration were analyzed as response variables.

For continuous response variables whose distributions were approximately normal, mixed linear models (Pinheiro and Bates, 2000) were estimated to relate changes in the response to environmental (e.g., depth, wind speed) and industrial covariates (e.g. received sound levels, vessel distances). For response variables that were not normally distributed, they were either transformed to achieve approximate normality or generalized mixed linear models were estimated. Generalized mixed linear models are similar to regular mixed linear models but do not assume that responses are normally distributed and use generalized estimating equations (gee) for estimation. Both types of models account for autocorrelation of responses measured on consecutive bins within a track or focal follow. The (regular or generalized) mixed linear models for a particular response take the following general formula,

$$\mathbf{y}_i = \mathbf{X}_i\boldsymbol{\beta} + \mathbf{Z}_i \mathrm{b}_i + \boldsymbol{\varepsilon}_i,$$

where $\mathbf{y}_i$ was the vector of responses for track *i*, $\boldsymbol{\beta}$ is a vector of fixed effects coefficients, b_i is a random effect associated with the the i^{th} track that was assumed to be normally distributed, $\mathbf{X}_i$ contains the (fixed) covariates associated with track *i*, $\mathbf{Z}_i$ is a vector of 1's the same length as $\mathbf{y}_i$, and $\boldsymbol{\varepsilon}_i$ was the vector of random within-track errors that follows a normal distribution with mean $\mathbf{0}$ and covariance $\boldsymbol{\Sigma}$. The error matrix $\boldsymbol{\Sigma}$ was assumed to have either an unrestricted, constant, or auto-regressive structure. Estimations for all effects was obtained by the method of generalized estimating equations.

Depending on the regression model, two types of model selection were used: stepwise variable selection using approximate *t* tests and stepwise variable selection using the Bayesian Information Criteria (BIC). Stepwise BIC was used when mixed linear models were being estimated. Similarly to Akaike Information Criteria (AIC), BIC values impose a penalty term for the number of parameters, which helps prevent overfitting. However, BIC is a more conservative estimate of model fit than AIC and generally produces models with fewer terms. Regular stepwise variable selection based on Wald *t* tests was used when generalized mixed linear models were being estimated. Regular stepwise selection was used in this case because a likelihood value, and hence BIC, cannot be explicitly calculated for generalized mixed linear models. Stepwise variable selection adds or removes variables based on *t*-test of the β-value associated with the variable under consideration.

In Stepwise BIC selection, both natural and impact effects were chosen based on a series of forward additive steps, with alpha-to-enter =0.15, and backward looks, with alpha-to-exit = 0.15. Each forward step started with the model resulting from the previous step, and added variables not already in the model, one at a time. The BIC was computed for each model, and the variable that reduced BIC the most was added to the current model. Following this forward step process, a backward step was conducted whereby all variables already in the current model were dropped one at a time. BIC was recomputed from each reduced model, and if removal of at least one variable reduced BIC, the variable that reduced BIC most was removed from the model. The model at the end of the backward step became the new model for the next forward step. This cycle of forward and backward steps was repeated until no variable reduced BIC. Once this occurred, stepwise selection was stopped and the current model was fixed as the final model. The initial model contained an intercept only. Estimation was conducted by the method of least squares. Standardized residual plots were inspected to assess model fit.

Scans – The response variables of whale abundance consisted of the number of whales per scan observation, the mean distance from shore of the sighted whales, and the number of pods per scan observation. Due to high correlation between the number of whales per scan and the number of pods per scan (Pearsons = 0.96), the number of pods was excluded from the analysis. Due to differences in data collection approaches, the broad scale and fine scale datasets were analyzed together with data collection approach (fine or broad) as a covariate. The fine scale approach was analyzed as a separate model. Generalized mixed linear models of the same type described above was estimated for relative abundance (number of individuals per scan). These models related relative abundance to environmental and industrial covariates, and account for potential auto-correlation between consecutive scans. Distance from shore was analyzed using regular mixed linear models.

In the abundance dataset, two data collection approaches were taken: 1) a broad scale – one sample per station per day and 2) fine scale – multiple samples for three stations per day. These approaches were analyzed together with data collection approach (fine or broad) as a covariate. The fine scale approach was also analyzed as a separate model. Models were selected using the data from both approaches and then re-selected using only the data from the fine scale sampling approach. No weights were used in modeling of abundance derived from the scan data because whales were not continuously sampled. A mixed liner model was used to model the mean distance from shore derived from the number of whales observed during a scan. These models were chosen based upon maximizing the normal likelihood and using stepwise BIC selection. The correlation structure of the error matrix was assumed to be a continuous auto-regressive structure (Continuous AR(1)) among groups sighted on the same scan on the same day at the same station. Station effects were modeled as random in the offshore distance models.

Generalized mixed linear models of the same type described above were estimated for relative abundance (number of individuals per scan). Since abundance is a count variable, the Poisson distribution was assumed. These models related relative abundance to environmental and industrial covariates, and accounted for potential autocorrelation among scans

A stepwise process was used to select variables in the relative abundance generalized mixed liner models. Selection was based upon forwards and backwards steps, but instead of BIC, the variable's corresponding *t*-value and *p*-value was assessed. During the forward step process, the variable with the lowest *p*-value was added to the model, provided it was below a specified minimum of 0.15. If one level of a factor had the minimum p-value less than 0.15, all levels were added to the model. During backward steps, a factor was removed if all p-values associated with its levels were greater than 0.15. The forward and backward stepwise process was repeated until the addition of no variables yielded a p-value less than 0.15. If the variable entering the model was a nearshore or offshore sound variable, then all other corresponding nearshore or offshore sound variables were excluded from the list of possible variables. For the abundance model, the correlation structure was assumed to be auto-regressive (AR(1)) among scans conducted on the same day. The station variable was included in the random part of the model.

Results

Distribution Response and Explanatory Variables

The univariate (empirical) distribution of each impact variable was computed to provide an overall indication of amounts and levels of impact variables to which western gray whales were exposed. The average sound levels for nearshore research vessels at a gray whale's location was 96 dB re µPa with a range of 79 to 127 dB re µPa for movement sessions, and a mean of 102 dB re µPa ranging from 63 to 136 dB re µPa for focal sessions. The closest observed approach between vessels and whales was 0.4 and 2.8 km for the track and focal data, respectively. The number of vessels within 5 km of a gray whale being monitored ranged from 0 to 2 vessels. Western gray whale speed of movement was on average 2.1 km/h with a maximum observed speed of 10.4 km/h.

During two hours preceding a scan, whales were exposed to a mean of 135 dB re µPa (range 113 - 166 dB re µPa) from nearshore vessels and a mean of 145 dB re µPa (range 105- 176 dB re µPa) from construction activity. Sound level exposures for other durations (8 hour, 1 day, 3 day, etc.) as well as distributions related to other impact variables can be found in Appendix B.

Relationship among the Response Variables (PCA)

The numbers of response variables analyzed were potentially inter-related. To understand these relationships and examine the benefits of combining response variables, both, Pearsons correlation and Principle Component Analyses were conducted.

For movement, speed and range were highly correlated (Pearsons = 0.98) variables (Table 5). These variables could be substantially different. For example, an animal moving at relatively high speeds in random directions would likely not move far spatially, producing high speeds with low range index. However, for western gray whales, low speeds tend to indicate that an animal is feeding in a localized area which results in smaller geographic range index, while higher speeds tend to be more directional with higher range indices which subsequently provide high correlations among these two variables. The two directional responses (mean vector length (TrackR) and Linearity (Lin)) were correlated with one another (Pearsons = 0.77, Table 5). Mean vector length compares angular differences to a mean direction (0 = great scatter and 1 = all movements in the same direction), while linearity evaluates directionality by distance traveled over the distances "made good" geographically. Although the indices are very similar, one may be a more sensitive index compared to another. As speed increases, western gray whales tend to move more directionally with low values of reorientation rate (changes in direction per minute) (Table 5). Such a movement pattern is indicative of traveling behavior.

The first principal component for the movement variables was largely interpreted to explain behavior related movement patterns. The lowest scores for the first component were largely classified in the field as traveling behavior while the highest scores were observed to be feeding behavior and intermittent scores consisted of mixed and/or feeding/traveling behavior. Therefore, the first principal component largely contrasts feeding versus traveling behavior (Figure 2 and Table 6).

The second principal component of movement was interpreted to contrast two different modes of traveling behavior. Bins with low scores on the second principal component were largely associated with straight-line steady traveling behavior while bins with high scores were largely associated with high acceleration. These changes in speed were also associated with high ranging index, reorientation rate, and speed. Taken together, high scores on the second principal component indicate multi-speed and multi-directional travel which could be associated with feeding/traveling behavior or feeding in patchy environment or on a different prey source (i.e. Mysid feeding) (Figure 2 and Table 6).

The first two principal components for movement accounted for 80% of the total variation encapsulated by six movement variables. Interpretation of components beyond the second component was difficult. We believe the remaining principal components of movement (principal components 3 through 6) attempted to encapsulate random variation and therefore these components were not considered as a response variable in further analyses (Table 6).

Table 5. Pearsons correlation matrix of the movement response variables.

Variable	DistFromShore	Speed	Acc	RR	Lin	TrackR	Range
DistFromShore	1	0.15	-0.04	-0.06	-0.03	0	0.11
Speed	0.15	1	0.18	-0.52	0.47	0.5	0.99
Acc	-0.04	0.18	1	-0.02	0.05	0.03	0.17
RR	-0.06	-0.52	-0.02	1	-0.78	-0.92	-0.58
Lin	-0.03	0.47	0.05	-0.78	1	0.77	0.55
TrackR	0	0.5	0.03	-0.92	0.77	1	0.57
Range	0.11	0.99	0.17	-0.58	0.55	0.57	1

Table 6. PCA loadings and importance of components for movement variables of western gray whales.

Component	1	2	3	4	5	6
Speed	-0.423	0.393	0.446			0.683
Acc		0.718	-0.692			
RR	0.464	0.281	0.213	0.375	-0.721	
Lin	-0.435	-0.244	-0.249	0.827		
TrackR	-0.459	-0.284	-0.239	-0.415	-0.692	
Range	-0.448	0.334	0.397			-0.727
Standard Deviation	1.918	1.068	0.906	0.518	0.289	0.082
Proportion of Variance	0.613	0.19	0.137	0.045	0.014	0.001
Cumulative Proportion	0.613	0.803	0.94	0.985	0.999	1

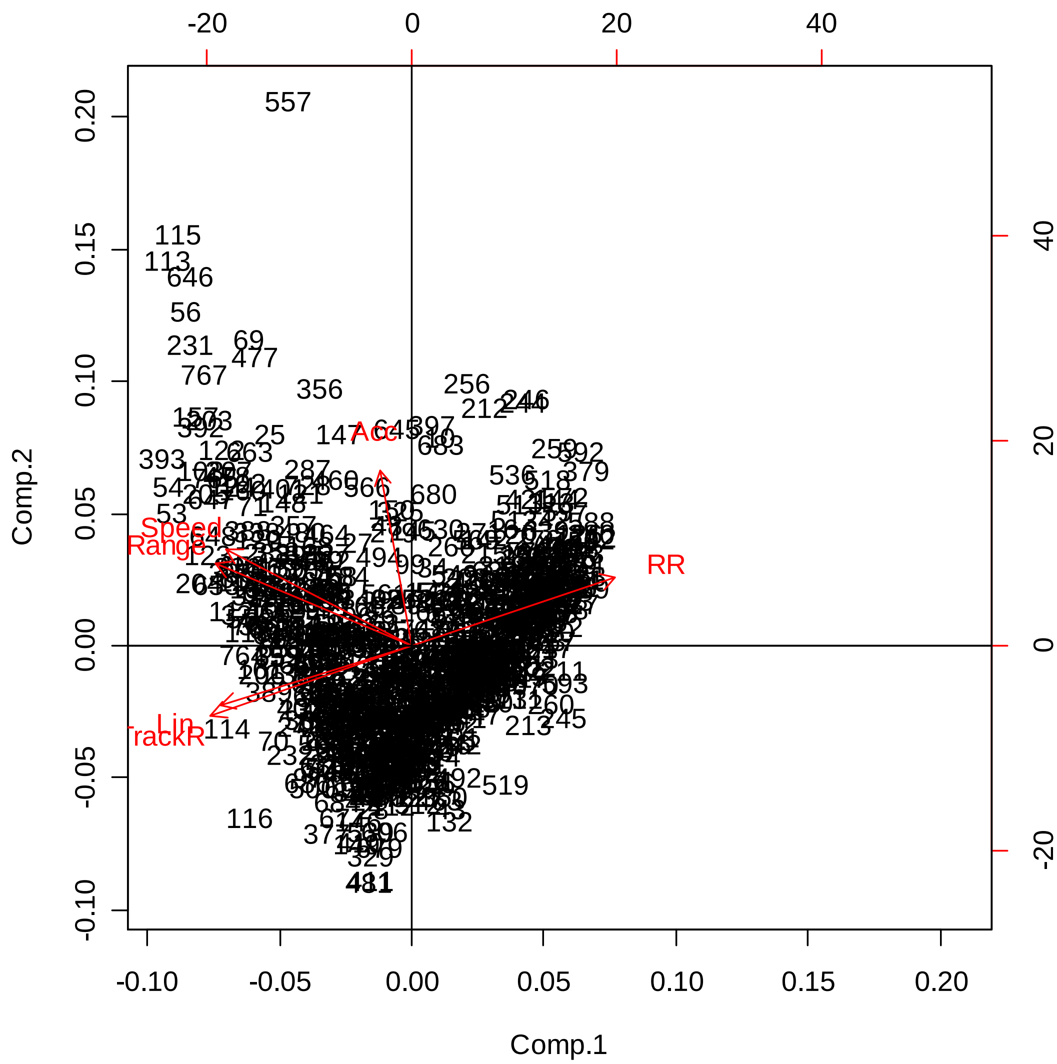


Figure 2. Bi-plot of the first two principal components of western gray whale movement variables.

For respiration response variables, surface time was highly correlated (Pearsons = 0.82) with the percent time at surface for a bin. So, the longer an animal was observed at the surface, the percent time of surface time increased correspondingly. In addition, with increasing surface time, the number of observed blows increased (Pearsons = 0.91, Table 7).

The principal component analyses indicated that as the dive duration increased, western gray whale’s time intervals between subsequent blows (RI), the overall surface time (Surfs), the number of blows per surfacing (NumSurfs), and percent time at the surface (TimeAtSurf) tends to decrease (Figure 3, Table 8). This could be indicative of whales cycling through their surfacings quicker to increase foraging efficiency.

As the interval between blows increased (RI), the time interval an animal remains at the surface increases. As western gray whales spend more time at the surface with an increase number of blows, the surface blow rate (# blows/surface time) tends to decrease. With longer dives, shorter surface time, and smaller number of blows per surfacing, the dive-surface blow rate (#blows/(dive time + surface time) decreases.

The first principal component of the respiration variables was interpreted to primarily contrast respiration behavior required by feeding versus respiration required by non-feeding activities. Low scores on the first respiration principal component tended to have longer dives and generally less time at the surface while high scores spend more time at the surface (Figure 3, Table 8).

The second principal component contrasted whales with large respiration intervals (RI) with all other respiration behaviors (Figure 3, Table 8). Bins with large scores on the second component tended to have high respiration intervals while low scores tended to have low respiration intervals. Consequently, the second principal component was interpreted to largely reflect respiration interval.

The third principal component reflected variation in surface-dive rate only. The first three principal components explained a large portion (88%) of the total variation encompassed by all respiration variables. Because analyses were conducted on both principal component scores and individual variables (see Model below), only the first principal component of respiration was analyzed. In other words, the second component was primarily contrasting respiration interval and the third component primarily contrasted surface-dive blow rate and these individuals variables are being analyzed separately. Therefore, the second and third components were not used in the analyses. Variation in components 3 through 7 were largely captured by variation in individual variables (Table 8).

Table 7. Pearsons correlation matrix of respiration patterns of western gray whales.

Variable	DistFromShore	RI	Surfs	Dives	NumSurfs	SRate	SDRate	TimeAtSurf
DistFromShore	1	-0.14	0.07	0.38	0.23	0.07	-0.01	-0.02
RI	-0.14	1	0.54	-0.47	0.26	-0.71	0.08	0.63

Surfs	0.07	0.54	1	-0.22	0.91	-0.49	0.42	0.82
Dives	0.38	-0.47	-0.22	1	0.03	0.26	-0.35	-0.41
NumSurfs	0.23	0.26	0.91	0.03	1	-0.33	0.54	0.7
SRate	0.07	-0.71	-0.49	0.26	-0.33	1	-0.12	-0.55
SDRate	-0.01	0.08	0.42	-0.35	0.54	-0.12	1	0.47
TimeAtSurf	-0.02	0.63	0.82	-0.41	0.7	-0.55	0.47	1

Table 8. PCA loadings and importance of components for respiration patterns of western gray whales.

Component	**1**	**2**	**3**	**4**	**5**	**6**	**7**
RI	-0.374	0.491	0.156		0.675	-0.338	-0.129
Surfs	-0.466	-0.244	0.180	0.324	-0.195	-0.292	0.687
Dives	0.234	-0.436	0.670	-0.280	0.430	0.142	0.155
NumSurfs	-0.400	-0.494	0.176		-0.176	-0.264	-0.677
SRate	0.352	-0.373	-0.329	0.673	0.412		
SDRate	-0.283	-0.368	-0.596	-0.544	0.319		0.162
TimeAtSurf	-0.474			0.231	0.136	0.837	
Standard Deviation	1.944	1.168	1.011	0.654	0.456	0.418	0.148
Proportion of Variance	0.54	0.195	0.146	0.061	0.029	0.025	0.003
Cumulative Proportion	0.54	0.735	0.881	0.942	0.971	0.999	1

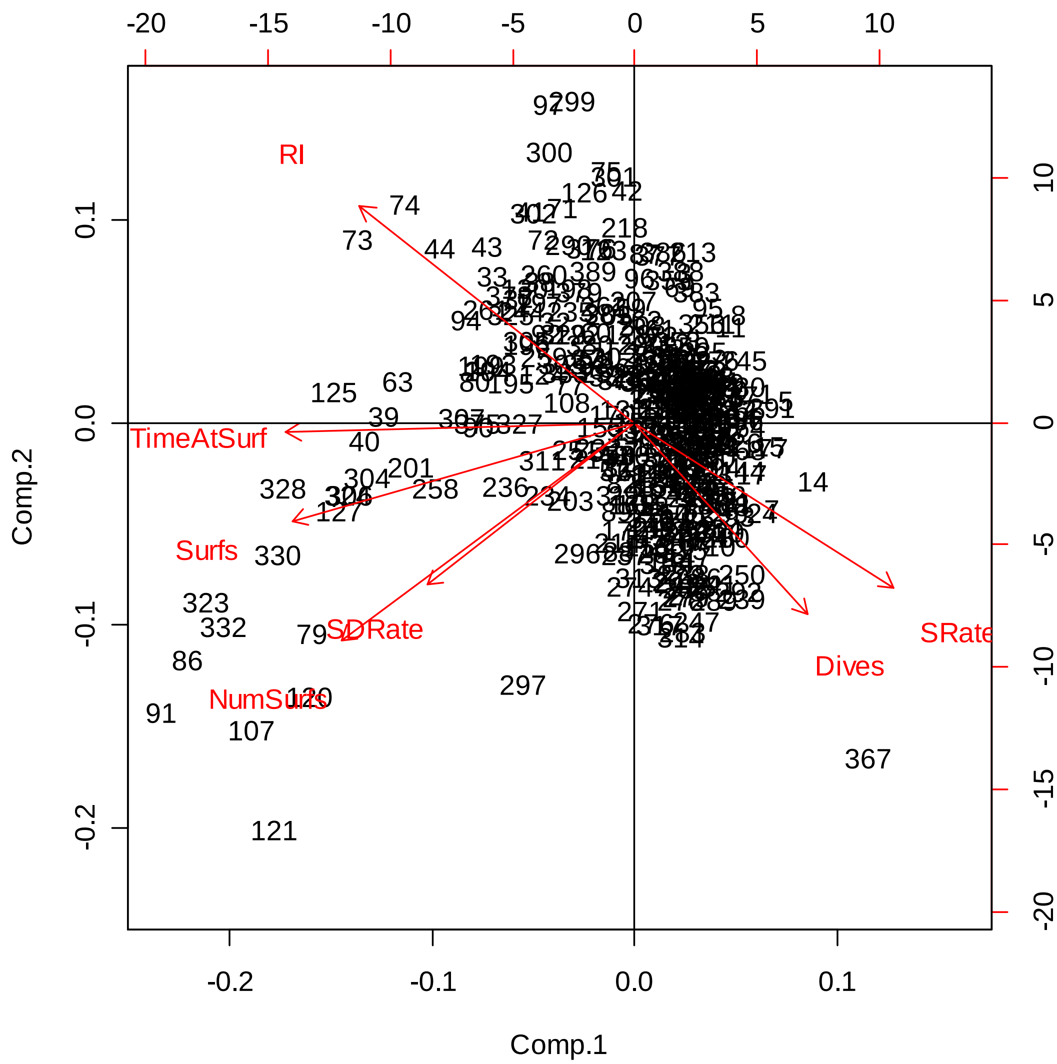


Figure 3. Bi-plot of the first two principal components of respiration patterns of western gray whales.

Principal Component Analyses were not conducted on the relative abundance variables. There was high correlation (Pearsons = 0.96) between the number of whales and pods observed during a scan (Table 9). This result was not surprising considering that the majority of gray whale sightings were identified as single animals. However, the number of pods/whales observed appeared to have no relationship with their mean distance from shore (Table 9). The number of pods was removed as a response variable from further analyses.

Table 9. Pearsons correlation of abundance response variables.

Variable	Pods	Individuals	Distfromshore

Pods	1	0.957	-0.0455
Individuals	0.957	1	-0.429
Distfromshore	-0.0455	-0.429	1

Movement Models

Of the 13 explanatory variables of natural variation in western gray whale movement, the behavioral state of the whale (feeding, feeding/traveling, traveling, and mixed) was the most dominant predictor for three of the individual response variables and both of the combined response variables. In general, coefficients of the movement models (Table 10.) indicate that gray whales' speeds increased, linearity increased, and reorientation decreased when whales changed from feeding activity to feeding/traveling to traveling behaviors. Behavioral states were not associated with acceleration, distance from shore, and either alongshore or shoreward direction of movement.

None of the explanatory variables met the criteria for predicting acceleration and whale movement inshore-offshore. Tide height was associated with whale movement alongshore. Speed also appeared to be higher for animals observed at increasing distances from the observation platform.

Geographically, whales were observed at different distances from shore. In general, the animals observed towards the southern portion of the observation region were observed further from shore then those animals observed in the northern part of the study area. Depth was also associated with the distance from shore model indicating that those animals observed further from shore were typically in deeper waters.

The first principal component (PC1) was interpreted to primarily contrast feeding and traveling behavior where lower scores were associated with traveling behavior, while higher values were associated with feeding behavior. The natural variables that entered the final principal component models were behavior, distance from station, and wind speed. When comparing among the different behaviors, the coefficient had the lowest value compared to the reference feeding behavior, which was consistent with the interpretation of the principal component scores.

The second principal component (PC2) of movement was interpreted to contrast multi-speed and multi-directional travel (higher values) with a more linear mode of traveling (lower values). Behavioral state, depth, and distance from station were the only natural covariates that entered into the PC2 model.

Coefficients for distance from station in both the PC1 and PC2 models indicated that whales tended to display feeding behavior closer to shore and more linear travel further away from shore.

One impact variable was associated with one of the movement (PC1) response variables indicating that as construction sound increased, whales tended to be observed having more feeding-like behavior.

Table 10. Regression models for western gray whale movement responses. Variables selected for inclusion were natural variables (Error! Reference source not found.**) and were chosen by a stepwise BIC procedure.**

Variable	PC1		PC2		Acceleration		Direction (Sin)		Direction (Cos)		Distance From Shore*		Linearity (logit)		Reorientation Rate		Speed (sqrt)	
	β	p	β	p	β	p	β	p	β	p	β	p	β	p	β	p	β	p
(Intercept)	0.5057	0.3047	-0.0905	0.5981	0.0068	0.2196	0.0155	0.5654	0.2670	0.0003	0.2005	0.0053	0.0741	0.5334	39.5683	0.0000	0.4869	0.0000
Behavior (Reference = Feeding)																		
Feeding/Traveling	-1.5830	0.0000	-0.4880	0.0000									1.6425	0.0000	-16.77321	0.0000	0.2844	0.0000
Mixed	-1.7116	0.0000	-0.0182	0.9071									1.6322	0.0000	-14.9827	0.0000	0.3670	0.0000
Traveling	-3.1065	0.0000	-0.2361	0.0348									2.9840	0.0000	-27.5563	0.0000	0.8021	0.0000
Depth			-0.0476	0.0077							0.1229	0.0000						
Distance from Station	-0.3637	0.0001	0.3770	0.0000													0.2458	0.0000
Sound Offshore	0.0142	0.0031																
Station (Reference = 1st Station)																		
2nd Station											-0.0612	0.4732						
Campsite Station											0.1666	0.1699						
Chaivo Station											0.7654	0.0000						
North Station											-0.3700	0.0008						
Odoptu Station											-0.3580	0.0000						
Pipeline Station											0.5113	0.0000						
South Station											0.0757	0.3920						
Station07											-0.1853	0.0236						
TideHeight									0.4219	0.0002								
WindSpeed	0.0302	0.0019																

Response (spans all response columns)

*Distance From Shore model did not include Distance from Station in variable selection due to high multicollinearity.

Respiration Models

Model coefficients and corresponding p-values for variables in the focal follow models can be seen in Table 11. Of the natural variables, time of day was the most dominate predictor of respiration. In fact, time of day was associated with almost all the respiration models. Time of day was the only variable associated with dive-surface blow rate, surface time, and time at surface respiration models indicating that as the day proceeded, whales tended to spend less time at the surface. The positive coefficients of time of day associated with dive time and surface blow rate indicated animals were spending more time underwater. The inclusion of the time of day was likely a result of observing similar activities, such as feeding, later as the day proceeded.

Natural variables included in the final respiration principal component model included behavior and time of day (Table 11). Recall that higher scores along PC1 meant that whales tended to spend more time at the surface, while lower scores meant longer dives and less time at the surface. The positive coefficient for time of day implied that whales tended to spend more time at the surface later in the day.

Respiration interval was the only respiration response that was found to be associated with one of the impact variable (sound offshore). The negative coefficient indicates that as offshore sound levels increased, whales decreased their duration between exhalations (Table 11).

Coefficients in the dive model indicated that the duration of the dive increased as depth increased (Table 11). As the water depth generally increases in the area as a function of distance from shore, and gray whales appear to have spent more time underwater, potentially related to bottom-feeding activity, in deeper waters. Distance from station was associated with the surface blow rate (Table 4). The coefficient for distance to station indicated that as distance from the station increased, number of blows per surfacing increased.

Table 11. Regression models for western gray whale respiration parameters resulting from model fitting. Variables selected for inclusion were natural and impact variables (Table 2) and were chosen by a stepwise BIC procedure.

	Response													
Variable	**PC1**		**Dive-Surface Blow Rate**		**Dive Time** (log)		**Respiration Interval**		**Surface Blow Rate** (log)		**Surface Time** (log)		**Time At Surface** (log)	
	β	**p**	**β**	**p**	**β**	**p**	**β**	**p**	**β**	**p**	**β**	**p**	**β**	**p**
(Intercept)	-1.2819	0.0970	1.5233	0.0000	0.0002	0.9992	0.4750	0.0000	1.1077	0.0000	0.8642	0.0088	3.7612	0.0000
Behavior (Reference = Feeding)														
Feeding/Traveling	-0.4949	0.0523					0.0432	0.0331	-0.1698	0.0080				
Mixed	-0.5228	0.0980					0.0455	0.0171	-0.1127	0.1287				
Traveling	-1.6259	0.0000					0.1803	0.0000	-0.4885	0.0000				
Depth					0.4330	0.0000								
Distance From Station									0.0858	0.0152				
Sound Offshore							-0.0021	0.0100						
Time of Day	0.1467	0.0073	-0.0243	0.0031	0.0299	0.0060			0.0334	0.0079	-0.0662	0.0060	-0.0455	0.0057

Abundance Models

Model coefficients and corresponding p-values for the abundance models are provided in Table 12.

For the models that included both fine and broad scale datasets, animals were observed to be further from shore as the tide height decreased. A dataset affect was found with the distance from shore model indicated the broad dataset saw animals further away then the fine dataset. However, the number of whales were not found to be different between the datasets. Gray whales were observed to decrease their distance to shore as a result of being exposed to increased cumulative sound exposure from nearshore research vessels in the preceding 3 days. In addition, the number of whales increased as they were exposed to increased cumulative sounds associated with the research vessels in the preceding day. The number of whales also increased as the number of weeks since the onset of construction activity.

For the models that only contained the fine scale dataset, the number of whales was found to decrease as the number of vessels increased. As with the combined dataset, the number of whales were observed to generally increase as the weeks of construction activity continued. Offshore sound cumulated over 2 hours was negatively associated with distance from shore, suggesting that gray whales ventured closer to shore when offshore sound levels increased.

Table 12. Regression models for abundance and distance from shore parameters.* Variables selected for inclusion were natural and impact related (Table 3) and were chosen by a stepwise t procedure.

	Response							
Variable	**DistFromShore (both)**		**DistFromShore (fine)**		**Individuals (both)**		**Individuals (fine)**	
	β	**p**	**β**	**p**	**β**	**p**	**β**	**p**
(Intercept)	2.5025	0.0000	3.2119	0.0000	-1.1592	0.1314	0.9930	0.0000
Scan Vessels*							-0.0329	0.0000
Team (Reference=Behavior)								
Scan	0.2397	0.0005						
TideHeight	-0.2399	0.0030						
WeekSince					0.0425	0.0005	0.0809	0.0000
X1d_NS_10					0.0163	0.0026		
X3d_NS_10	-0.0070	0.0059						
X2h_OS_10			-0.0124	0.0000				
X1d_OS_10								
X3d_OS_10								

*Scan Vessels was excluded from the list of possible covariates for models when both datasets were included.

Discussion

Response Variables

The PCA results indicate that several of the response variables were inter-related. As a gray whales speed increases, the range at which they traverse correspondingly increases. In addition, both of the directionality indices (Linearity and Mean Vector Length) were highly associated with one another. As the reorientation rate increases (i.e. the whale changing direction more frequently), the directionality indices correspondingly decreases. Taken together, the PCA analyses captured the relationship of movement while animals are in different modes of behavior. A gray whale that is traveling is usually moving with directional persistence with higher speeds compared to a gray whale that is feeding in a benthic rich area where they remain in one spot and change directions frequently.

Acceleration has been shown from these and previous analyses, to have no relationship with any of the explanatory or response variables. While gray whales are engaged in a particular activity, such as traveling, they tend to move consistently. Therefore, the speed of the animal changes little over time. In other words, an animal that is traveling, travels consistently from one 10.5 min. bin to the next. However, this does not imply that acceleration is not a useful response variable to consider while assessing potential impacts of western gray whale behavior. In fact, Gailey *et al.* (2006) found higher acceleration as vessels approached within 500 m of a whale which illustrates that the whales increased their speed of movement as the vessel approached compared to previous observations.

As western gray whales increased their dive duration they correspondingly decreased their intervals between respirations. This association is likely associated with benthic feeding, where individuals attempt to decrease their surface time (i.e. time needed to replenish oxygen/purge carbon dioxide supply) in order to return back to their benthic prey resource. Correspondingly, the surface time and time at the surface variables decrease in relation to increasing dive time. Shorting the surface time while increasing the dive time would be an effective strategy to increase foraging efficiency. This pattern of decreasing the surface time and increasing the dive time may also occur in bouts, where an animal consistently feeds at this rate for some time, then takes a "break" or resting periods to recover. When gray whales are feeding, a common repeating respiration pattern is a 3-5 blow sequence for one surfacing, a single blow for the second surfacing, back to a 3-5 blow sequence third surfacing, and so on. This single blow sequence would have contributed to the decreased surface time and increased dive time pattern.

The total number of whales seen during a scan survey was highly correlated with the number of pods. Approximately 80% of the sightings of western gray whales in 2006 were of single whales. With the exception of mother-calf pairs, gray whales tend to be solitary on their feeding grounds. Gray whales are not known to be a highly social species with pairs or groups occurring more frequently during migration and on the breeding grounds (Jones and Swartz, 2002). However, if a particular prey dense area is found, feeding aggregations can occur. In addition, socializing behavior tends to form larger groups, but such behavior is infrequently seen on the feeding grounds (approximately 2-8 times during a feeding season) and usually occurs in the latter part of the feeding season (late August-early October).

Natural variation

The behavioral state of the focal animal was the largest predictor of movement and respiration patterns. This was consistent with a previous univariate analyses that examined differences among activities (see Gailey *et al.* 2007c) and previous multivariate analyses (Gailey *et al.* 2007b). Since behavioral states were generally characterized by observing a animal's movement and respiration patterns during its brief periods at the surface, the behavioral characterization may be influenced by the very response variables that we are attempting to explain. Consequently, we acknowledge that some (unquantified) circularity may have been introduced by including behavioral state as a natural predictor for responses such as speed, reorientation rate, and linearity. We included behavioral state of the animal as a predictor, despite some circularity in its definition, because these activities were "normal" for western gray whales and we were interested in explaining aberrant behavior associated with anthropogenic variables. Several previous studies also demonstrated that whales may respond differently depending on their current behavioral activity. For example, resting whales are more likely to be disturbed by sounds than animals engaged in foraging and social activity (NRC 2003, Richardson *et al.* 1995).

We reasoned *a priori* that if behavioral states entered a model, the model would be immediately interpretable and anthropogenic activity, if also included as a strong predictor, would explain aberrant behavior within the behavioral state categories. For example, anthropogenic sound could explain why a particular whale's speed was higher than that normally observed for traveling whales. In other words, we could estimate that traveling whales normally do so at a speed of *X* km/h, then in effect check for association between higher (or lower) speeds for traveling whales in the presence of higher (or lower) anthropogenic sound levels. We are confident that the amount of circularity present in behavioral states is small and does not diminish our ability to detect industrial effects. Empirical evidence supports this position since a substantial amount of variation remained in the models when behavioral states were included.

Water depth explained a large amount of variation in both dive duration and the distance from shore models. Water depth does generally increases as a function of distance from shore. Correspondingly, benthic feeding gray whales observed in deeper waters increased their dive durations. Past observations of western gray whales indicated that they dive approximately 1.0 minute shorter, on average, than eastern gray whales. It was hypothesized that this difference in dive time was due to the very shallow nature of the western gray whale study area (for example, Weller *et al.* 1999). Indeed, Würsig *et al.* (1986) found a general increase in eastern gray whale dive time in deeper (> 20 m) water, which agrees with the dive time model presented here. Dolphin (1987) also found correlations of humpback whale (*Megaptera novaeangliae*) dive duration and depth of prey target patches. The relationship may be related to the extended time to reach the prey source in deeper waters.

Distance from station was included as an explanatory variable in the model for surface blow rate indicating more blows or shorter surface time as a whale was observed further from the station. As the distance the observation platform increases, the observer's ability to identify a respiration event could potentially decrease. However, this potential distance bias should have decreased the number of blows seen. It is unclear why the number of blows would have increased with increasing distance from the observation platform. Since about one-half of whales observed were generally in deeper water, this relationship may be due to a general depth-related surface/dive pattern, and may thus represent a real phenomenon. Indeed, Würsig *et al.* (1986) found that whales in deeper water also had slightly longer surface times and concomitant greater numbers of blows/surfacing. Perhaps whales that dive longer in deeper water require more breaths at the surface to offset increased oxygen needs (Wartzok 2002). Interestingly, the distance from station was also found to be associated with the number of blows/surfacing in previous analyses (Gailey *et al.* 2007b) with increasing number of blows as a function of increasing distance from the observer.

Time of day entered into 6 of the 7 respiration models. Respiration interval was the only variable which was unaffected by the time of day. As the day progressed from morning to evening, whales were observed to increase their dive duration and surface blow rate while decreasing their time at the surface and the dive-surface blow rate. This association could be related to increased foraging activity as the day progressed. Migrating gray whales have been observed to have diel variation with larger pod sizes and increased distance from shore during the day (Perryman *et al.* 1999). However, Perryman *et al.* (1999) did not find any changes in surfacing intervals for migrating gray whales as reported here. This difference could be related to the different activities of migration and feeding behaviors. With increased lighting during the day, gray whales could potentially identify prey species more efficiently and therefore, feed more throughout the day and less during low lighting and night time periods. Stelle (2008) and Guerrero (1989) have also suggested increasing resting periods at night for feeding eastern gray whales.

Compared to the previous multivariate analyses of western gray whale behavior, the variables that entered into the model were highly consistent. The whales speed, reorientation rate, linearity, respiration interval, and surface blow rate were found to be associated with the behavioral state of the animal. Acceleration, distance from shore, dive-surface blow rate, and dive time were not found to have differences when animals were engaged in different activities. However, compared to the previous multivariate analyses, the behavioral state was found to be associated with surface time, while there was no association found in the current analyses. Time of day was not found to be associated with any of the respiration variables in the 2005 analyses, but the temporal explanatory variable entered into most of the respiration models for the 2006 analyses. Such differences could be related to sample size as three teams collected data for a longer field season in 2006 and less data was included, due to data sampling issues, in the 2005 analyses. Alternatively, differences in analytical approach could be another explanation. However, we believe the changes in the type of model and procedures had little effect on the overall results and variable inclusion in the models.

Despite differences in analytical approach, the coefficients that explain the amount of variation in each response variable were remarkably similar to the previous multivariate analyses on western gray whale movement and respiration patterns. For example, when comparing the speed of the whale while feeding compared to traveling, the coefficient was 0.80 and the coefficient for comparing feeding to feeding/traveling was 0.28 in 2006. The 2005 analyses found the coefficients to be 0.83 and 0.31, respectively. The other coefficients for behavioral states that entered into the models were remarkably similar in magnitude to the previous example.

As part of the review of previous behavioral analyses (see WGWAP 1/INF2, WGWAP2 report), several additional explanatory and response variables were suggested and incorporated, when feasible, to the current analyses. Subject (adults, mother-calf pair, yearling, etc.) was not found to significantly explain variation in any of the models. Out of the 139 tracklines, thirteen (9%) tracks were of mother-calf pairs and five (4%) of yearlings. The remaining tracks were adults or unknown individuals. In 2006, only four mother-calf pairs were identified with only four potential yearlings from calves observed in 2005 (Yakovlev *et al.* 2007). This limiting sample size may have provided low statistical power to detect differences in behavioral patterns. Increased sample size could provide additional insights in future analyses.

In 2006, few observations of nearshore (research) vessel activity was observed. In fact, only two tracks observed zodiacs within 5 km of western gray whales and only two samples observed any vessel within 1 km of a focal whale. Previous analyses (Gailey *et al.* 2007b) suggested that as a vessel approached within 0.5 km of a whale, an animal's speed significantly increased relative to when vessels were at greater distances. Due to the limited number of observations of vessel activity within 0.5 km of a whale, it is unknown if this vessel affect continued in 2006. From other studies, gray whales have been noted to respond to nearby (generally less than 0.5 km) vessel activity (see Moore and Clark 2002). Such a response to vessels can be obvious in the field. For example, an animal can be tracked for several hours with consistent movement and behavior prior to an approaching vessel and then alter their behavior and movement when the vessel is nearby. These vessel-whale interactions tend to be short-term and arguably not biologically significant, but may become truly disruptive if the disturbance becomes frequent enough.

Direction of movement (north-south, east-west) and percent time at the surface were additional individual response variables compared to previous analyses. The percent time at the surface largely reflected the results of surface time. These two variables also had a relatively high correlation (Pearsons = 0.82). Almost none of the explanatory variables were found to be significantly associated with inshore-offshore or alongshore movement patterns.

The abundance models suggest there was a team affect with the broad scale data observing whales further from shore compared to the fine scale data. The mean distance to shore also suggested that as tide levels increased, the whales distance relative to the coastline decreased. One of the fundamental analytical difficulties with analyzing sound levels in this study was that they were spatially associated. Sounds generated from research vessel activity was concentrated in the northern region and progressively smaller contributions to the southern part of the study area. Sounds associated with dredging and pipeline construction had the opposite pattern, with more sounds to the south with less or higher exposure values to the northern region. This resulted in colliearity issues of adding station and sound levels into the same model. For the team effect, the broad scale data have more observation platforms with higher elevations to the north and could see whales further from those platforms. These differences likely contributed to the observed team affect.

Anthropogenic Impact

In 2006, there was a large number of vessels operating near the western gray whale feeding grounds. The location of these vessels and activities varied with research vessels conducting research on western gray whales, dredging spreads offshore for part of the feeding season, and a nearshore dredger that remained for the entire feeding season. Gray whale could potentially react differently to the location and activities of these vessels. For example, Tyack and Clark (1998) found differences in avoidance by migrating eastern gray whales when the sound source was placed in the migratory path compared to when it was placed seaward of the migratory pathway. Comparatively, sounds generated by research vessels operating inside their primary feeding grounds may not have the same impacts on gray whale movement and behavior as sounds generated from construction. Other baleen whales, such as fin and right whales, have also been noticed to tolerate stationary sound sources, such as the nearshore dredger, more than sound sources that are moving towards them (Watkins 1986). For this reason, we attempted to separate sound levels associated with research vessels conducting observations compared to those sound levels associated with pipeline construction activity. Previous analyses (Gailey *et al.* 2007b) lumped all sounds levels regardless of the source which hindered the ability to detect important reactions from a particular sound source or activity.

When examining potential impacts, the models consisted of both variables that could potentially explain natural variation and variables that could examine responses to sounds and vessel activity during the pipeline construction. This approach deviated from the analytical approach in Gailey *et al.* (2007b), where a two step model selection process was taken to initially account for the "natural" variation prior to inclusion of the "impact" variables. The inclusion of natural variables prior to testing anthropogenic effects could either hinder or help our ability to test for industrial impacts. Overall, we believe the approach taken provided similar results to the previous analytical approach while simplifying the overall model.

Sound level was found to have significantly affect respiration patterns in the gray whales observed during the construction activity. As the offshore (construction) sound level increased, western gray whales were observed to shorten their time between respirations. Williams *et al.* (2009) also found a similar association with killer whales decreasing their inter-breath interval in relation to increasing vessel activity. The decrease in respiration interval could be akin to panting behavior or stress in response to the sound exposure or at the very least a higher energetic state.

For the abundance models, vessel activity entered into the models with respect to the fine scale data. The model suggested that as the number of vessels increased, the number whales in the area decreased. To represent auditory fatigue, a variable WeekSince was included to provide a temporal component from the onset of construction activity. Both the fine and broad scale data found more whales to be in the area from the onset of construction. In addition, the abundance of whales was found to increase as sound levels increased. This pattern may be a result of whales arriving to the feeding area as construction started as early as feasibly possible (June) so that few whales were in the area, but as the feeding season progressed more whales were observed on the feeding grounds.

The distance from shore was not found to be associated with any of the anthropogenic sound levels for the movement and respiration models. Distance from shore was, however, significantly associated with sound levels in previous analyses of western gray whale behavior (Gailey *et al.* 2007 a,b). These previous studies indicated that as the sound exposure levels increased, gray whales were predicted to be further from shore. Distance from shore was significantly associated with research vessels on a three day scale indicating a closer distance to shore with increasing sound exposure from the vessel that frequently seen in the same area. The fine scale data also suggested a closer distance to shore for sounds generated from construction activity in the preceding two hours. However, as previously mentioned, this result could be a station effect with whales being closer to shore in the northern part of the study area as opposed to a response to sound. The positive coefficients do reflect a more offshore distance from shore for those whales exposed to areas of higher offshore construction activity. In fact, for the movement data, distance from shore was significantly associated with geographic locations with whales generally being further from shore in the southern part of the study area and closer to shore in the northern part of the study area. It is known from other studies that both marine and land mammals can feel “hemmed in” by a perceived danger, and will often edge away by moving into more open, unfettered space where presumably they can run, or swim, in any direction (Würsig and Evans 2001).

Biological Significance

Conceptual models, such as the Population Consequences of Acoustic Disturbance (PCAD) model, are important tools that provide a structure to evaluate potential consequences of anthropogenic activity in regards to biologically significant affects (Figure 4). Although some understanding of relationships between sound and behavioral responses of baleen whale populations exists; with the expectation of loss of life, the relationship between these associations and their potential effects on life history functions and vital rates are largely unknown for marine mammal populations (NRC 2005). In other words, the PCAD model is not a predictive mathematical tool, but rather a tool to help structure evaluations of biological significance.

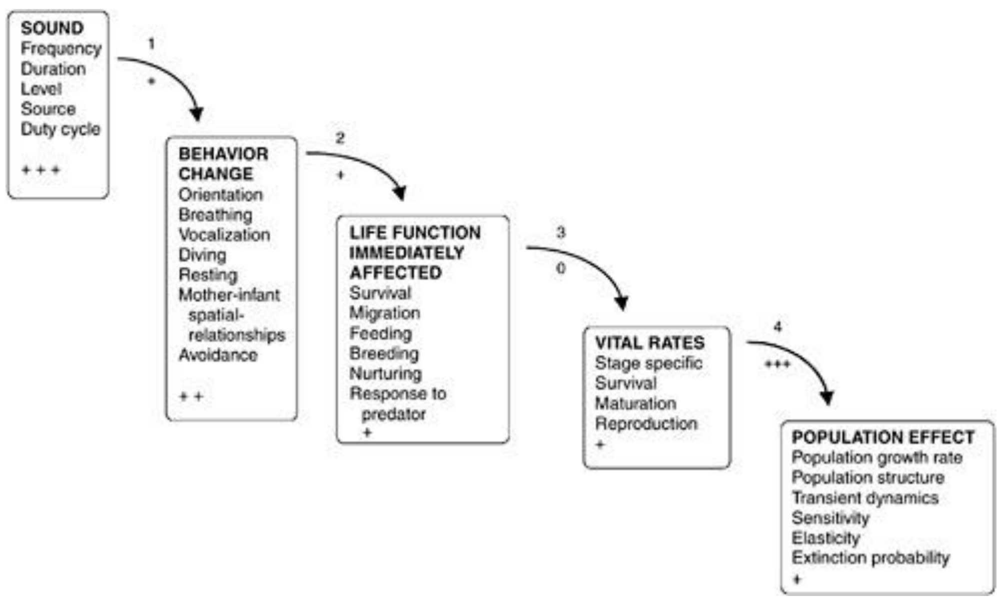


Figure 4. The conceptual Population Consequences of Acoustic Disturbance model that illustrates stages required to relate acoustic disturbances to effects on marine mammal populations. Taken from NRC(2005).

Any behavioral change obviously has associated costs to the individuals since the energy invested to avoid the disturbance could have been invested towards other needs, such as acquiring more food. In addition, repetitive exposure to a stimulus that elicits behavioral response has the potential of causing cumulative stress or could have the reverse effect of habituation. Even short-term responses that have the potential to separate mom-calf pairs could become biologically significant (NRC 2003). However, it is extremely difficult to attribute the immediate response of an individual to biologically significant parameters such as decreased foraging efficiency, growth, survivability, reproductive successes, etc., since the result occurs on a much larger temporal and spatial scale than the immediate response alone (NRC 2005). In addition, unknown physiological factors such as stress and cumulative exposure may lead to biological significant effects.

The objective of this study was to examine if construction sound or proximity of vessels that elicit behavioral response potentially affected the animals ability to feed, which is the primary activity of this endangered population during this time period. Our focus here has been on the behavioral effects and it is important to recognize that animals will tolerate small disturbances assuming they do not reach a threshold that affects feeding, compromises survival, reproduction of the animals, etc. Since behavioral response indicators are likely the first signs of disturbance that could lead to diminished feeding activity, we believe this is a good management approach towards protecting this population.

Sounds generated by vessels continually operating in one area with relatively longer durations of exposure may elicit a different response to vessels traveling through the nearshore area with shorter durations of exposure. Continual exposure of sound may lead to habituation of certain individuals, but also could lead to abandonment of frequently exposed areas by other more sensitive individuals to anthropogenic activity (for example, Bejder *et al.* 2006). It should also be recognized that not all individuals may react in the same manner and there is likely individual variation to a particular stimulus. For example, mothers with calves are likely to be more sensitive than other individuals. Skinny whales may stay in an area that is particularly disturbing or physiologically damaging compared to other individual due to their immediate need to replenish their energy reserves.

The respiration model did indicate associations between intervals between breathing and sound. This increase in rate of breathing could be associated with stress and prolonged exposure could have biological significant consequence. For animals that are already stressed, such as skinny whales, the contributed stress could ultimately be detrimental in the long-term survivability or reproductive success of a whale.

Out of the fifteen movement and respiration response variables, only one indicated a strong association with sound levels. This could suggest that the affects, if existed, were rather minimal and arguably not biological significant at a population level. Multiple response variables, such as those found in Gailey *et al.* 2007a, would be more indicative of a strong response to anthropogenic activity. As in all studies that fail to reject a null hypothesis of no impact, anthropogenic sound could have affected these behavioral parameters but our data set did not contain enough information to conclusively identify that the effect existed.

Conclusions

We believe this study provides insights that examine changes in western gray whales abundance, movement, and respiration. This report highlights that there is a great deal of natural variation as well as some associations with anthropogenic activity.

Our results indicate that the primary behavioral effects observed during the 2006 dredging and pipe-laying construction were those associated with a decreased respiration interval which could be an indicator of stress. This suggests that if sounds were consistently high enough and individuals continued to remain near the activity, there could have been some biological consequences. However, the effect could have been more short-term with animal's moving out of the area. Gray whale movement patterns from previous years suggest that they typically spend a relatively short time period remaining in one localized area. Unlike the 2005 construction season, there were few obvious indicators (i.e. breaching, rapid movement, etc.) of disturbance from the construction activity monitored in the field that would have raised concerns of impact to individuals or to the western gray whale population.

From our analyses of the western gray whale behavior in nearshore waters off the northeastern coast of Sakhalin Island during pipeline construction, we draw the following conclusions:

(1) There were no detectable effects of increased anthropogenic underwater sounds on any of the individual movement response variables.

(2) There was a detectable effect in gray whale's respiration patterns with whale's breathing at a faster rate which could indicate a stress response or at least a higher energetic state with higher sound level exposure.

(3) None of the combined or individual response movement and respiration variables were found to be associated with the nearshore sound levels or vessel (# vessel, closest distance, type of vessel, etc.) activity.

(4) As the number of vessels within 5 km increased, the number of whales were observed to decrease.

A few general caveats apply to the results of this study. The methodologies employed here collected data on a single individual or group at a time. Ideally, we would have collected information on a random sample of individuals from the population, but this was impossible without unique identifiers or real-time tracking of all individuals of the population. If the cumulative set of individuals we observed were not representative of the entire population, our results would not apply to the entire population. However, we have no reason to believe that the individuals we observed were non-representative of the entire population, and in fact we believe we collected information on a large fraction of the individuals in the population. A second caveat is that we weighted the number of bins to the individual in an attempt to account for inclusion bias issues (see methods) and to minimize pseudoreplication. We argue that weighting to the individual would likely produce a more accurate result than simply ignoring these biases, but we acknowledge that weighting itself is unlikely to be perfect.

We also acknowledge analytical difficulties in the abundance models that yielded results that are largely inconclusive. We believe alternative methods need to be employed to account for the complexities of whale abundance in combination with the activities that could potentially impact the number of whales feeding in different areas. However, such models need to account for the degree of daily and seasonal abundance variation that has been observed for this population on their summering feeding grounds.

Recommendations

Vessels that are operating near gray whales on their feeding grounds can be disruptive by not only the sound levels that are produced but also the distance of approach. In addition, as the number of vessels increases, a cumulative effect will increase as well. As noted previously, there was limited amount of detailed positional data for all construction and other vessels operating near the feeding area. There should be a conscious effort to minimize both the time that vessels are within the feeding grounds of western gray whales, and the number of simultaneous vessels operating within one localized area. It is critically important that any vessel operating within the nearshore feeding area should keep detailed records of vessel movements and activities. This will not only improve the accuracy of determining received sound levels and evaluating impacts on the behavior of western gray whales, but also provide a record of the extent and duration of such activity for the entire season.

Perhaps the most important consideration to account for natural variation in gray whale abundance and behavioral patterns on their feeding grounds is prey availability and concentration. Data collected on gray whale prey distribution and biomass in the western gray whale feeding grounds identifies relationships between food availability and shifts in whale distribution on the feeding grounds (Fadeev 2005-2010). However, little quantitative analyses have been conducted to date.

Analyses of western gray whale abundance, distribution, and behavior have been conducted annually with assessment of potential impact focused on a single anthropogenic event (i.e. CGBS installation in 2005, pipeline construction in 2006, etc.). One of the limiting factors of these annual analyses is sample size to account for both natural and anthropogenic effects. It is believed a multi-annual dataset would provide increased sample size and provide additional insights into changes in western gray whale habitat use and movement patterns.

Acknowledgments

We acknowledge Lisanne Aerts, Doug Bell, Koen Broker, James Hall, Vladimir Nechayuck, Rodger Melton, and Judy Muir for assisting with all phases of the study. We are grateful for the valuable comments and suggestions provided by Jonathan Gordon, Mike Lonergan, Bruce Mate, AEAT, and the WGWAP panel that helped improve upon the analytical approach. This project was jointly funded by Sakhalin Energy Investment Company (SEIC) and Exxon-Mobil Neftgas.

Literature Cited

Belsley, D.A., E. Kuh, and R.E. Welsch. 1980. *Regression Diagnostics: Identifying Influential Data and Sources of Collinearity*. New York: Wiley.

Bejder. L. A. Samuels, H. Whitehead, and N. Gales. 2006. Interpreting short-term behavioural responses to disturbance within a longitudinal perspective. Animal Behaviour 72(5):1149-1158.

Cain, M.L. 1989. The analysis of angular data in ecological field studies. Ecology(70): 1540-1543.

Dolphin, W.F. 1987. Ventilation and dive patterns of humpback whales, *Megaptera novaeangliae*, on their Alaskan feeding grounds. Can. J. Zool. 65(1): 83-90.

Fadeev. V.I. 2005. Benthos and prey studies in feeding grounds of the Okhotsk-Korean population of gray whales. Marine biology institute (The Far East Branch), Russian Academy of Sciences. Vladivostok, Russia. .

Fadeev. V.I. 2006. Benthos and prey studies in feeding grounds of the Okhotsk-Korean population of gray whales. Marine biology institute (The Far East Branch), Russian Academy of Sciences. Vladivostok, Russia.

Fadeev. V.I. 2007. Benthos and prey studies in feeding grounds of the Okhotsk-Korean population of gray whales. Marine biology institute (The Far East Branch), Russian Academy of Sciences. Vladivostok, Russia.

Fadeev. V.I. 2008. Benthos and prey studies in feeding grounds of the Okhotsk-Korean population of gray whales. Marine biology institute (The Far East Branch), Russian Academy of Sciences. Vladivostok, Russia.

Fadeev. V.I. 2009. Benthos and prey studies in feeding grounds of the Okhotsk-Korean population of gray whales. Marine biology institute (The Far East Branch), Russian Academy of Sciences. Vladivostok, Russia.

Fadeev. V.I. 2010. Benthos and prey studies in feeding grounds of the Okhotsk-Korean population of gray whales. Marine biology institute (The Far East Branch), Russian Academy of Sciences. Vladivostok, Russia.

Gailey, G., O. Sychenko, and B. Würsig. 2006. Western gray whale behavior, movement, and occurrence patterns off Sakhalin Island, 2005, Prepared for LGL ecological research associates Ltd, for Exxon-Neftegas Ltd. and Sakhalin Energy Investment Company, Yuzhno-Sakhalinsk, Russian Federation.

Gailey, G., B. Würsig and T. McDonald. 2007a. Abundance, behavior, and movement patterns of western gray whales in relation to a 3-D seismic survey, Northeast Sakhalin Island, Russia. Environmental Monitoring and Assessment.

Gailey, G., T. McDonald, R. Racca, O. Sychenko, A. Rutenko, and B. Würsig. 2007b. Influences of Underwater Sound and Nearshore Vessel Activity on Western Gray Whale Behavior during the Installation of a Concrete Gravity Based Structure off Sakhalin Island, Summer 2005. Prepared for LGL ecological research associates Ltd, for Exxon-Neftegas Ltd. and Sakhalin Energy Investment Company, Yuzhno-Sakhalinsk, Russian Federation. 150 pp.

Gailey, G., O. Sychenko, and B. Würsig. 2007c. Western gray whale behavior, movement, and occurrence patterns off Sakhalin Island, 2006, Prepared for LGL ecological research associates Ltd, for Exxon-Neftegas Ltd. and Sakhalin Energy Investment Company, Yuzhno-Sakhalinsk, Russian Federation.

Guerrero, J.A. 1989. Feeding behavior of gray whales in relation to patch dynamics of their benthic prey. M.Sc. thesis, San Jose State University. 49 pp.

Horvitz, D. G. and D. J Thompson. 1952. A generalization of sampling without replacement from a finite universe. Journal of the American Statistical Association, 47:663-685.

Jahoda, M., C. Lafortuna, N. Biassoni, C. Almirante, A. Azzellino, S. Panigada, M. Zanardelli, and G. Nortarbartolo Di Sciara. 2003. Mediterranean fin whale's (Balaenoptera Physalus) response to small vessels and biopsy sampling assessed through passive tracking and timing of respiration. Marine Mammal Science 19(1): 96-110.

Johnson, S.R., W.J. Richardson, S.B. Yazvenko, S.A. Blokhin, G. Gailey, M. Jenkerson, S.K. Meier, H.R. Melton, M. Newcomer, A.S. Perlov, S.A. Rutenko, B. Würsig, C.R. Martin, and D.E. Egging. *Submitted*. A western gray whale mitigation and monitoring program for a 3-D seismic survey, Sakhalin Island, Russia. Environmental Monitoring and Assessment.

Jones, M.L. and S..L. Swartz. 2002. Gray Whale (*Eschrichtius robustus*). Pp. 524-536 in The Encyclopedia of Marine Mammals, ed. by W.F. Perrin, B. Würsig, and J.G.M. Thewissen, Academic Press, San Diego, CA.

Malme, C.I., B. Würsig, J.E. Bird and P. Tyack. 1986. Behavioral responses of gray whales to industrial noise: feeding observations and predictive modeling. Outer Continental Shelf Environmental Assessment Program, Final report of Principal Investigators, NOAA.

Malme, C.I., Würsig, B., Bird, J.E. and Tyack, P. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure.pp. 55-73. *In:* W.M. Sackinger, M.O. Jefferies, J.L. Imm and S.D. Treacy (eds.) Vol. 2. *Port and*

Ocean Engineering under Arctic Conditions. University of Alaska, Fairbanks, AK. 111pp.

Moore, S.E. and Clarke, J.T. 2002. Potential impact of offshore human activities on gray whales (*Eschrichtius robustus*). J. Cetacean Res. Manage. 4, 19-25.

NRC. 2003. Ocean noise and marine mammals. The National Academic Press. Washington, D.C. 192 pp.

NRC. 2005. Marine mammal populations and ocean noise: Determining when noise causes biologically significant effects. The National Academic Press. Washington, D.C. 126 pp.

Overton, W. S., and S.V. Stehman. 1995. The Horvitz-Thompson Theorem as a Unifying Perspective for Probability Sampling: With Examples from Natural Resource Sampling. The American Statistician. 49:261-268.

Perryman, W.L., M.A. Donahue, J.L. Laake, and T.E. Martin. Diel variation in migration rates of eastern Pacific gray whales measured with thermal imaging sensors. Marine Mammal Science 15(2): 426-445.

Pinheiro, J. C. and D. M. Bates (2000) *Mixed-Effects Models in S and S-PLUS*, Springer.

Richardson, W.J. and B. Würsig. 1995. Significance of responses and noise impacts, pp. 387-424, Ch. 11 of Marine Mammals and Noise, by W.J. Richardson, C.R. Greene Jr., C.I. Malme, and D.H. Thomson. Academic Press, San Diego, CA.

Rutenko. 2007. Acoustic Studies on the North East Sakhalin Shelf. Final report to Exxon Neftegas and Sakhalin Energy Investment Company. Yuzhno-Sakhalinsk, Russia. 79pp.

Stelle, L.L., W.M. Megill, and M.R. Kinzel. 2008. Activity budget and diving behavior of gray whales (Eschrichtius robustus) in feeding grounds off coastal British Columbia. Marine Mammal Science 24(3): 462-478.

Turchin, P. 1998. Quantitative Analysis of Movement. Sinauer Associates, Sunderland, Massachusetts. 396pp.

Tyack, P.L. and C.W. Clark. 1998. *Quick-look report: Playback of low-frequency sound to gray whales migrating past the central California coast*. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Vladimirov, V.A., S.P. Starodymov, A.T. Ashchepkov, A.G. Afanasyev-Grigoriyv, J.E. Muir, and A.V. Vladimirov. 2007. Distribution and abundance of gray whales of the Okhotsk-Korean population in the waters of northeastern Sakhalin Island during June – October 2006 (based in data from onshore and vessel-based surveys). Final report to Exxon Neftegas and Sakhalin Energy Investment Company. Yuzhno-Sakhalinsk, Russia.

Wartzok, D. 2002. Breathing. Pp. 165-168 in Encyclopedia of Marine Mammals, ed. By. W.F. Perrin, B. Würsig and T.J.M. Thewissen. Academic Press, New York, NY.

Watkins, W.A. 1986. Whale reactions to human activities in Cape Cod waters. Marine Mammal Science. 2:251-262.

Weller, D.W., B. Würsig, A.L. Bradford, A.M. Burdin, S.A. Blokhin, H. Minakuchi, and R.L. Brownell, Jr. 1999. Gray whales (*Eschrichtius robustus*) off Sakhalin Island, Russia: Seasonal and annual occurrence patterns. Mar. Mamm. Sci. 15:1208-1227.

Weller, D.W., A.M. Burdin, A.L. Bradford, G.A. Tsidulko, and Y.V. Ivashchenko. 2002. Gray whales off Sakhalin Island, Russia: June-September 2001. A Joint U.S. – Russia Scientific Investigation. Final contract report to Sakhalin Energy Investment Company (unpublished). 51pp.

Weller, D.W., S.H. Rickards, A.M. Bradford, A.M. Burdin, and R.L. Brownell, Jr. 2005. The influence of 1997 seismic surveys on the behaviour of western gray whales off Sakhalin Island, Russia. IWC SC/58/E4.

Williams, R., D.E. Bain, J.C. Smith, and D. Lusseau. 2009. Effects of vessels on behaviour patterns of individual southern resident killer whales *Orcinus orca*. Endangered Species Research 6: 199-209.

Würsig, B., R.S. Wells and D.A. Croll. 1986. Behavior of gray whales summering near St. Lawrence Island, Bering Sea. Canadian Journal of Zoology 64:611-621.

Würsig, B., D. Weller, A. Burdin, S. Blokhin, S. Reeve, A. Bradford, and R. Brownell, Jr. 1999. Gray whales summering off Sakhalin Island, Far East Russia: July-October 1997. A joint U.S.-Russian scientific investigation. Final Contract Report to Sakhalin Energy Investment Company and Exxon Neftegas (unpublished). 101 pp.

Würsig, B. and P.G.H. Evans. 2001. Cetaceans and humans: Influence of noise. Pp. 565-587 in Marine Mammals: Biology and Conservation, ed. By. P.G.H. Evans and J.A. Raga. Plenum Press, New York, NY.

Würsig, B., G. Gailey, T. McDonald, R. Nielson, J.G. Ortega-Ortiz, P. Wainwright, M. Jenkerson, O. Sychenko, K. Tarasyan, and N. Brown. 2002. Western gray whale occurrence patterns and behavior: Shore-based observations off Sakhalin Island, August-September 2001. Prepared by LGL ecological research associates Ltd, for

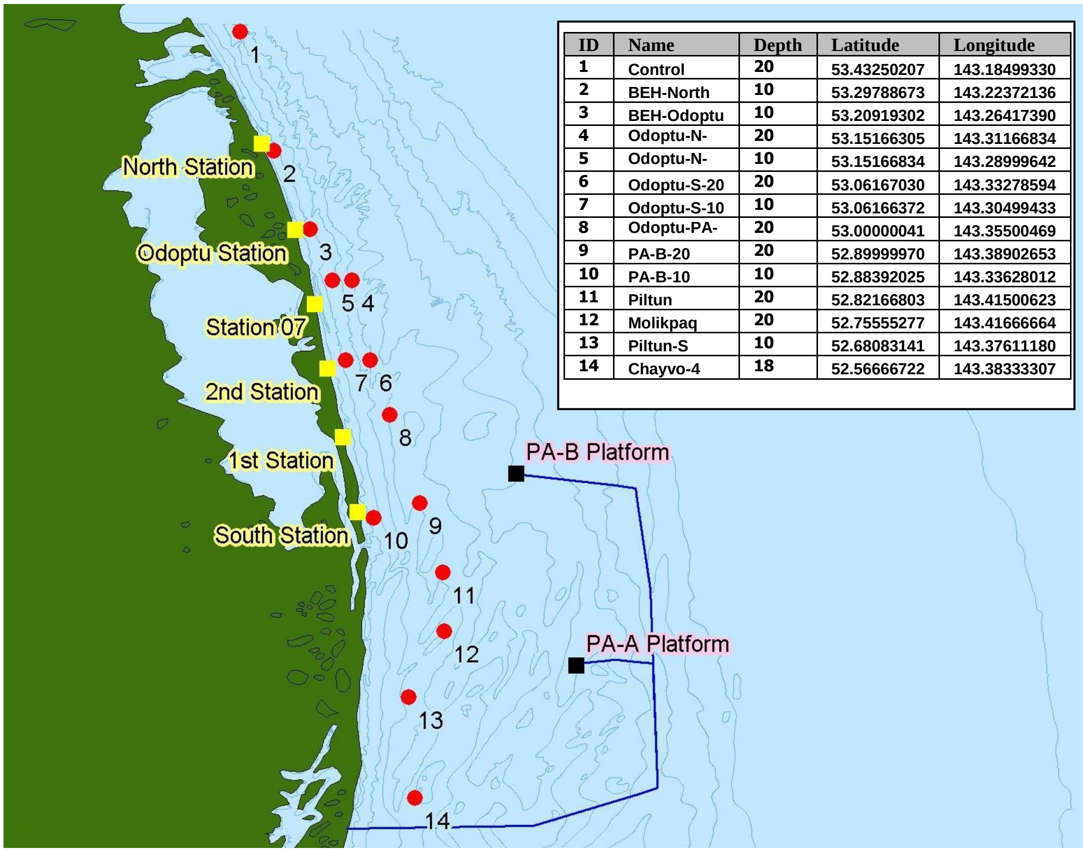
Exxon-Neftegas Ltd. and Sakhalin Energy Investment Company, Yuzhno-Sakhalinsk, Russian Federation.

Yakovlev, Y., O. Tyurneva, and V. Vertyankin. 2007. Photographic identification of the Korean-Okhotsk gray whale (*Eschrichtius robustus*) offshore northeast Sakhalin Island and southeastern Kamchatka, Russia, 2006. Final report to Exxon Neftegas and Sakhalin Energy Investment Company. Yuzhno-Sakhalinsk, Russia. 99pp.

Appendix A: Acoustic Energy Estimation to Whale Locations

Acoustic Recorder Deployment

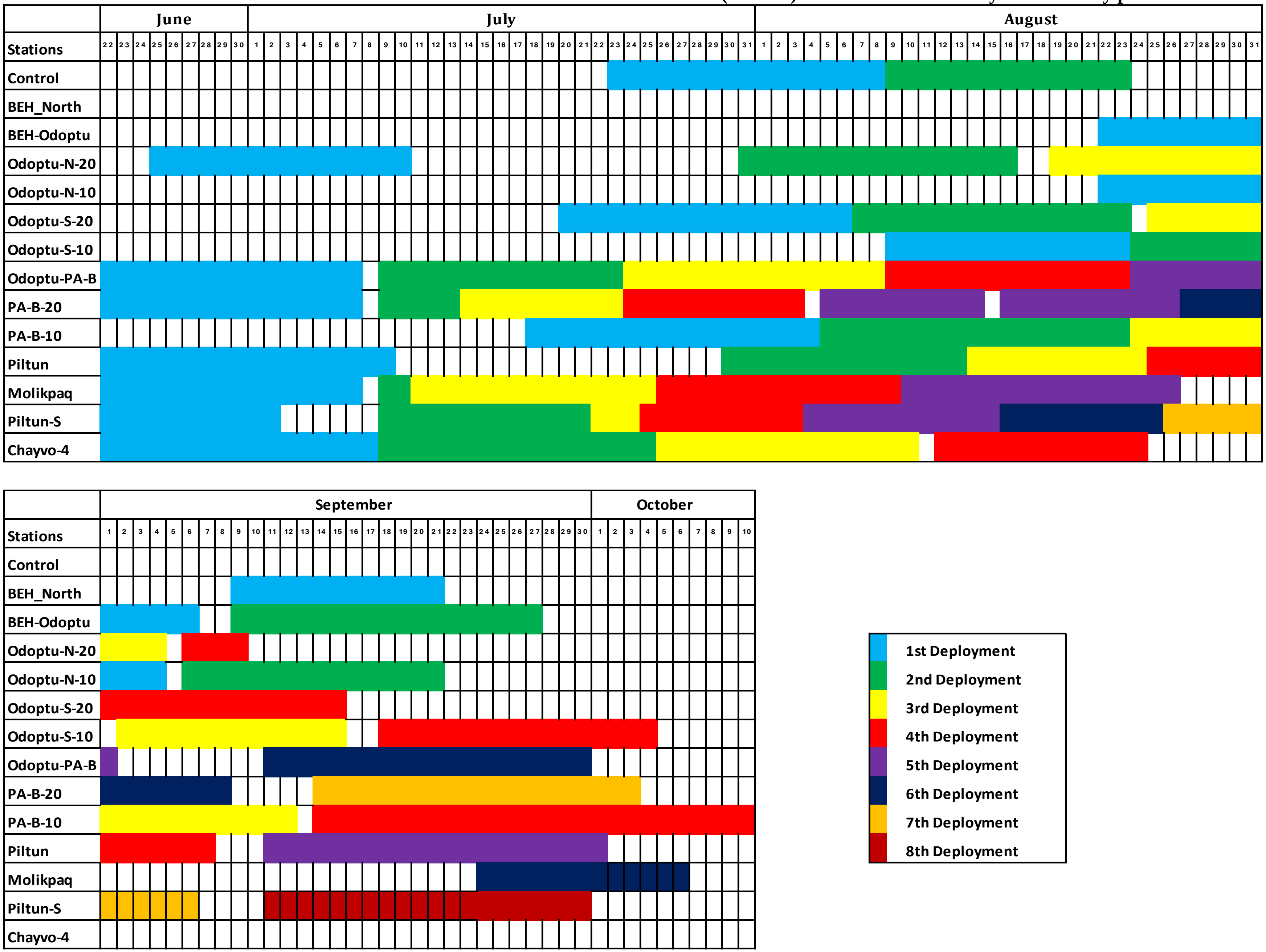
One-minute broadband acoustic energy levels at the 14 locations shown in Figure A 1 were provided by the acoustics team of the Pacific Oceanological Institute from continuous measurements made by autonomous underwater acoustic recorders, or AUARs, deployed during the 2006 field season. The AUARs were designed to enable accurate, autonomous, synchronous acoustic measurements over a broad range of frequencies (20 Hz – 15 kHz). The primary AUAR storage medium was an 80-120 GB rotating platter hard drive to which data were written periodically when the buffer memory (a 1 GB flash memory drive) was full. Due to the single-port design (no simultaneous I/O) of the flash memory, this resulted in 22-minute gaps in the data every 4.3 hours. The AUARs were serviced on an approximately biweekly schedule to replace the batteries and to download the data. Servicing caused relatively short (of the order of several hours) periods of downtime in their operation. Some of the AUARs were deployed for only part of the season. Table A. 1 provides an overview of the periods of data availability for all the AUARs used in this study, with the proviso that the start and end days of each period would only have partial coverage due to the redeployment downtime.



ID	Name	Depth	Latitude	Longitude
1	Control	20	53.43250207	143.18499330
2	BEH-North	10	53.29788673	143.22372136
3	BEH-Odoptu	10	53.20919302	143.26417390
4	Odoptu-N-	20	53.15166305	143.31166834
5	Odoptu-N-	10	53.15166834	143.28999642
6	Odoptu-S-20	20	53.06167030	143.33278594
7	Odoptu-S-10	10	53.06166372	143.30499433
8	Odoptu-PA-	20	53.00000041	143.35500469
9	PA-B-20	20	52.89999970	143.38902653
10	PA-B-10	10	52.88392025	143.33628012
11	Piltun	20	52.82166803	143.41500623
12	Molikpaq	20	52.75555277	143.41666664
13	Piltun-S	10	52.68083141	143.37611180
14	Chayvo-4	18	52.56666722	143.38333307

Figure A 1. Nominal location of the autonomous underwater acoustic recorders (AUARs).

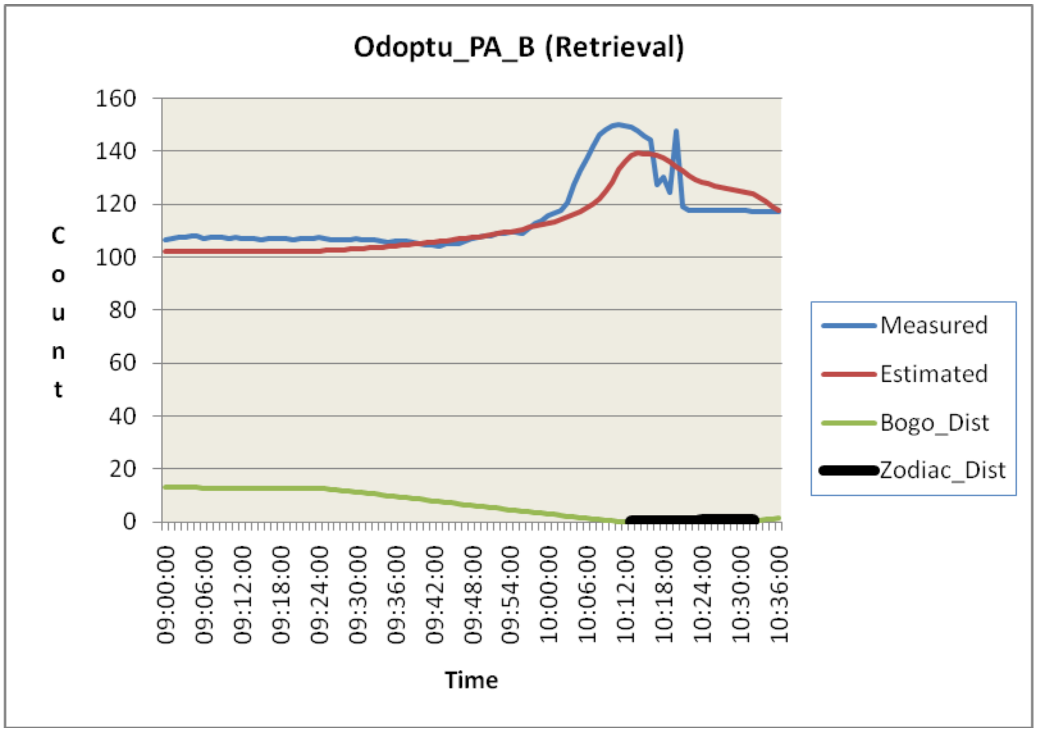
Table A. 1. Periods when data were available from autonomous underwater acoustic recorders (AUARs). Note that start/end days contain only partial data.



Method of Estimation

A hybrid approach was used to estimate underwater sound levels at points of interest (e.g. focal follow observation points) using a combination of direct acoustic measurements at AUAR locations and numerical modelling of sound level variations over the region of interest. Sound distribution was modelled assuming the acoustic field consisted of nearshore sound sources (in the form of nearby research vessels) and a quasi-static offshore scenario (based on activities and vessel traffic far from shore). This assumption is reasonable given that offshore activities are relatively far from the region of interest (more than 8 km) and occasional displacement of vessels there would have only a minor effect on nearshore sound distribution, while the acoustic footprint from nearby vessels (within 5 km) could significantly affect local sound level, depending on proximity. The 2006 offshore construction season was divided temporally into ten scenarios based on vessel activities that included a combination of pipeline trench dredging and pipelaying. Received sound levels at all AUAR locations and points of interest (focal points, scan points, tracks) were modeled using the scenario definitions through full runs of the parabolic equation underwater acoustic propagation model MONM (JASCO Applied Sciences).

Full numerical modelling of nearshore sound levels from research vessels *Academik Oparin* and *Professor Bogorov*, which routinely operated in the proximity of the feeding area, would have been computationally prohibitive. A simplified broadband attenuation law given by received level = source level - 17 $\log_{10}$R, where R is the distance in metres from the vessel to the receiver point, was used instead. The approximation was found to fit modeled transmission loss curves over a range of relevant distances. The source level was based on measurements of transit conditions at normal speed. While this may overestimate noise when a ship is operating on low power or is stationary, a study of vessel noise level for AUAR retrieval and deployment suggests that the assumption is indeed reasonable. This study also shows that the local noise contribution from the zodiac (semi-rigid outboard inflatable vessel) used to approach the AUAR locations to facilitate retrieval was negligible. A plot of measured and estimated sound levels during a close vessel approach typical of AUAR retrieval and deployment is shown below (Figure A 2). As can be seen from Figure A 2 (a) the acoustic footprint of the *Bogorov's* zodiac operating within sighting distance from the ship did not significantly affect measured sound level, as the noise generated by the main vessel entirely dominates that fromthe smaller craft. Similar studies also showed that another zodiac used for Photo ID studies did not significantly affect measured sound level even when transiting at relatively close range from an AUAR. These smaller craft were therefore not considered in the acoustic levels estimation process for the purpose of these analyses.



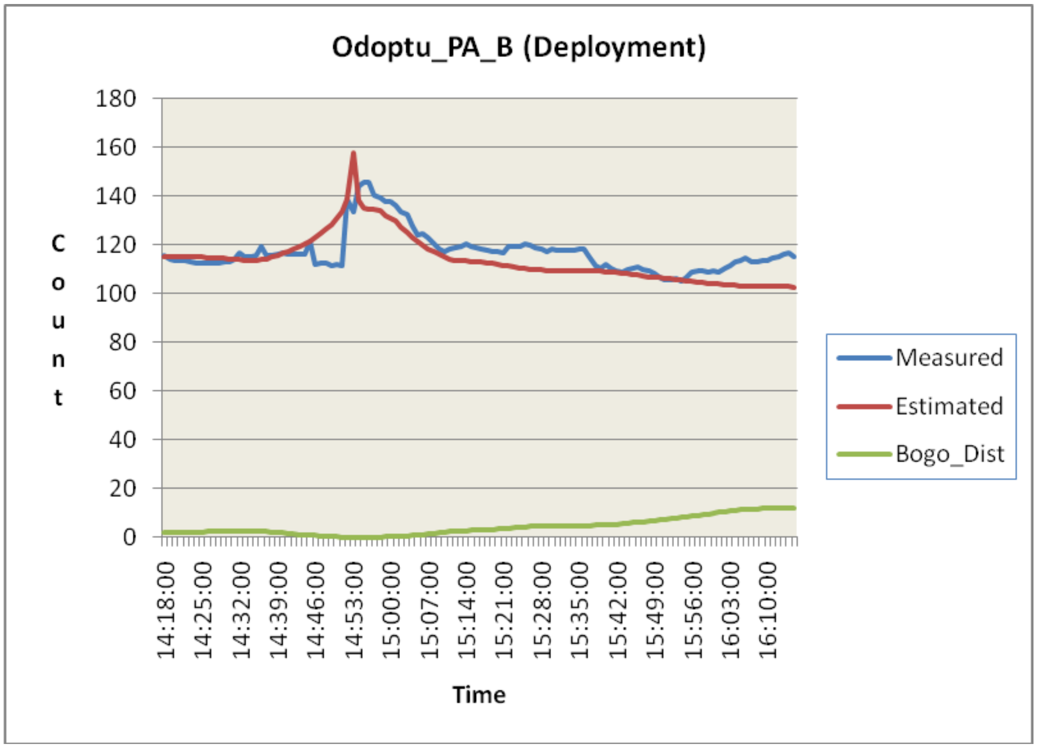


Figure A 2. Plots of modeled and estimated sound level during an AUAR retreival (a) and subsequent deployment (b) at Odoptu PA-B on 23 August.

The processing sequence used for estimating acoustic energy at each point and time of interest (*P*,*t*) was as follows:

1) Look up modelled sound level at point of interest for a notional receiver depth of 10 metres (or at the seafloor, whichever is shallower), based on relevant scenario definition.

2) Determine position of vessels *Oparin* and *Bogorov* at desired time from GPS track records; compute their ranges to point of interest and estimate the received sound level at that point from each vessel using approximate transmission loss formulae.

3) Sum sound levels from 1) and 2) to obtain total modelled sound level at point of interest.

4) Identify nearest AUAR to point of interest for which a data value was available at time of interest. If a data value from nearest AUAR was not available, select next nearest AUAR – up to a specified maximum range.

5) Compute modelled sound level at the selected AUAR location by applying steps 1) to 3) above, but for receiver depth at the seafloor (same as the depth of the AUAR).

6) Retrieve the measured one-minute average sound level at the selected AUAR at the time of interest.

7) Compute the dB difference between modeled sound levels at the grid point and at the selected AUAR.

8) Adjust by that dB difference the energy measurement at the selected AUAR to obtain the estimated sound level at the point of interest.

The process above can be encapsulated by the following equations, where *V* and *O* denote modeled level due to nearshore vessels and offshore scenario respectively, *M* denotes measured level (all in linear units), and the subscripts refer to the point of interest *P* and the nearest AUAR:

$$\text{Offshore Level at P(t) (in dB)} = 10\text{Log}[O_P(t)] + 10\text{Log}[M_{AUAR}(t)] - 10\text{Log}[V_{AUAR}(t)+O_{AUAR}(t)]$$

$$\text{Local Level at P(t) (in dB)} = 10\text{Log}[V_P(t)] + 10\text{Log}[M_{AUAR}(t)] - 10\text{Log}[V_{AUAR}(t)+O_{AUAR}(t)]$$

After processing estimates, the last operation in generating sound level results for analytical purposes was to average the one-minute acoustic levels over the temporal bin width that was used for behavioral observations, such as tracks and focal follows. This was done by linearly summing the one-minute acoustic level values within the bin interval and dividing the result by the bin duration in minutes to obtain an average sound level that was then expressed in dB re μPa. A different computation was used for generating cumulative acoustic energy metrics for the scan locations over periods lasting from 2 hours to 3 days prior to a given scan time: in this case the acoustic energy for each one-minute sample was summed linearly over the period of interest to obtain a value in dB re μPa^2-s. Provision was made for the possibility of a certain number of one-minute sound level estimates being unavailable for the computation of the cumulative acoustic energy due to gaps in AUAR data recordings: as long as 80% or more of the one-minute values were available, the cumulative energy would be computed by summing the available data and proportionally scaling the result to account for the missing ones.

Self-validation of estimation method

In order to examine the error distribution associated with the estimation method described above, a process of self-validation was performed. Given that direct sound level measurements are only available at AUAR locations, validation of the method was carried out by comparing the mean measured sound level at a given AUAR (the target AUAR) over a ten minute period with the mean sound level at that AUAR estimated using data from the nearest available AUAR (the estimator AUAR). It should be noted that this approach arguably provides an upper bound on the actual error distribution of the estimation method as actually applied, since the self-validation requires that the estimates not make use of the one AUAR that would normally be the most relevant, i.e. the one closest to the point of interest. For each AUAR, consecutive ten minute intervals during all periods in which whale observations occurred were used in the analysis provided there were at least five one-minute measurements and at least five one-minute estimates in a ten-minute interval. The overall distribution of the difference between estimated and measured averaged sound level for all scenarios is shown in Figure A 3.

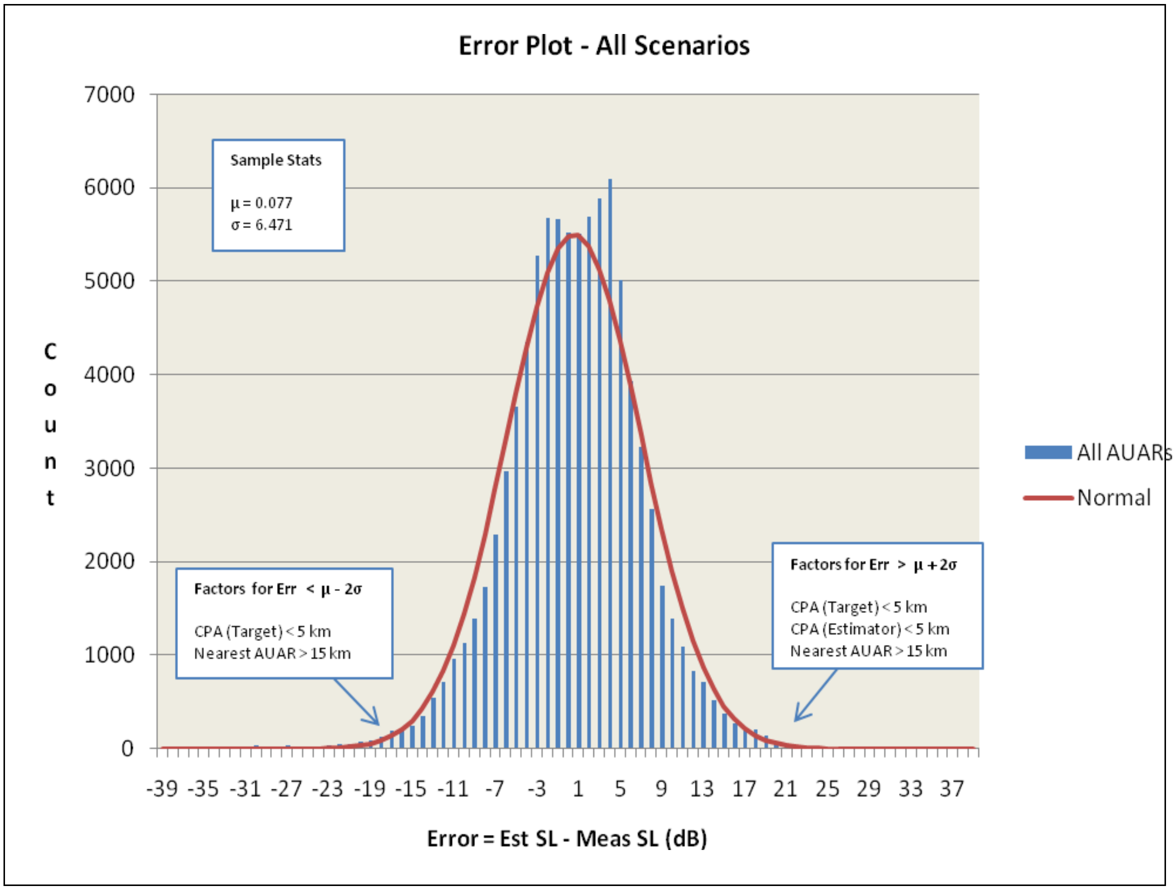


Figure A 3. Plot of binned error between averaged estaimted and measured sound level for all modeled scenarios. Factors appearing with significantly greater frequency in the tails than in the rest of the dataset are highlighted.

The overall error distribution was found to have a mean of $\mu = 0.077$ and a standard deviation of $\sigma = 6.471$. The 95th percentile of the overall error distribution was bounded between -12.9 dB and +13.0 dB. Visually, the distribution of the error appears to be approximately normal but possesses some apparent biases (and thus fails any statistical test for sample normalcy). For comparison, a plot of the exact normal distribution with $\mu = 0.077$ and $\sigma = 6.471$ is overlaid on the error plot in Figure A 2.

Several factors potentially contributing to the error in sound level estimates were investigated. We used the fact that the dataset followed an approximately normal distribution as a basis for studying the factors affecting the tails of the distribution (i.e. the data point corresponding to$|\text{Err} - \mu| > 2\sigma$). These factors were: (a) closest point of approach (CPA) of a known vessel to the target AUAR < 5 km, (b) CPA of a known vessel to the estimating AUAR < 5 km, (c) distance between target and estimating AUAR > 15 km, and (d) data taken on either the first or last day of a given scenario. The first two factors relate to the possibility of an inaccurate estimation of local vessel noise by the simplified log(R) relationship, the third to the influence on accuracy of using a very distant measurement point, and the fourth to the potential for time shift between the nominal transition dates between offshore construction scenarios and the actual change in the operations. For each factor, we calculated the probability p that the factor was present in the dataset clustered within 2σ of the mean.

Binomial hypothesis testing (at significance level α = 0.1%) was performed with the null hypothesis H_0 = {Data in each tail is distributed binomially with probability $\leq p$} and the alternative hypothesis H_1 = {Data in each tail is distributed binomially with probability $> p$}. It was found that CPA (target) < 5 km and AUAR distance > 15 km were significantly more likely to be associated with data in either of the two tails. In addition, CPA (estimator) < 5 km was significantly more likely to be associated with right tail data. The implication of these results is that the model based estimation of sound levels is deteriorated when a vessel comes into proximity of the point of interest or the AUAR used for reference, or when estimations are made using a very distant AUAR. In the actual use of the method it can be expected that the estimates will be more accurate than indicated by the results of the self-validation because of the additional inclusion of the nearest AUAR.

Appendix B: Statistical Details

This appendix contains additional results and details on the multivariate models used to analyze whale behavior surrounding the Pipeline construction during the summer of 2006 by providing 1) correlation and box-plot information and 2) residuals of the final model. Textural descriptions are given first, followed by all tables and figures.

Correlations and Box-plots Among Explanatory Variables

Tables B.1-B.5 and Figures B.1 – B.9 show relationships between natural and industrial covariates. Table B.1 contains estimated correlations between continuous natural covariates and industrial covariates. Tables B.2-B.7 contains contingency tables between pairs of non-continuous natural variables and impact variables. Figures B.1 – B.7 contain box and whisker plots of categorical covariates and industrial covariates. High correlation (generally, > 60%) or definite patterns in the box and whisker plots between one or more natural covariates and one or more industrial covariates would imply confounding effects, and interpretation would be difficult in those cases. No such correlations were found in the data.

Residual Plots

At the end of this appendix, following Figures B.1-B.6, a series of 65 residual plots appear, one for each response × industrial variable model fitted during the project. Each figure plots Studentized residuals versus fitted, or predicted, values from each model. Studentized residuals (Belsley *et al.* 1980, p. 20) are regular model residual standardized by an estimate of their variance obtained when the observation is deleted. Studentized residuals are,

$$e_i^* = \frac{e_i}{s(i)\sqrt{1-h_i}}$$

Where $e_i = y_i - \hat{y}_i$ (the regular residual), $s(i)$ = the estimated residual standard error from a model fit to a data set with the i^{th} observation deleted, and h_i is the i^{th} diagonal element of the “hat” matrix, $\mathbf{X(X'X)^{-1}X'}$. If the normality assumption holds, Studentized residuals follow a *t*-distribution with $n - p - 1$ degrees of freedom, and if the normality assumption does not hold, studentized residuals can be expected to approximate the *t*-distribution. In these plots, the most influential 3% - 5% of all observations are highlighted. These highlighted observations have predicted values that change by a relatively large amount when they are deleted and the model refit. These residual plots reveal some individual observations that are not well predicted by the model, but no systematic over or under prediction for large or small predicted values.

Table B. 1. Pearson correlation coefficients between continuous natural covariates and industrial covariates for movement and respiration data. Correlations > 0.6 highlighted.

Data Type	Natural Covariates	Industrial Covariates: Number of Vessels	Sound Nearshore	Sound Offshore
Track	Track Days	-0.07	0.29	-0.24
	Time of Day	0.04	0.01	0.04
	Distance From Station	0.09	-0.29	0.35
	Depth	0.03	-0.14	0.06
	Tide Height	-0.08	0.02	-0.10
	Wind Speed	0.03	0.07	-0.16
	Swell Height	0.10	0.29	-0.15
Focal Follows	Focal Days	0.05	0.27	-0.41
	Time of Day	0.12	0.15	0.18
	Distance From Station	-0.06	-0.33	0.35
	Depth	-0.03	-0.19	0.18
	Tide Height	0.07	0.08	-0.18
	Wind Speed	0.00	0.13	-0.39
	Swell Height	0.17	0.38	-0.16

Table B. 2. Pearson correlation coefficients between continuous natural covariates and industrial covariates for abundance data. Correlations > 0.6 highlighted.

Data Type	Natural Covariates	Industrial Covariates: 2H_OS	8H_OS	1D_OS	3D_OS	2H_NS	8H_NS	1D_NS	3D_NS
Scan	Days	0.11	0.11	0.14	0.18	0.37	0.34	0.35	0.36
	Time of Day	-0.05	-0.02	-0.06	-0.04	-0.05	0.06	0.00	0.03
	Tide Height	0.00	-0.04	-0.06	-0.08	0.09	0.01	0.00	-0.06
	Wind Speed	-0.02	-0.03	-0.03	-0.02	0.05	0.02	-0.04	0.00
	Number of Vessels	-0.03	-0.03	-0.03	-0.03	0.29	0.28	0.25	0.20
	Week Since	0.11	0.11	0.13	0.18	0.35	0.32	0.35	0.36

Table B. 3. Contingency tables of movement covariates and closest vessel.

Variable	Factor Level	Closest Vessel [0,0.5]	(0.5,1]	(1,2]	(2,5]	(5+]	TOTAL
Beaufort	[0]	0	0	0	0	17	**17**
	[1]	0	1	4	10	43	**58**
	[2]	0	0	1	14	326	**341**
	[3]	0	0	0	3	157	**160**
	[4]	1	0	0	3	124	**128**
	[5]	0	0	0	3	17	**20**
Behavior	Feeding	0	0	2	13	245	**260**
	Feeding / Traveling	0	1	0	6	157	**164**
	Mixed	0	0	0	3	57	**60**
	Traveling	1	0	3	11	225	**240**
Station	1st Station	0	0	0	1	99	**100**
	2nd Station	0	0	1	10	87	**98**
	Campsite Station	0	0	0	2	33	**35**
	Chaivo Station	0	0	0	6	62	**68**
	North Station	1	0	0	0	45	**46**
	Odoptu Station	0	0	3	7	94	**104**
	Pipeline Station	0	0	1	0	55	**56**
	South Station	0	1	0	5	75	**81**
	Station 07	0	0	0	2	134	**136**
Subject	Adult	0	1	1	25	501	**528**
	Mom-Calf	1	0	4	5	53	**63**
	Unknown	0	0	0	3	98	**101**
	Yearling	0	0	0	0	32	**32**
Visibility	[1]	0	0	0	0	236	**236**
	[2]	1	1	5	30	318	**355**
	[3]	0	0	0	3	115	**118**
	[4]	0	0	0	0	15	**15**
Wind Direction	East	0	1	0	7	67	**75**
	North	0	0	0	12	152	**164**
	South	1	0	5	10	242	**258**
	West	0	0	0	4	223	**227**

Table B. 4. Contingency tables of movement covariates and Vessel Type

Variable	Factor Level	Vessel Type			TOTAL
		Construction	Nearshore	Zodiac	
Beaufort	[0]	1	16	0	**17**
	[1]	20	36	2	**58**
	[2]	120	208	13	**341**
	[3]	48	111	1	**160**
	[4]	57	67	4	**128**
	[5]	12	8	0	**20**
Behavior	Feeding	92	164	4	**260**
	Feeding / Traveling	58	100	6	**164**
	Mixed	13	45	2	**60**
	Traveling	95	137	8	**240**
Station	1st Station	40	57	3	**100**
	2nd Station	41	55	2	**98**
	Campsite Station	24	11	0	**35**
	Chaivo Station	31	37	0	**68**
	North Station	19	25	2	**46**
	Odoptu Station	1	99	4	**104**
	Pipeline Station	29	27	0	**56**
	South Station	36	44	1	**81**
	Station 07	37	91	8	**136**
Subject	Adult	214	301	13	**528**
	Mom-Calf	31	28	4	**63**
	Unknown	11	90	0	**101**
	Yearling	2	27	3	**32**
Visibility	[1]	47	174	15	**236**
	[2]	161	190	4	**355**
	[3]	49	68	1	**118**
	[4]	1	14	0	**15**
Wind Direction	East	41	34	0	**75**
	North	31	123	10	**164**
	South	104	145	9	**258**
	West	82	144	1	**227**

Table B. 5. Contingency tables of respiration covariates and closest vessel.

Variable	Factor Level	Closest Vessel [0,0.5]	(0.5,1]	(1,2]	(2,5]	(5+]	TOTAL
Beaufort	[0]	0	0	0	0	12	**12**
	[1]	0	0	0	3	23	**26**
	[2]	0	0	0	11	177	**188**
	[3]	0	0	0	1	78	**79**
	[4]	0	0	0	0	48	**48**
	[5]	0	0	0	0	0	**0**
Behavior	Feeding	0	0	0	4	140	**144**
	Feeding / Traveling	0	0	0	4	78	**82**
	Mixed	0	0	0	2	17	**19**
	Traveling	0	0	0	5	103	**108**
Station	1st Station	0	0	0	0	62	**62**
	2nd Station	0	0	0	5	48	**53**
	Campsite Station	0	0	0	2	19	**21**
	Chaivo Station	0	0	0	0	24	**24**
	North Station	0	0	0	0	14	**14**
	Odoptu Station	0	0	0	2	23	**25**
	Pipeline Station	0	0	0	0	18	**18**
	South Station	0	0	0	3	42	**45**
	Station 07	0	0	0	3	88	**91**
Subject	Adult	0	0	0	10	233	**243**
	Mom-Calf	0	0	0	0	0	**0**
	Unknown	0	0	0	5	81	**86**
	Yearling	0	0	0	0	24	**24**
Visibility	[1]	0	0	0	1	97	**98**
	[2]	0	0	0	14	175	**189**
	[3]	0	0	0	0	58	**58**
	[4]	0	0	0	0	8	**8**
Wind Direction	East	0	0	0	5	28	**33**
	North	0	0	0	3	69	**72**
	South	0	0	0	5	113	**118**
	West	0	0	0	2	128	**130**

Table B. 6.. Contingency tables of respiration covariates and vessel type.

Variable	Factor Level	Vessel Type			TOTAL
		Construction	Nearshore	Zodiac	
Beaufort	[0]	0	12	0	**12**
	[1]	8	18	0	**26**
	[2]	61	115	12	**188**
	[3]	31	48	0	**79**
	[4]	20	28	0	**48**
	[5]	0	0	0	**0**
Behavior	Feeding	42	99	3	**144**
	Feeding / Traveling	35	41	6	**82**
	Mixed	2	16	1	**19**
	Traveling	41	65	2	**108**
Station	1st Station	18	44	0	**62**
	2nd Station	26	27	0	**53**
	Campsite Station	18	3	0	**21**
	Chaivo Station	16	8	0	**24**
	North Station	0	14	0	**14**
	Odoptu Station	0	25	0	**25**
	Pipeline Station	11	7	0	**18**
	South Station	19	24	2	**45**
	Station 07	12	69	10	**91**
Subject	Adult	111	120	12	**243**
	Mom-Calf	0	0	0	**0**
	Unknown	9	77	0	**86**
	Yearling	0	24	0	**24**
Visibility	[1]	9	79	10	**98**
	[2]	88	101	0	**189**
	[3]	23	33	2	**58**
	[4]	0	8	0	**8**
Wind Direction	East	19	12	2	**33**
	North	10	52	10	**72**
	South	50	68	0	**118**
	West	41	89	0	**130**

Table B. 7. Contingency tables of abundance covariates and closest vessel.

		Closest Vessel				
Variable	**Factor Level**	**(0.5,1]**	**(1,2]**	**(2,5]**	**(5+]**	**TOTAL**
Beaufort	**[0]**	1	0	0	9	**10**
	[1]	0	0	8	142	**150**
	[2]	0	6	11	281	**298**
	[3]	0	1	2	107	**110**
Station	**Station 1**	0	0	0	23	**23**
	Station 2	0	0	0	20	**20**
	Station 3	0	1	0	18	**19**
	Station 4	0	0	0	13	**13**
	Station 8	0	0	0	14	**14**
	Station 9	0	0	1	13	**14**
	Station 10	0	0	0	16	**16**
	Station 11	0	0	1	18	**19**
	Station 12	0	0	1	13	**14**
	Station 13	0	0	0	12	**12**
	1st Station	1	0	6	76	**83**
	2nd Station	0	2	2	58	**62**
	Campsite Station	0	0	0	32	**32**
	Chaivo Station	0	2	0	43	**45**
	North Station	0	0	0	21	**21**
	Odoptu Station	0	1	5	17	**23**
	Pipeline Station	0	1	3	39	**43**
	South Station	0	0	2	46	**48**
	Station 07	0	0	0	47	**47**
Glare Present	**[0]**	1	4	13	372	**390**
	[1]	0	3	8	167	**178**
Visibility	**[1]**	0	1	3	93	**97**
	[2]	0	3	4	172	**179**
	[3]	1	2	9	76	**88**
Wind Direction	**East**	1	2	4	117	**124**
	North	0	2	3	68	**73**
	South	0	2	9	203	**214**
	West	0	1	5	151	**157**

Table B. 8. Contingency tables of abundance covariates and vessel type.

Variable	Factor Level	Vessel Type: Construction	Nearshore	Zodiac	TOTAL
Beaufort	[0]	2	8	0	**10**
	[1]	63	85	2	**150**
	[2]	121	175	2	**298**
	[3]	29	78	3	**110**
Station	Station 1	8	15	0	**23**
	Station 2	8	12	0	**20**
	Station 3	6	13	0	**19**
	Station 4	5	8	0	**13**
	Station 8	5	9	0	**14**
	Station 9	3	11	0	**14**
	Station 10	4	12	0	**16**
	Station 11	6	13	0	**19**
	Station 12	7	7	0	**14**
	Station 13	3	9	0	**12**
	1st Station	31	51	1	**83**
	2nd Station	23	39	0	**62**
	Campsite Station	12	20	0	**32**
	Chaivo Station	25	20	0	**45**
	North Station	3	17	1	**21**
	Odoptu Station	4	18	1	**23**
	Pipeline Station	27	16	0	**43**
	South Station	18	26	4	**48**
	Station 07	17	30	0	**47**
Glare Present	[0]	150	235	5	**390**
	[1]	65	111	2	**178**
Visibility	[1]	30	64	3	**97**
	[2]	86	92	1	**179**
	[3]	28	57	3	**88**
Wind Direction	East	54	68	2	**124**
	North	25	47	1	**73**
	South	69	143	2	**214**
	West	67	88	2	**157**

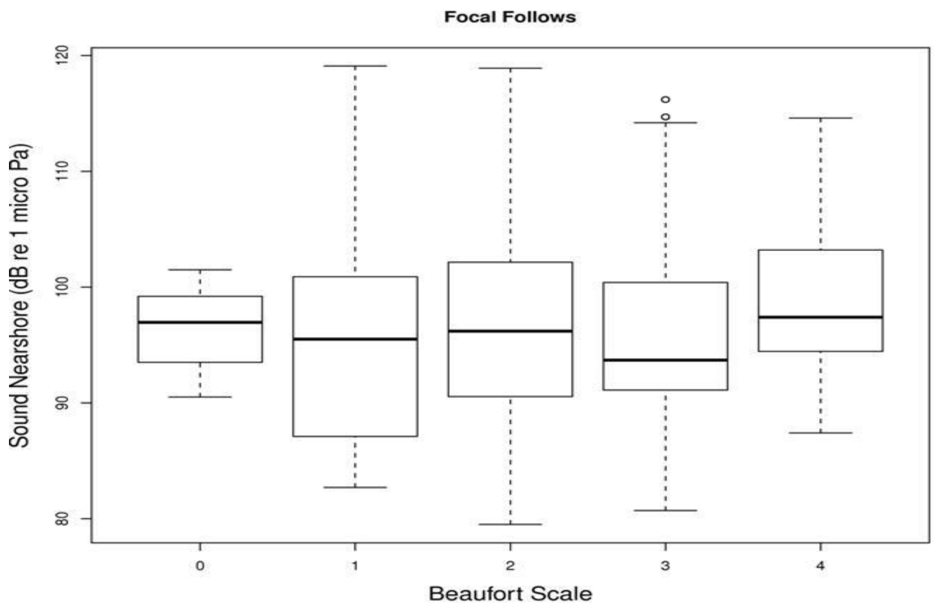


Figure B.1. Box and whisker plots of nearshore sound levels by Beaufort scale for the respiration dataset. Upper and lower ends of box mark 75th and 25th percentiles, respectively. Dark line in the box denotes median. Whiskers extend to an observation at most 1.5*box height away from the box. Observations beyond whiskers are marked with circles.

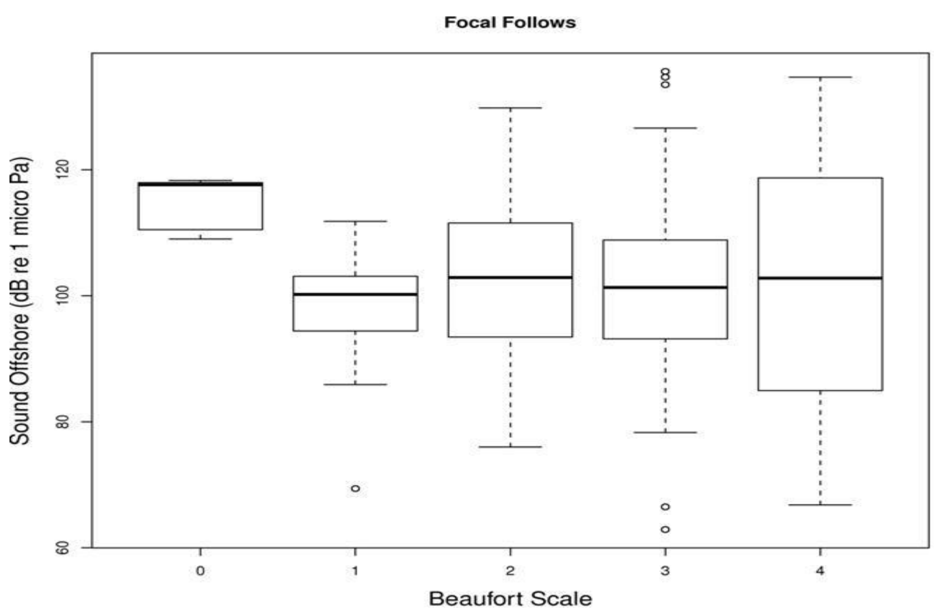


Figure B.2. Box and whisker plots of offshore sound levels by Beaufort scale for the respiration dataset. Boxes as described in caption to Figure B.1.

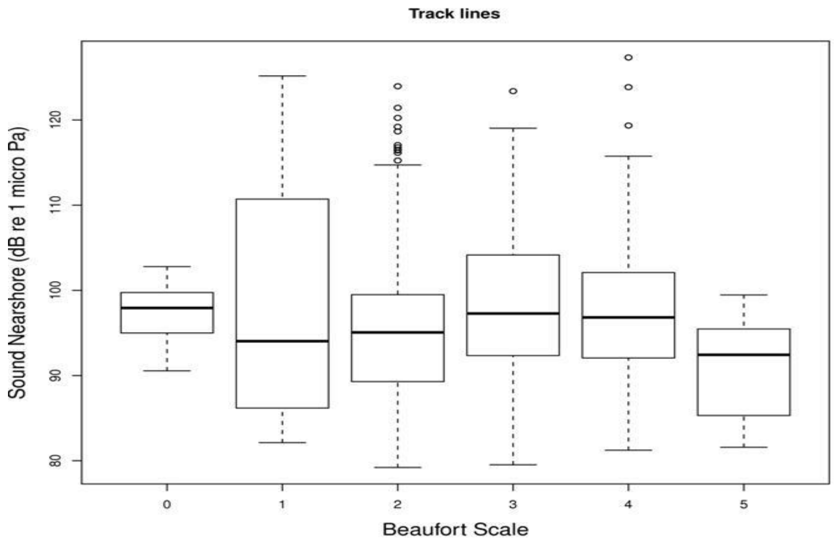


Figure B.3. Box and whisker plots of nearshore sound levels by Beaufort scale for the movement dataset. Boxes as described in caption to Figure B.1.

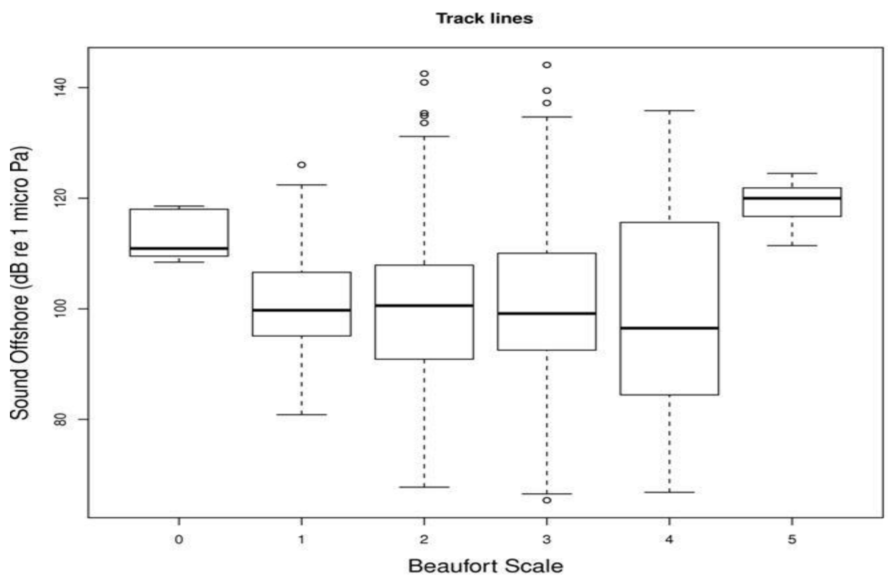


Figure B.4. Box and whisker plots of offshore sound levels by Beaufort scale for the movement dataset. Boxes as described in caption to Figure B.1.

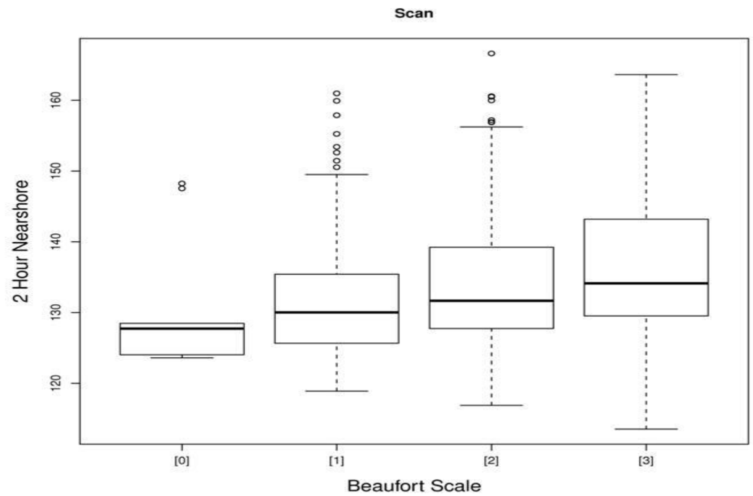


Figure B.5. Box and whisker plots of nearshore cumlative 2 hour sound levels by Beaufort scale for the abundance dataset. Boxes as described in caption to Figure B.1.

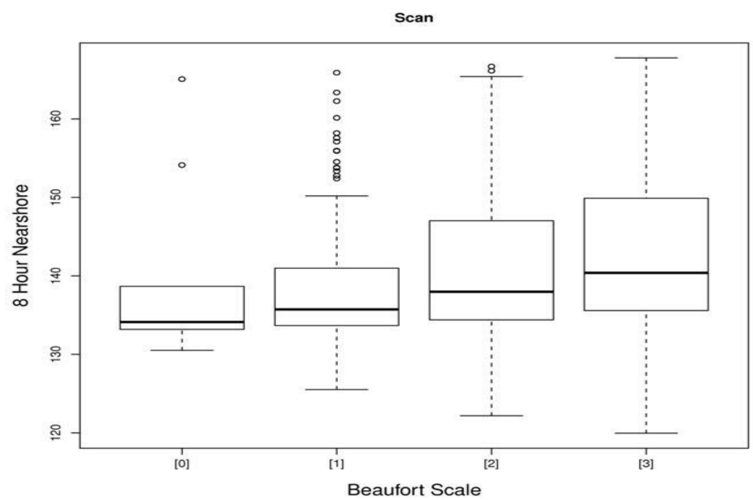


Figure B.6. Box and whisker plots of nearshore cumulative 8 hour sound levels by Beaufort scale for the abundance dataset. Boxes as described in caption to Figure B.1.

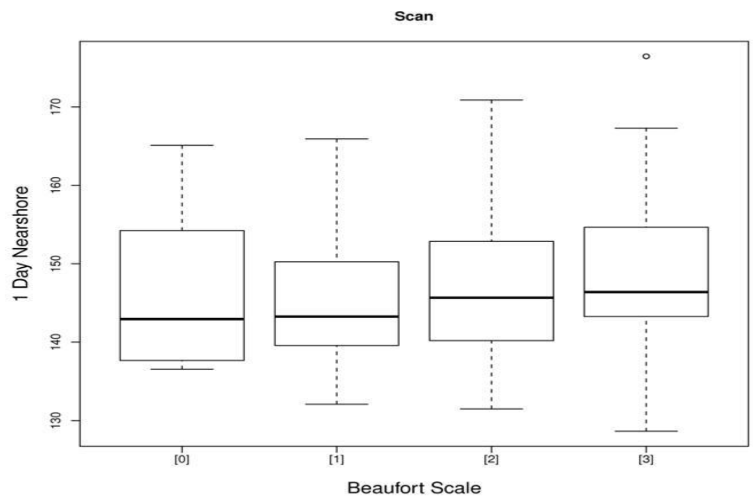


Figure B. 7. Box and whisker plots of nearshore cumulative 1 day sound levels by Beaufort scale for the abundance dataset. Boxes as described in caption to Figure B.1.

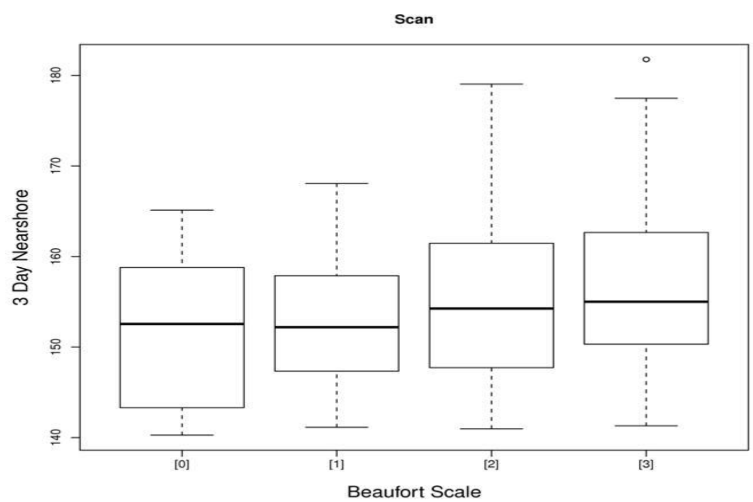


Figure B.8. Box and whisker plots of nearshore cumulative 3 day sound levels by Beaufort scale for the abundance dataset. Boxes as described in caption to Figure B.1.

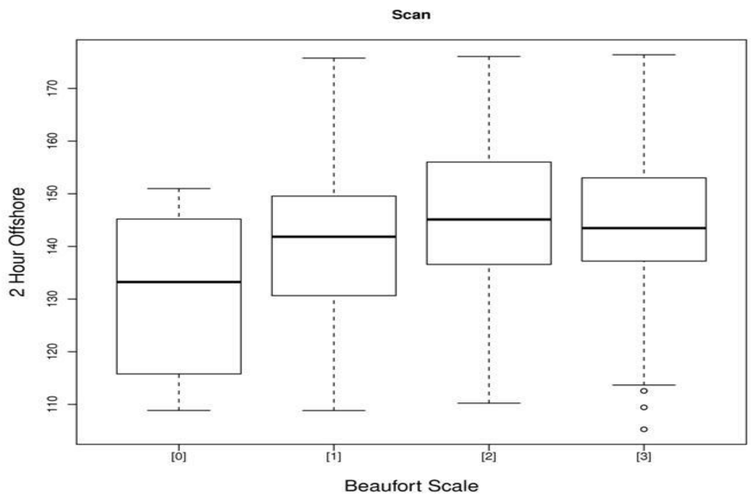


Figure B.9. Box and whisker plots of offshore cumulative 2 hour sound levels by Beaufort scale for the abundance dataset. Boxes as described in caption to Figure B.1.

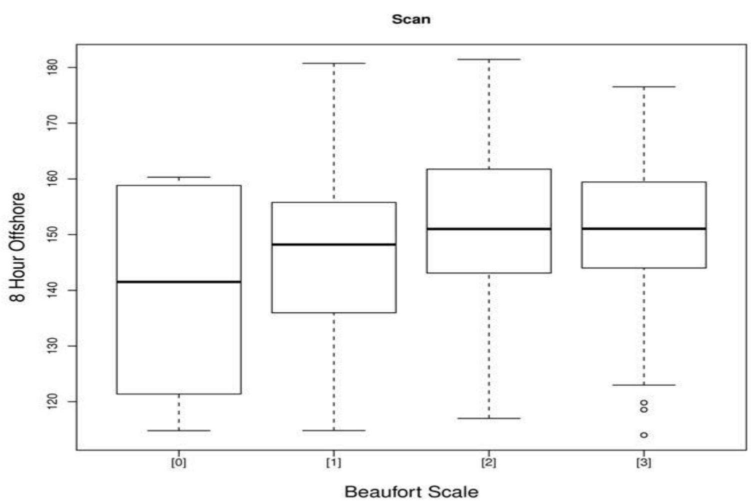


Figure B.10. Box and whisker plots of offshore cumulative 8 hour sound levels by Beaufort scale for the abundance dataset. Boxes as described in caption to Figure B.1.

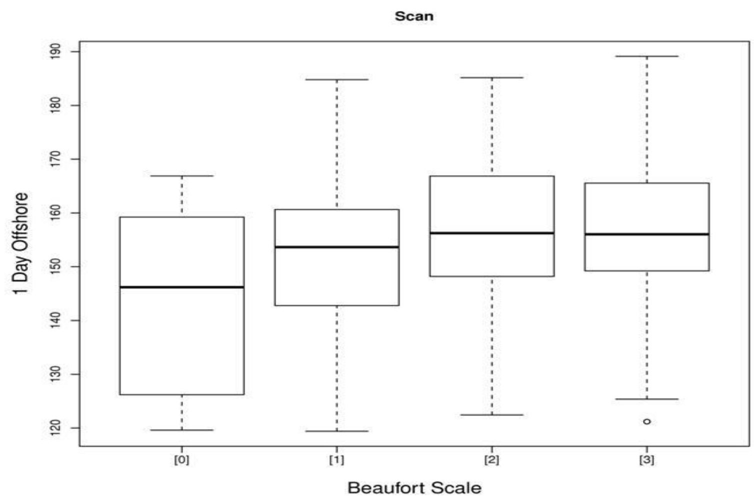


Figure B.11. Box and whisker plots of offshore cumulative 1 day sound levels by Beaufort scale for the abundance dataset. Boxes as described in caption to Figure B.1.

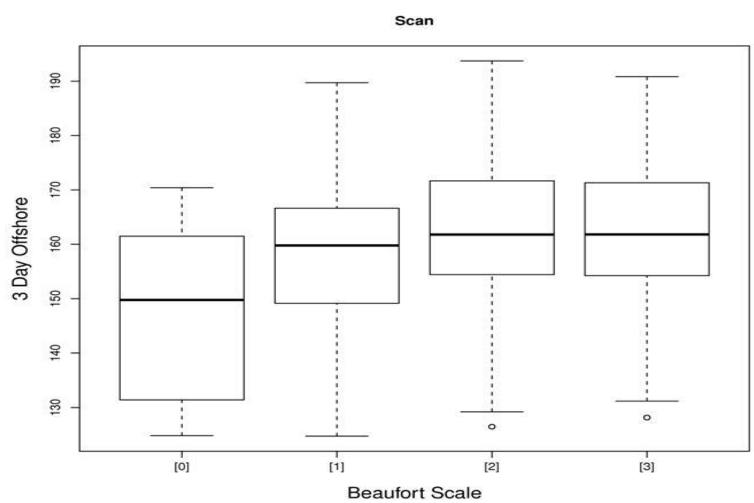


Figure B. 12. Box and whisker plots of offshore cumulative 3 day sound levels by Beaufort scale for the abundance dataset. Boxes as described in caption to Figure B.1.

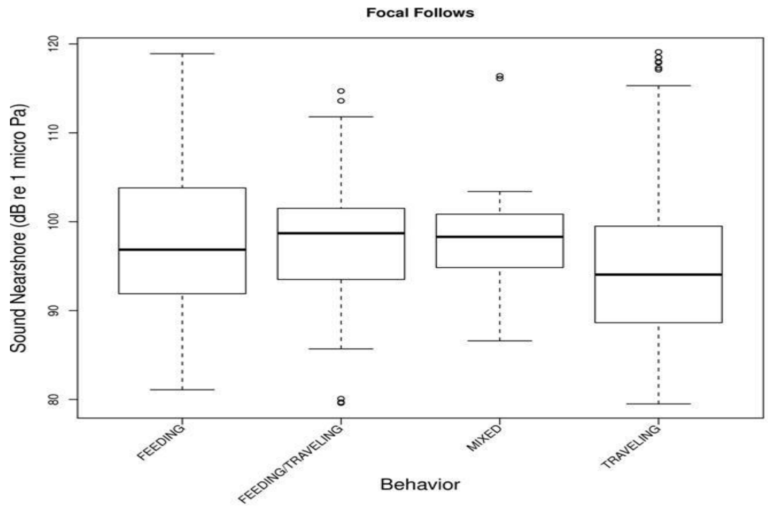


Figure B. 13. Box and whisker plots of nearshore sound levels by behavioral states for the respiration dataset. Boxes as described in caption to Figure B.1.

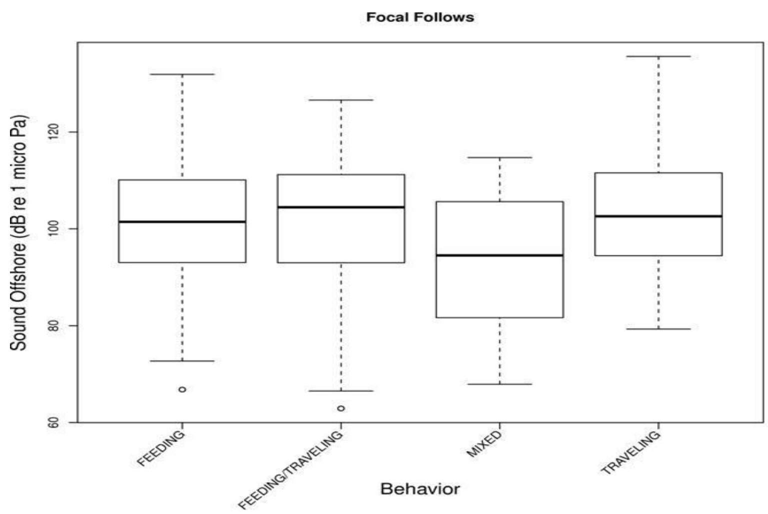


Figure B. 14. Box and whisker plots of offshore sound levels by behavioral states for the respiration dataset. Boxes as described in caption to Figure B.1.

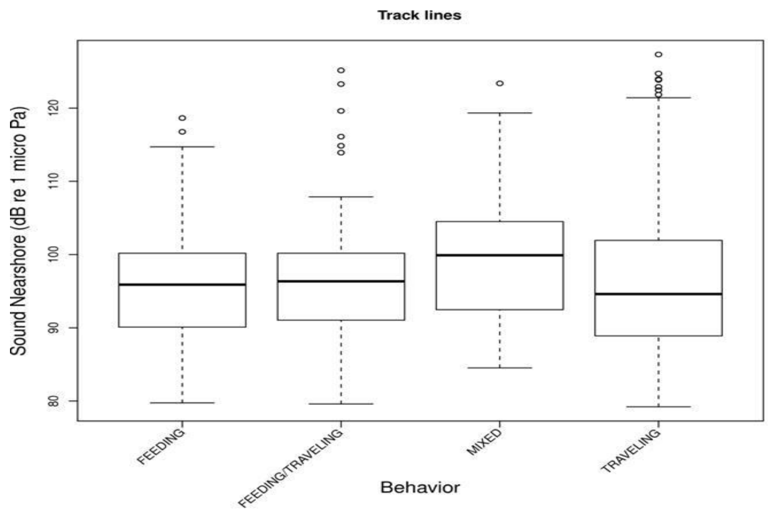


Figure B. 15. Box and whisker plots of nearshore sound levels by behavioral states for the movement dataset. Boxes as described in caption to Figure B.1.

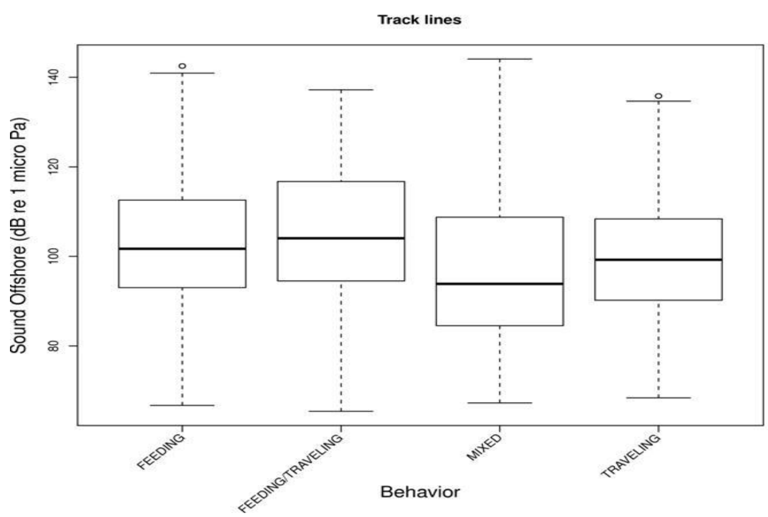


Figure B. 16. Box and whisker plots of offshore sound levels by behavioral states for the movement dataset. Boxes as described in caption to Figure B.1.

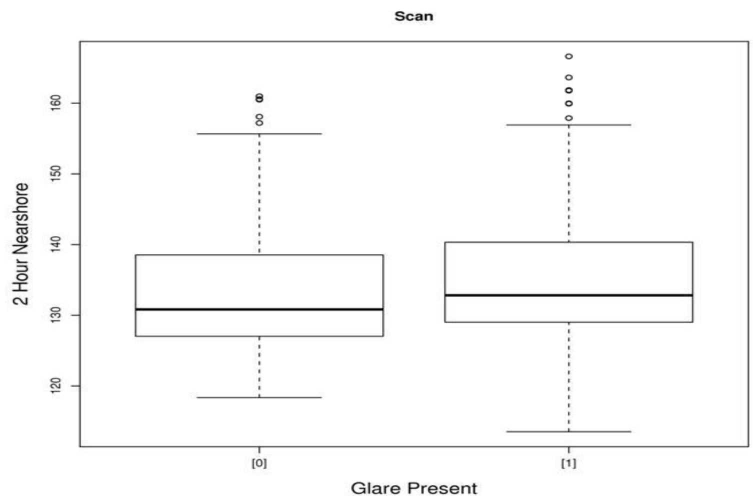


Figure B. 17. Box and whisker plots of cumulative 2 hour nearshore sound levels by glare present for the abundance dataset. Boxes as described in caption to Figure B.1.

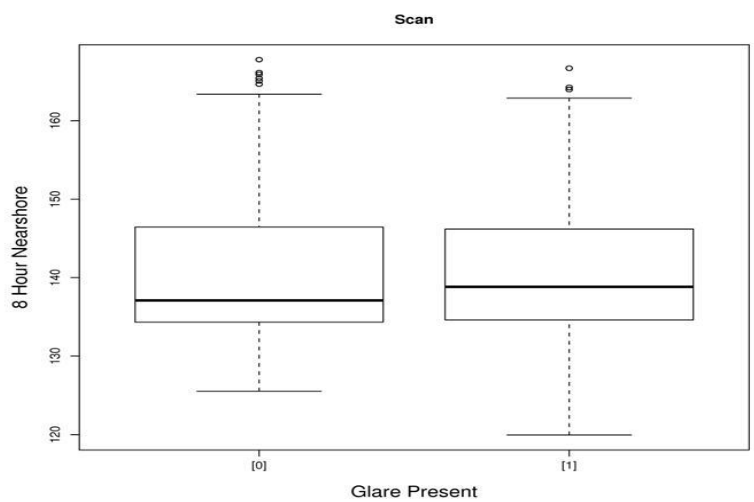


Figure B. 18. Box and whisker plots of cumulative 8 hour nearshore sound levels by glare present for the abundance dataset. Boxes as described in caption to Figure B.1.

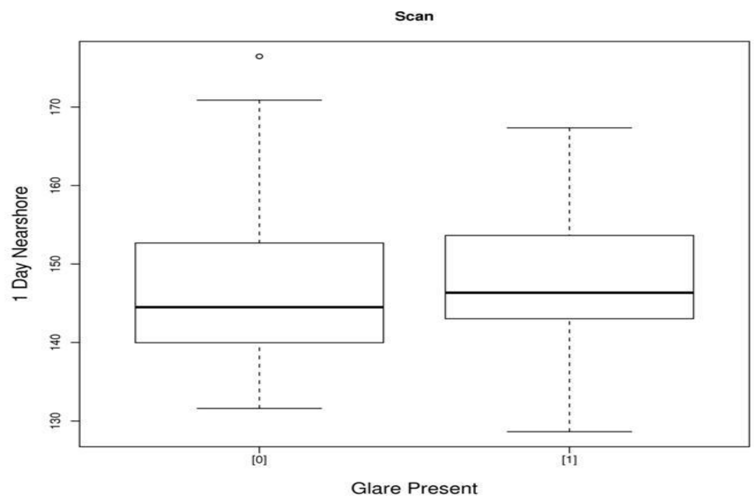


Figure B. 19. Box and whisker plots of cumulative 1 day nearshore sound levels by glare present for the abundance dataset. Boxes as described in caption to Figure B.1.

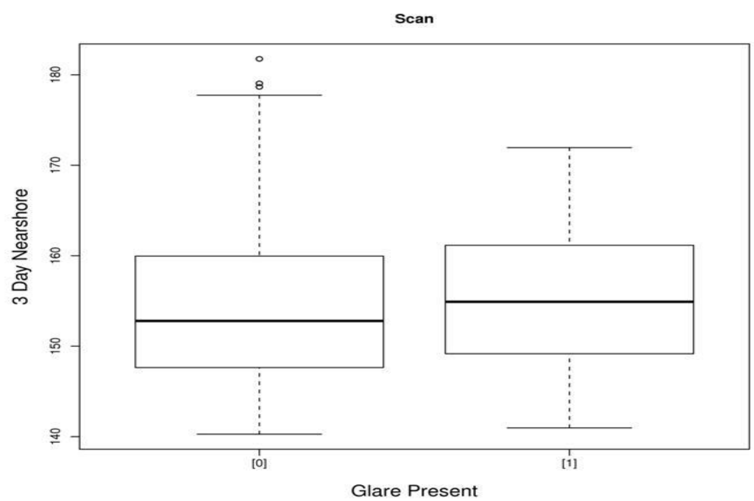


Figure B. 20. Box and whisker plots of cumulative 3 day nearshore sound levels by glare present for the abundance dataset. Boxes as described in caption to Figure B.1.

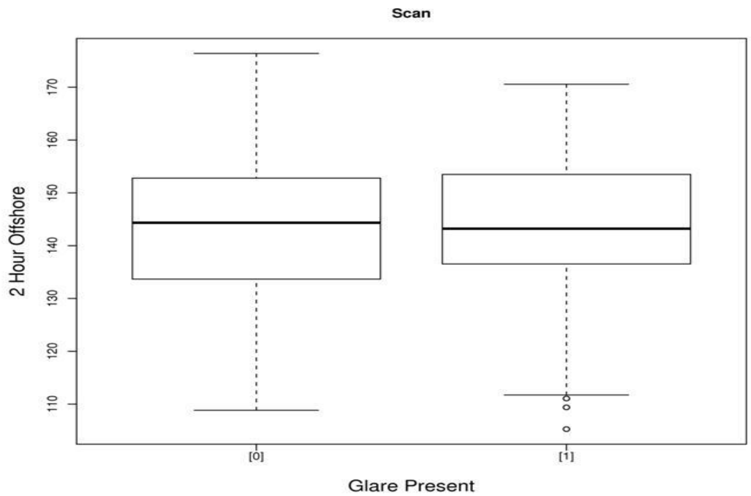


Figure B. 21. Box and whisker plots of cumulative 2 hour offshore sound levels by glare present for the abundance dataset. Boxes as described in caption to Figure B.1.

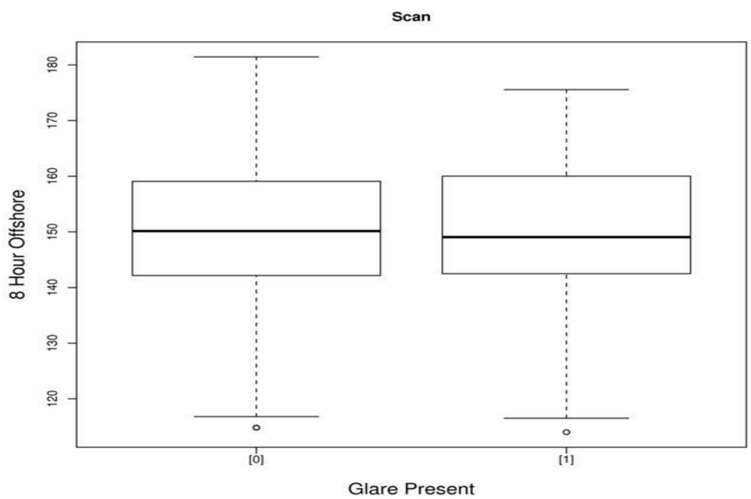


Figure B. 22. Box and whisker plots of cumulative 8 hour offshore sound levels by glare present for the abundance dataset. Boxes as described in caption to Figure B.1.

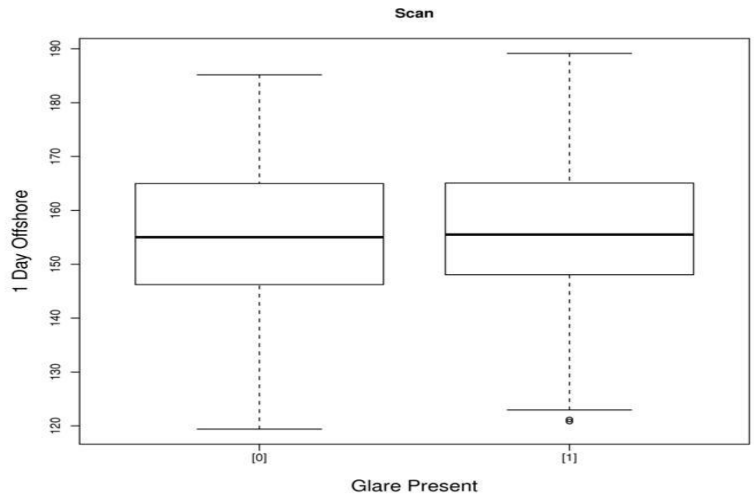


Figure B. 23. Box and whisker plots of cumulative 1 day offshore sound levels by glare present for the abundance dataset. Boxes as described in caption to Figure B.1.

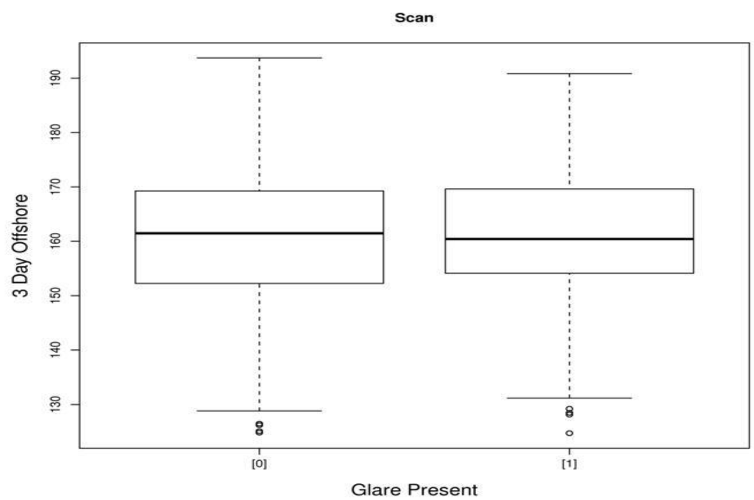


Figure B. 24. Box and whisker plots of cumulative 3 day offshore sound levels by glare present for the abundance dataset. Boxes as described in caption to Figure B.1.

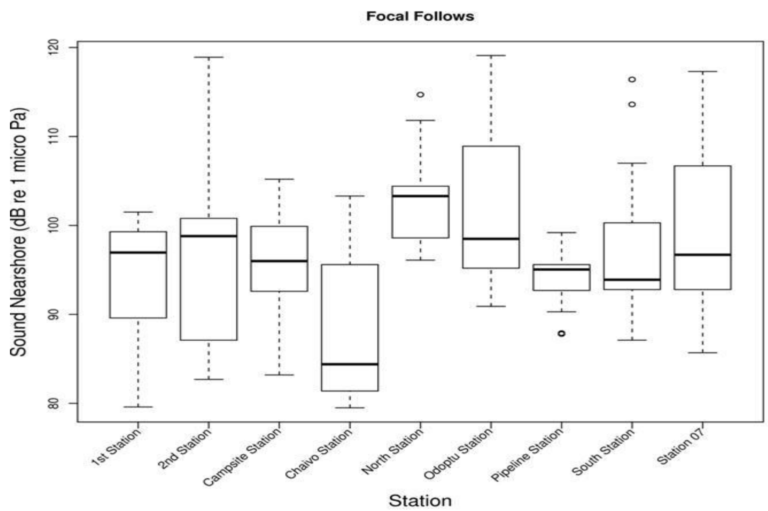


Figure B. 25. Box and whisker plots of nearshore sound levels by geographic location for the respiration dataset. Boxes as described in caption to Figure B.1.

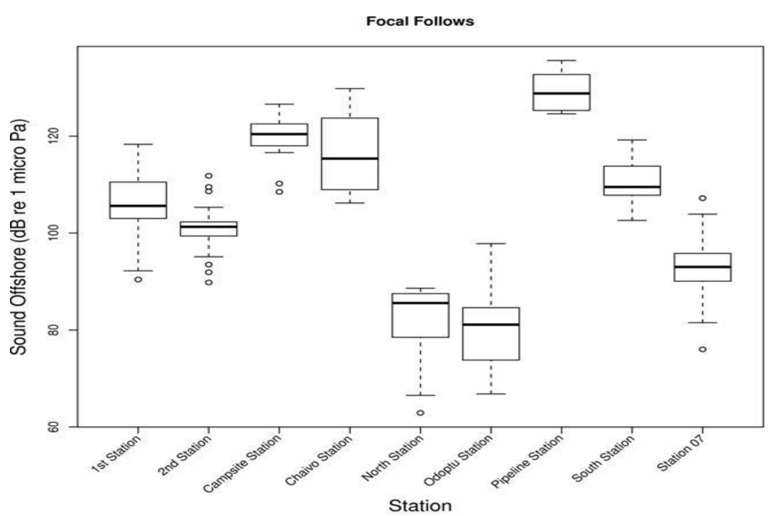


Figure B. 26. Box and whisker plots of offshore sound levels by geographic location for the respiration dataset. Boxes as described in caption to Figure B.1.

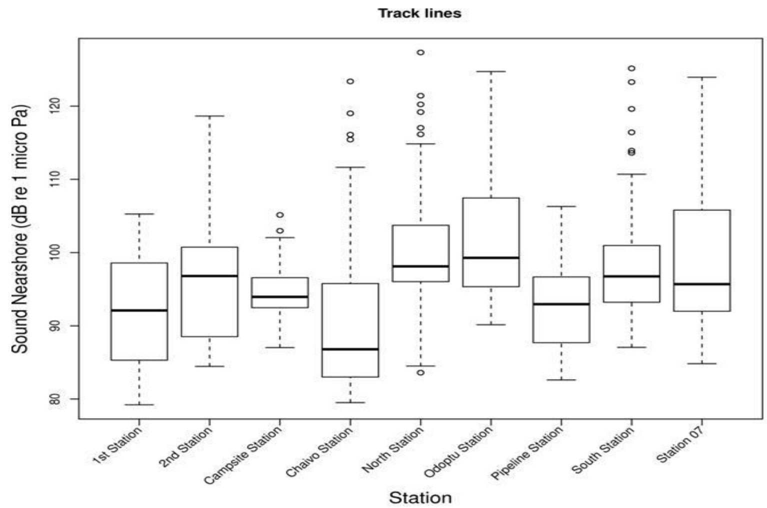


Figure B. 27. Box and whisker plots of nearshore sound levels by geographic location for the movement dataset. Boxes as described in caption to Figure B.1.

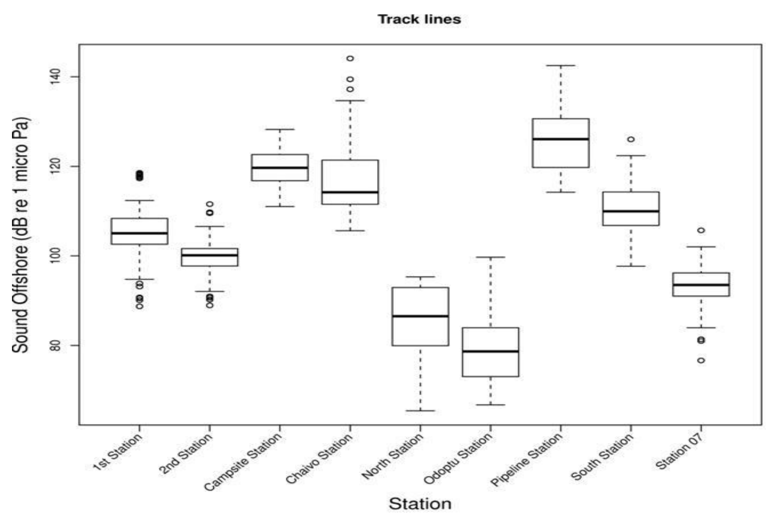


Figure B. 28. Box and whisker plots of offshore sound levels by geographic location for the movement dataset. Boxes as described in caption to Figure B.1.

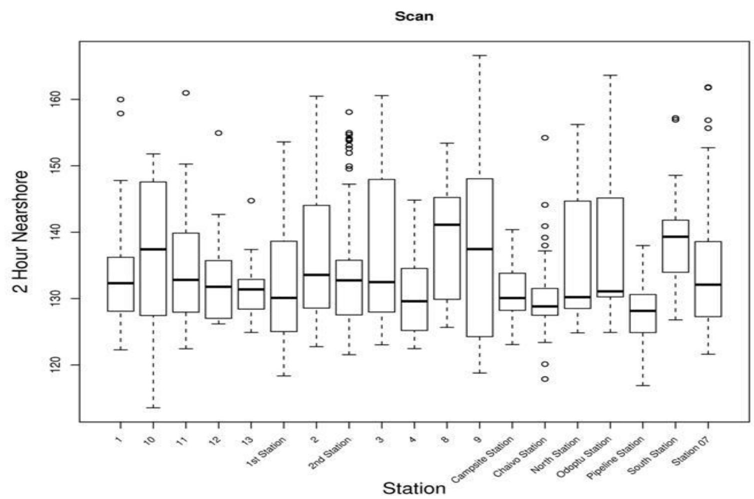


Figure B. 29. Box and whisker plots of cumulative 2 hour nearshore sound levels by geographic location for the abundance dataset. Boxes as described in caption to Figure B.1.

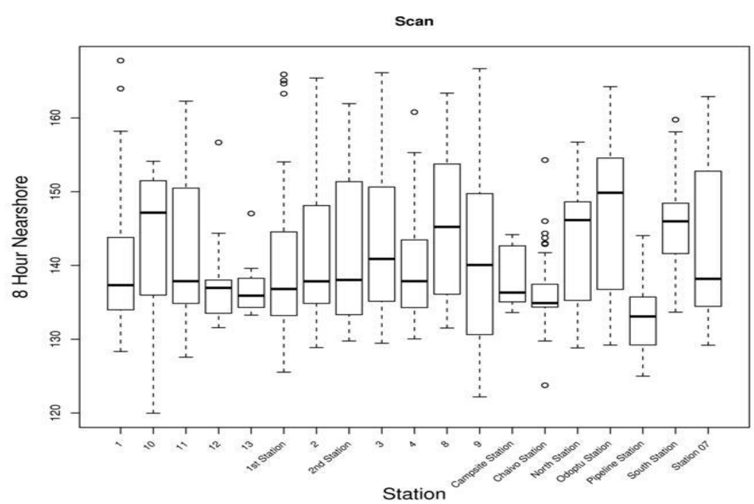


Figure B. 30. Box and whisker plots of cumulative 8 hour nearshore sound levels by geographic location for the abundance dataset. Boxes as described in caption to Figure B.1.

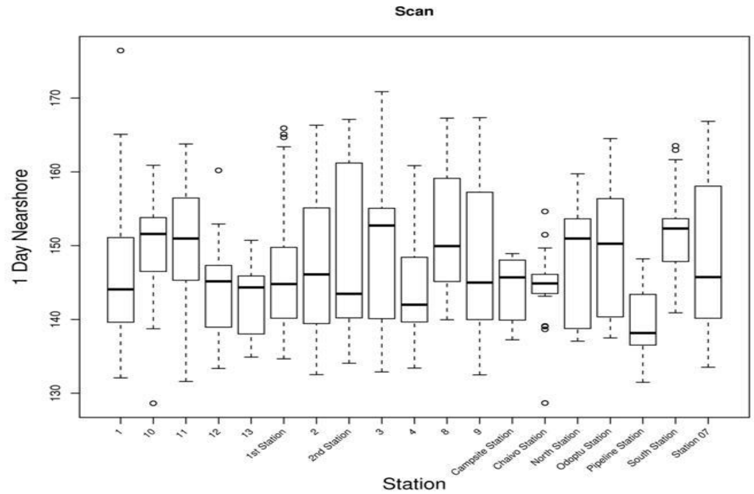


Figure B. 31. Box and whisker plots of cumulative 1 day nearshore sound levels by geographic location for the abundance dataset. Boxes as described in caption to Figure B.1.

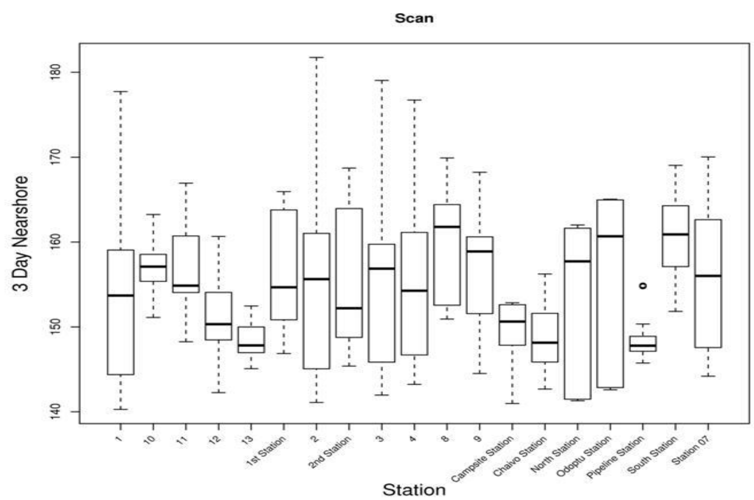


Figure B. 32. Box and whisker plots of cumulative 3 day nearshore sound levels by geographic location for the abundance dataset. Boxes as described in caption to Figure B.1.

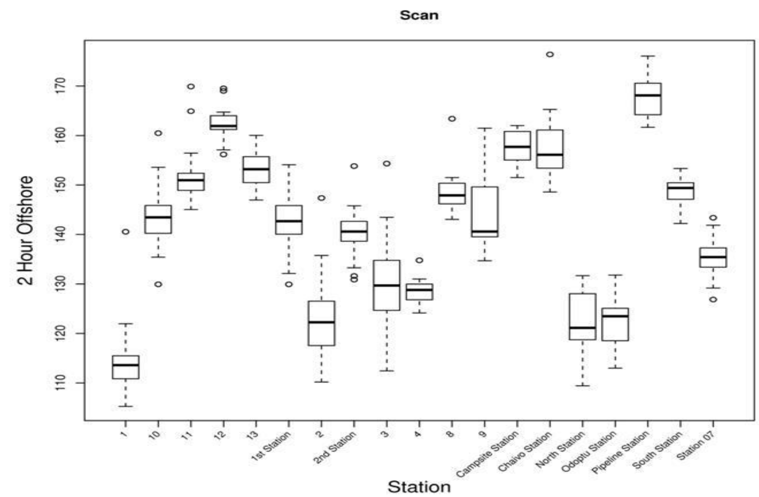


Figure B. 33. Box and whisker plots of cumulative 2 hour offshore sound levels by geographic location for the abundance dataset. Boxes as described in caption to Figure B.1.

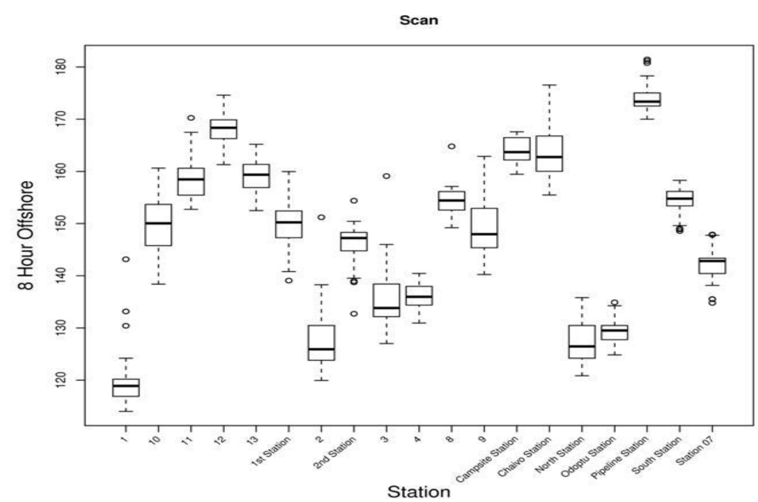


Figure B. 34. Box and whisker plots of cumulative 8 hour offshore sound levels by geographic location for the abundance dataset. Boxes as described in caption to Figure B.1.

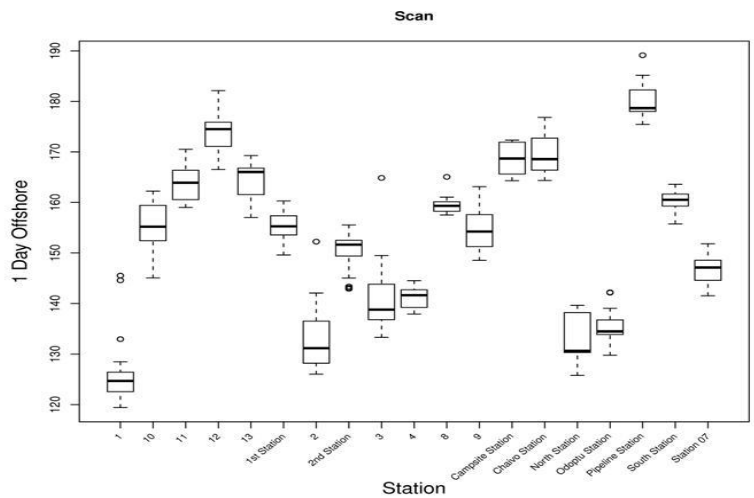


Figure B. 35. Box and whisker plots of cumulative 1 day offshore sound levels by geographic location for the abundance dataset. Boxes as described in caption to Figure B.1.

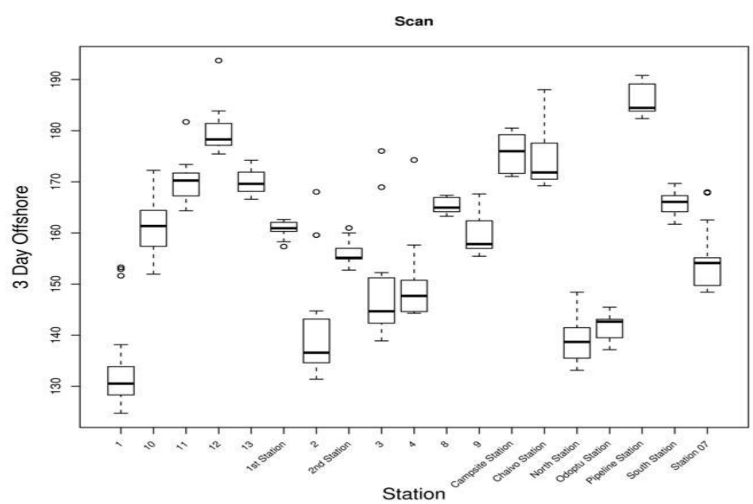


Figure B. 36. Box and whisker plots of cumulative 3 day offshore sound levels by geographic location for the abundance dataset. Boxes as described in caption to Figure B.1.

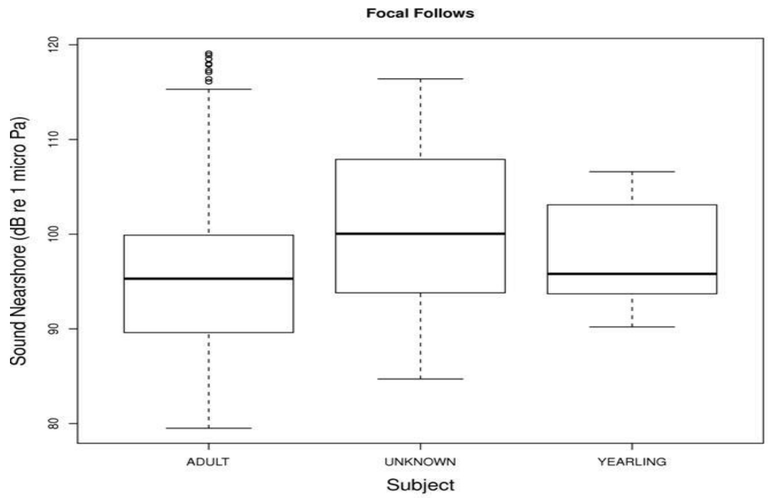


Figure B. 37. Box and whisker plots of nearshore sound levels by subject for the respiration dataset. Boxes as described in caption to Figure B.1.

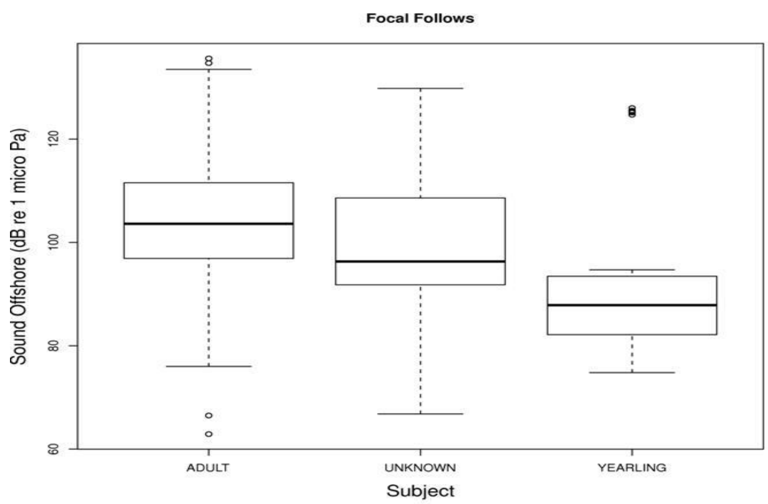


Figure B. 38. Box and whisker plots of offshore sound levels by subject for the respiration dataset. Boxes as described in caption to Figure B.1.

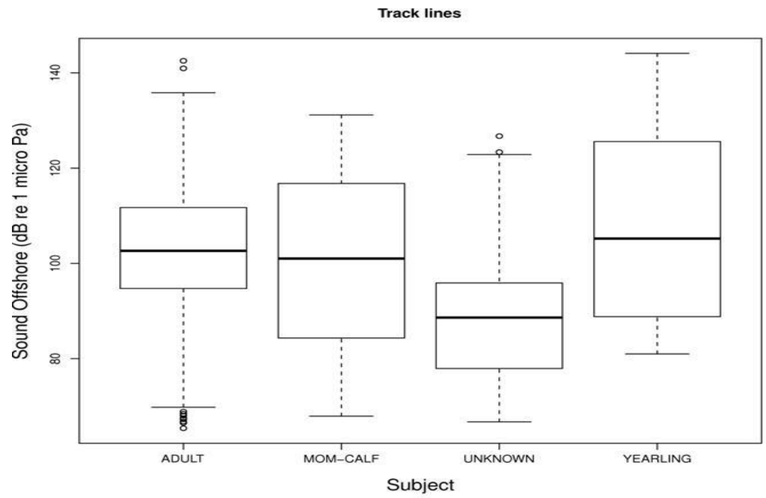


Figure B. 39. Box and whisker plots of nearshore sound levels by subject for the movement dataset. Boxes as described in caption to Figure B.1.

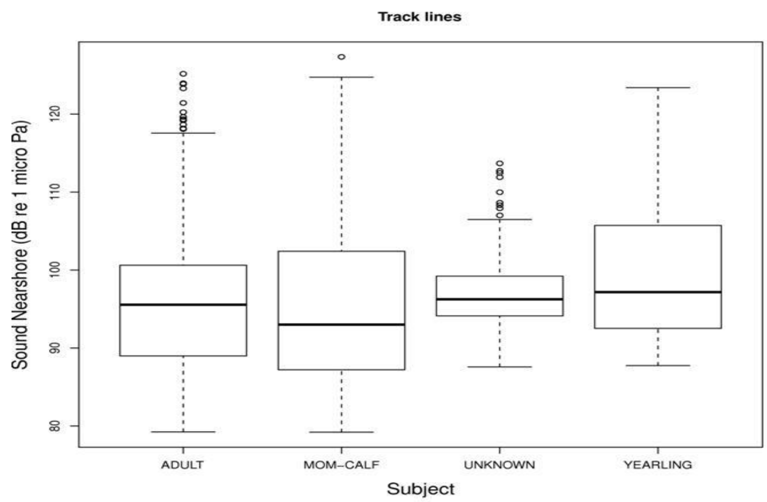


Figure B. 40. Box and whisker plots of offshore sound levels by subject for the movement dataset. Boxes as described in caption to Figure B.1.

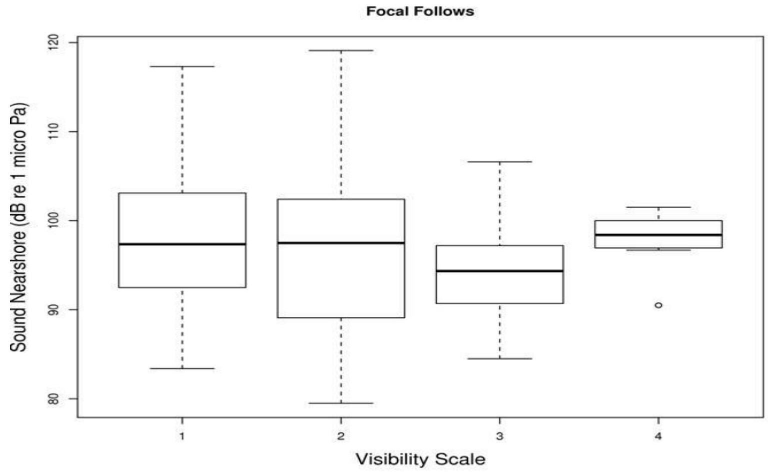


Figure B. 41. Box and whisker plots of nearshore sound levels by visibility for the respiration dataset. Boxes as described in caption to Figure B.1.

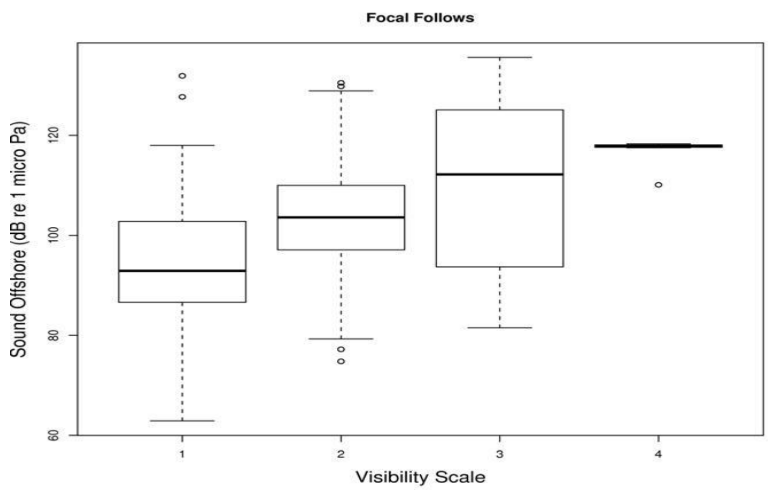


Figure B. 42. Box and whisker plots of offshore sound levels by visibility for the respiration dataset. Boxes as described in caption to Figure B.1.

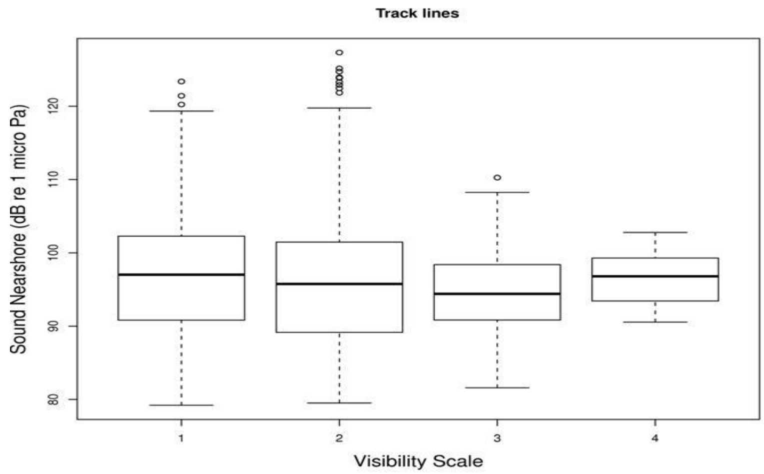


Figure B. 43. Box and whisker plots of nearshore sound levels by visibility for the movement dataset. Boxes as described in caption to Figure B.1.

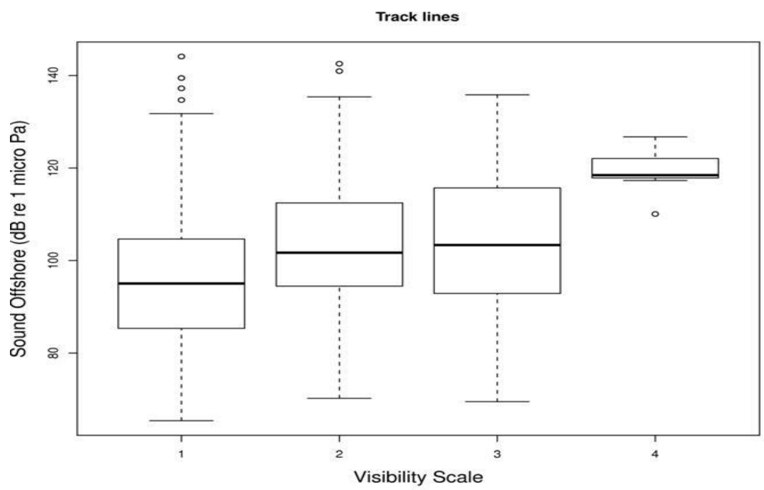


Figure B. 44. Box and whisker plots of offshore sound levels by visibility for the movement dataset. Boxes as described in caption to Figure B.1.

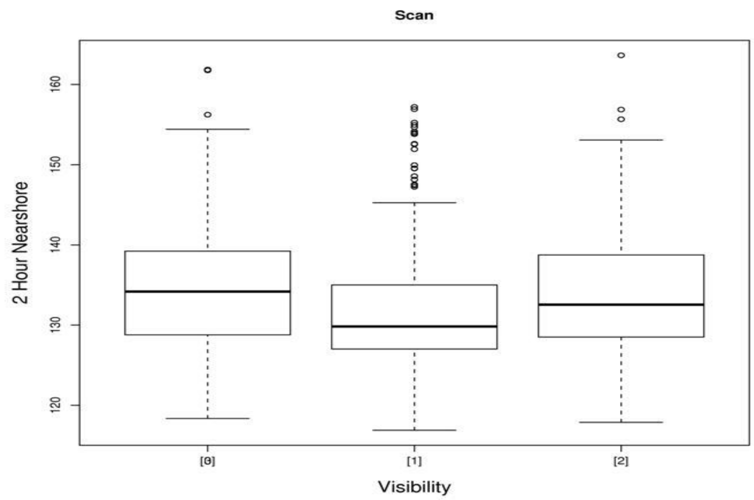


Figure B. 45. Box and whisker plots of cumulative 2 hour nearshore sound levels by visibility for the abundance dataset. Boxes as described in caption to Figure B.1.

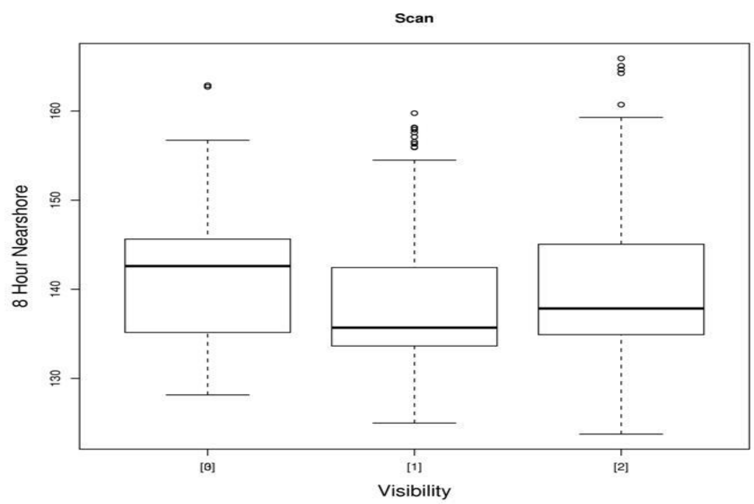


Figure B. 46. Box and whisker plots of cumulative 8 hour nearshore sound levels by visibility for the abundance dataset. Boxes as described in caption to Figure B.1.

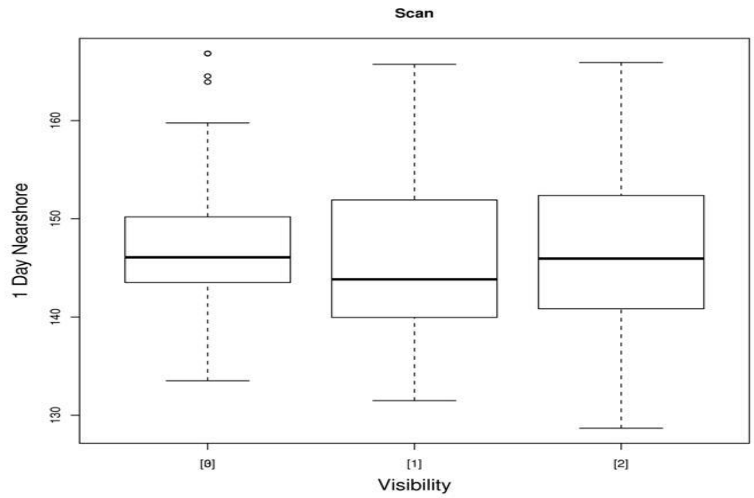


Figure B. 47. Box and whisker plots of cumulative 1 day nearshore sound levels by visibility for the abundance dataset. Boxes as described in caption to Figure B.1.

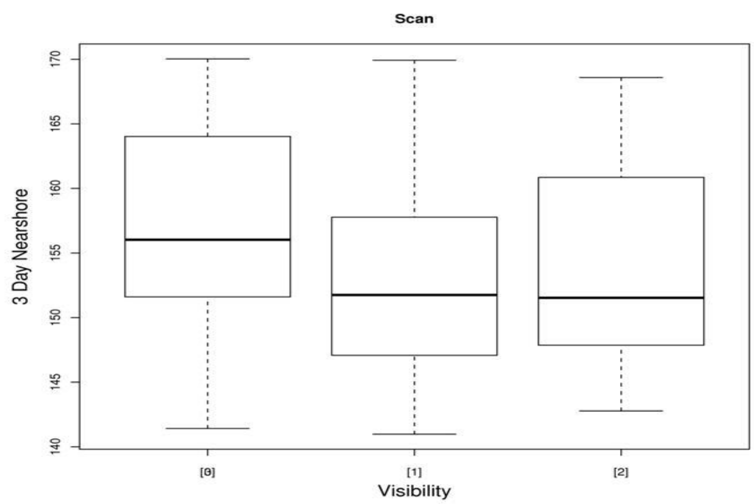


Figure B. 48. Box and whisker plots of cumulative 3 day nearshore sound levels by visibility for the abundance dataset. Boxes as described in caption to Figure B.1.

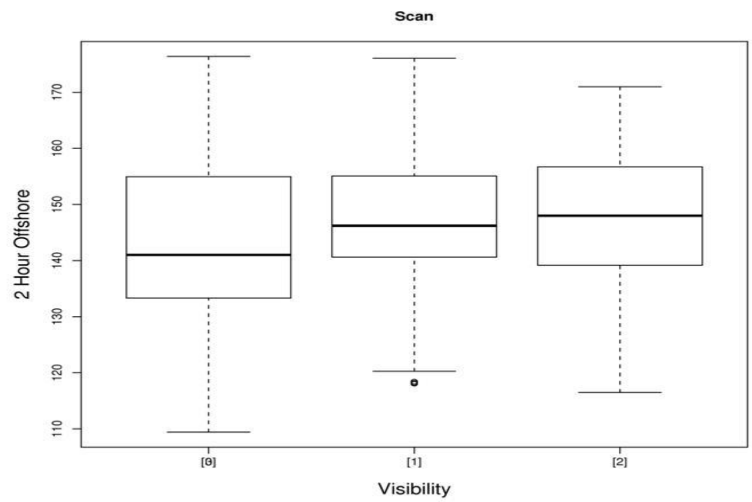


Figure B. 49. Box and whisker plots of cumulative 2 hour offshore sound levels by visibility for the abundance dataset. Boxes as described in caption to Figure B.1.

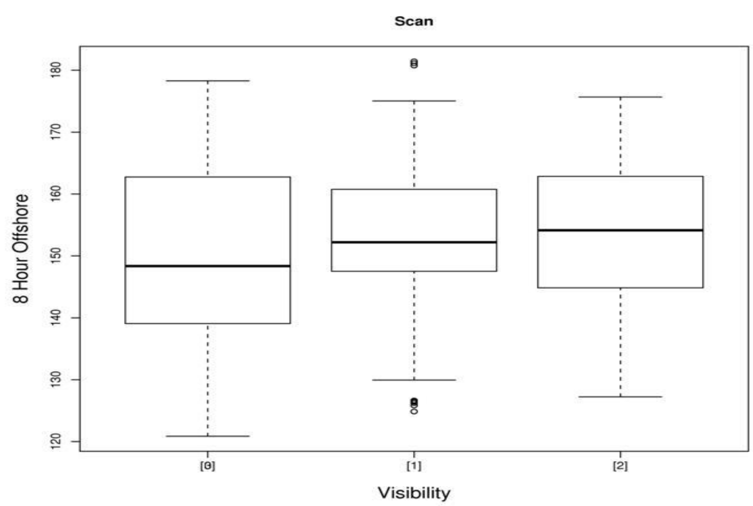


Figure B. 50. Box and whisker plots of cumulative 8 hour offshore sound levels by visibility for the abundance dataset. Boxes as described in caption to Figure B.1.

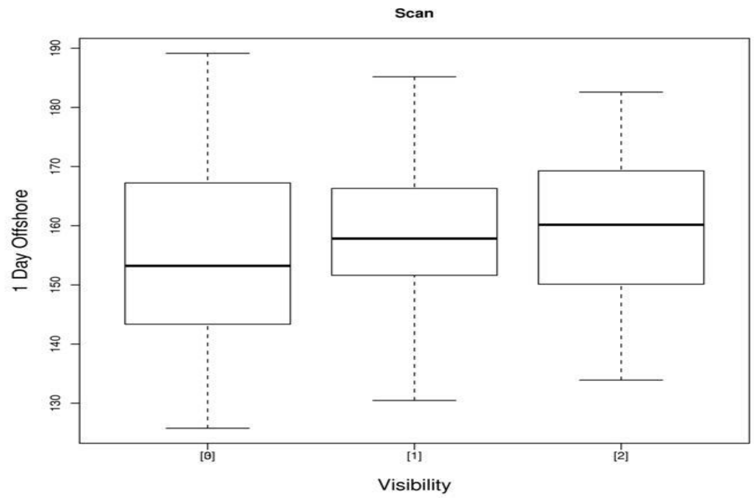


Figure B. 51. Box and whisker plots of cumulative 1 day offshore sound levels by visibility for the abundance dataset. Boxes as described in caption to Figure B.1.

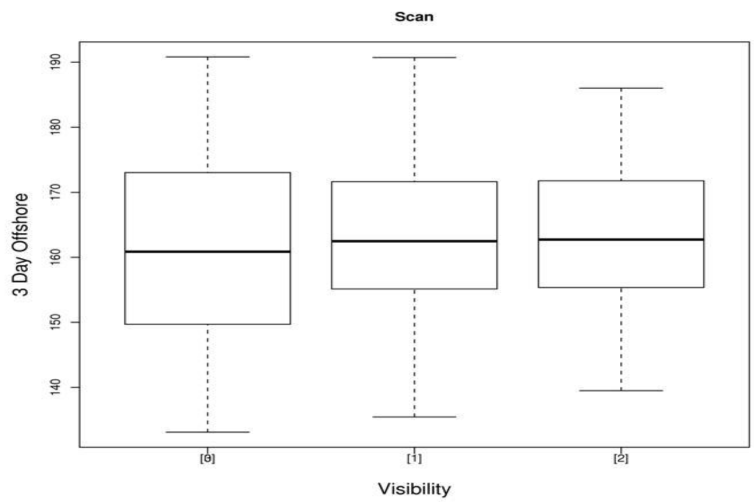


Figure B. 52. Box and whisker plots of cumulative 3 day offshore sound levels by visibility for the abundance dataset. Boxes as described in caption to Figure B.1.

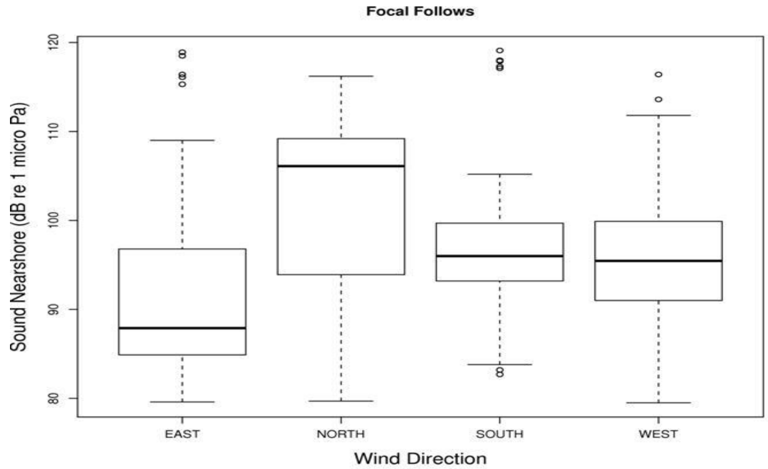


Figure B. 53. Box and whisker plots of nearshore sound levels by wind direction for the respiration dataset. Boxes as described in caption to Figure B.1.

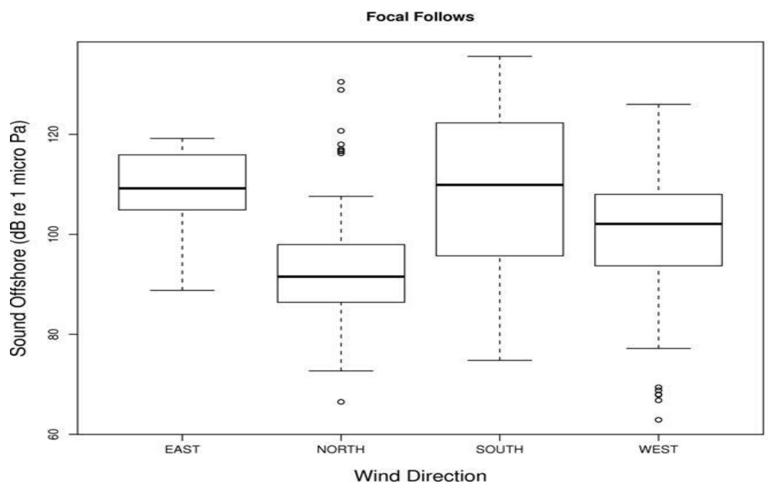


Figure B. 54. Box and whisker plots of offshore sound levels by wind direction for the respiration dataset. Boxes as described in caption to Figure B.1.

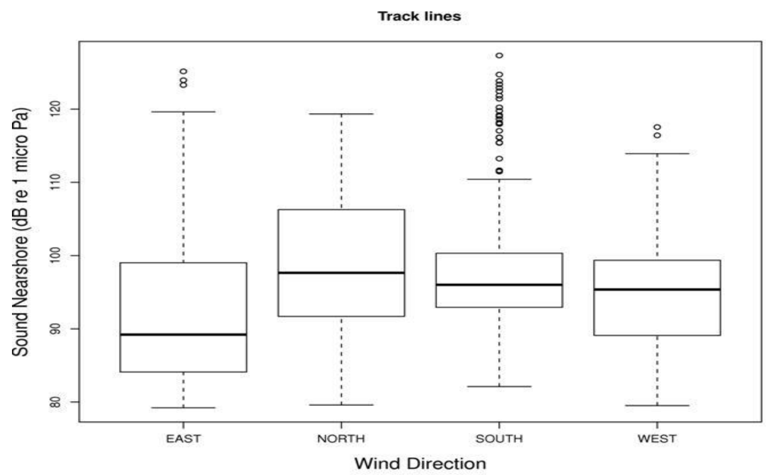


Figure B. 55. Box and whisker plots of nearshore sound levels by wind direction for the movement dataset. Boxes as described in caption to Figure B.1.

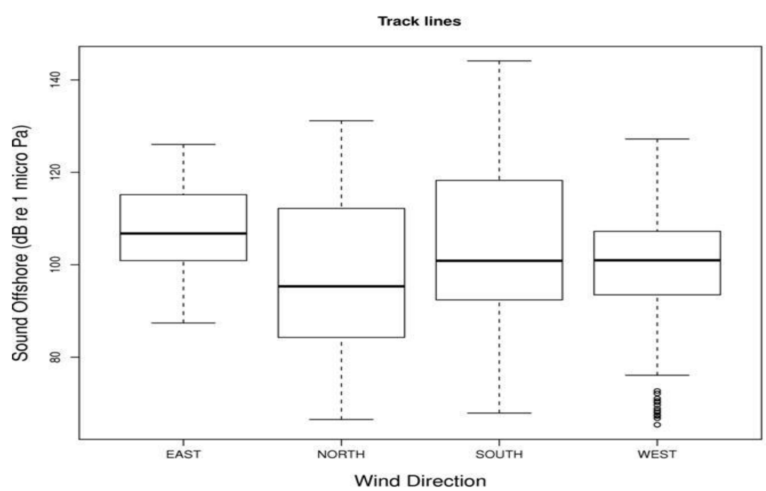


Figure B. 56. Box and whisker plots of offshore sound levels by wind direction for the movement dataset. Boxes as described in caption to Figure B.1.

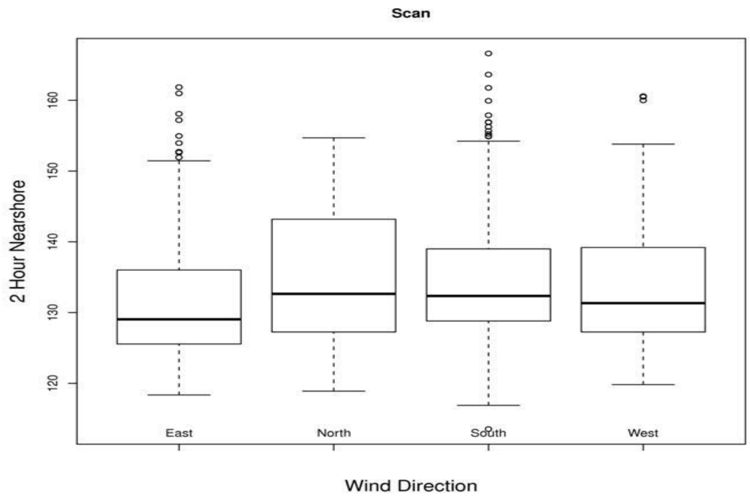


Figure B. 57. Box and whisker plots of cumulative 2 hour nearshore sound levels by wind direction for the abundance dataset. Boxes as described in caption to Figure B.1.

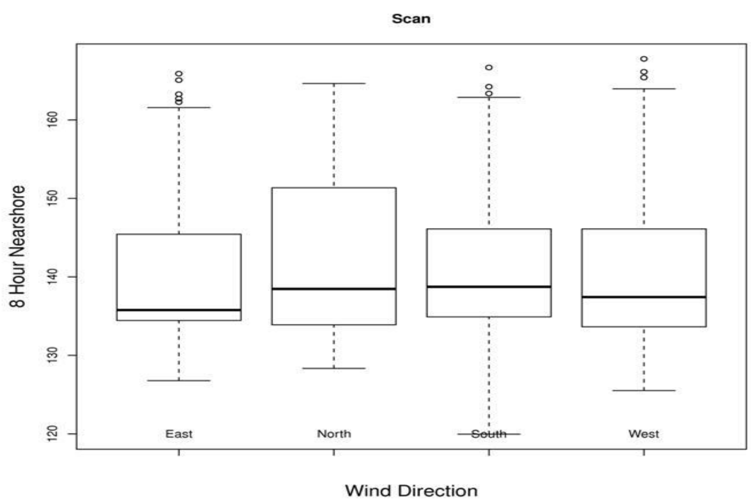


Figure B. 58. Box and whisker plots of cumulative 8 hour nearshore sound levels by wind direction for the abundance dataset. Boxes as described in caption to Figure B.1.

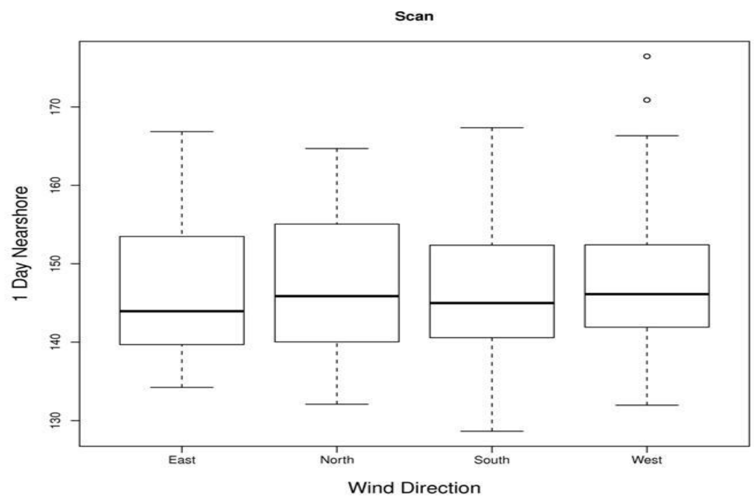


Figure B. 59. Box and whisker plots of cumulative 1 day nearshore sound levels by wind direction for the abundance dataset. Boxes as described in caption to Figure B.1.

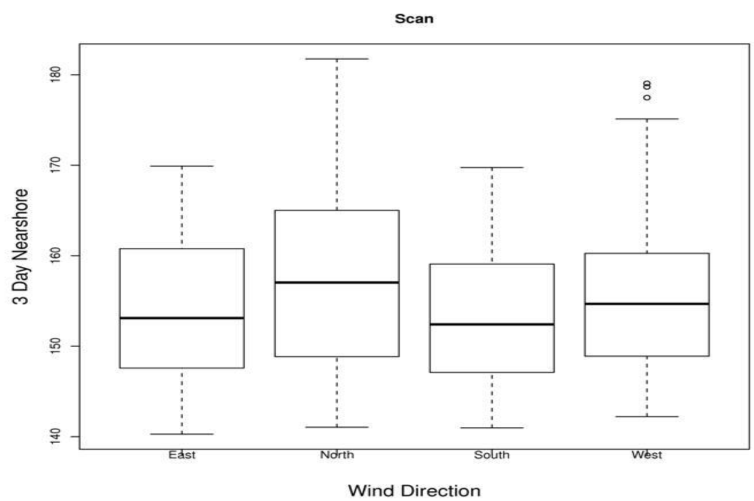


Figure B. 60. Box and whisker plots of cumulative 3 day nearshore sound levels by wind direction for the abundance dataset. Boxes as described in caption to Figure B.1.

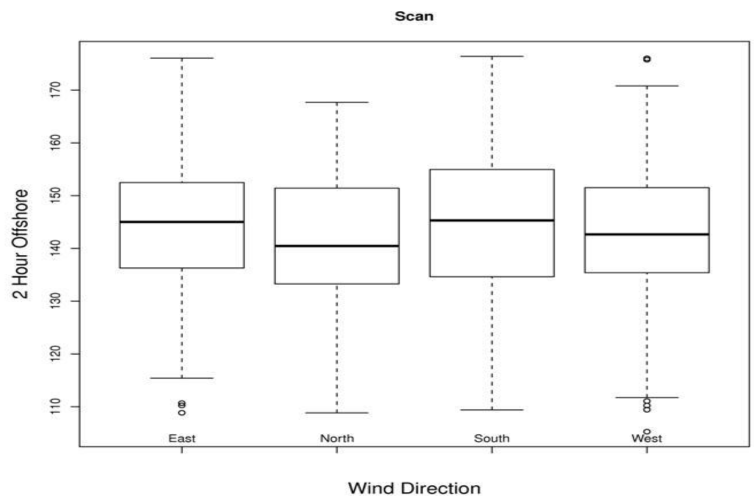


Figure B. 61. Box and whisker plots of cumulative 2 hour offshore sound levels by wind direction for the abundance dataset. Boxes as described in caption to Figure B.1.

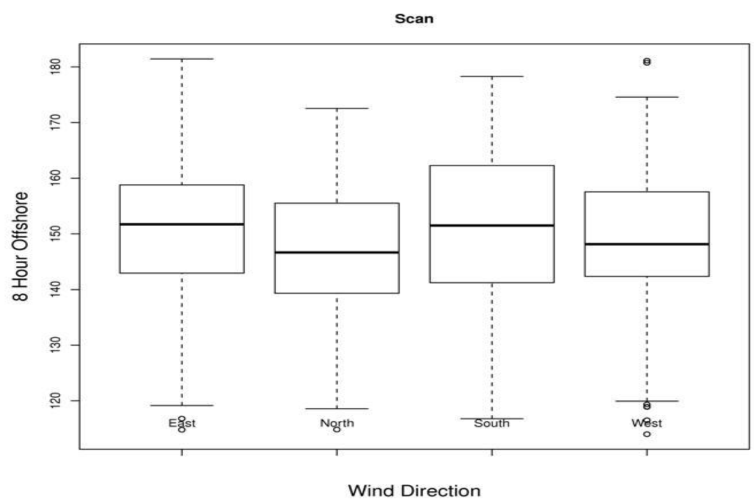


Figure B. 62. Box and whisker plots of cumulative 8 hour offshore sound levels by wind direction for the abundance dataset. Boxes as described in caption to Figure B.1.

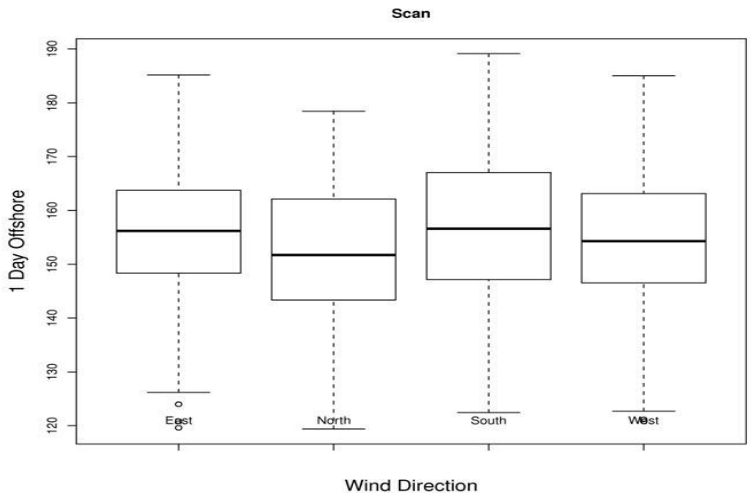


Figure B. 63. Box and whisker plots of cumulative 1 day offshore sound levels by wind direction for the abundance dataset. Boxes as described in caption to Figure B.1.

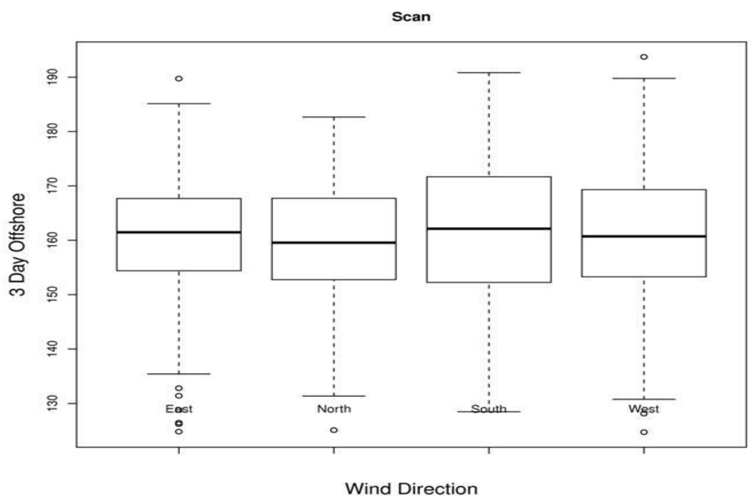


Figure B. 64. Box and whisker plots of cumulative 3 day offshore sound levels by wind direction for the abundance dataset. Boxes as described in caption to Figure B.1.

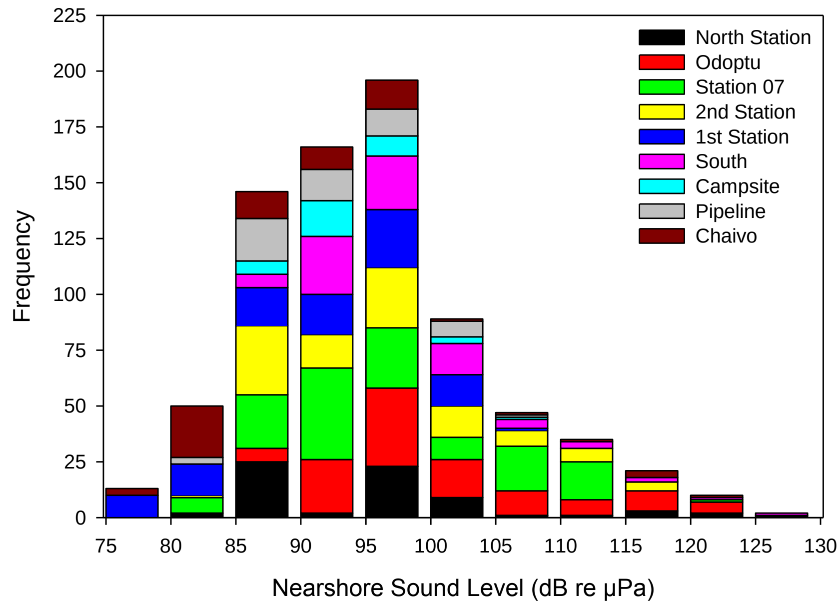


Figure B. 65. Frequency distribution of nearshore underwater sound levels during theodolite tracking observations.

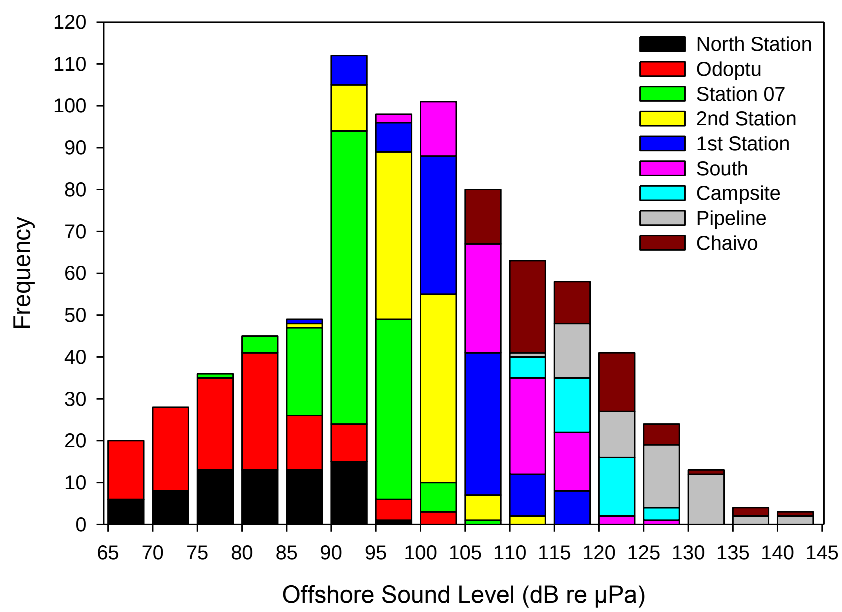


Figure B. 66. Frequency distribution of offshore underwater sound levels during theodolite tracking observations.

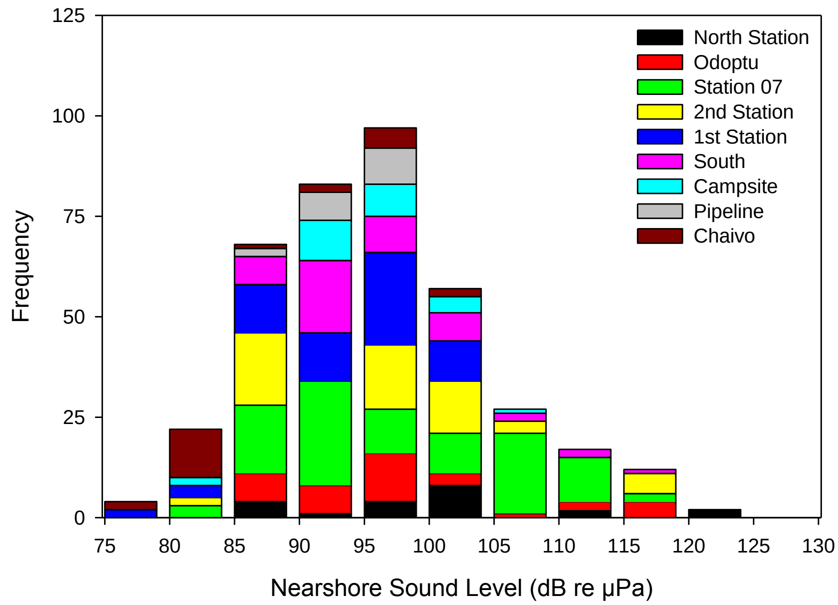


Figure B. 67. Frequency distribution of nearshore underwater sound levels during focal follow observations.

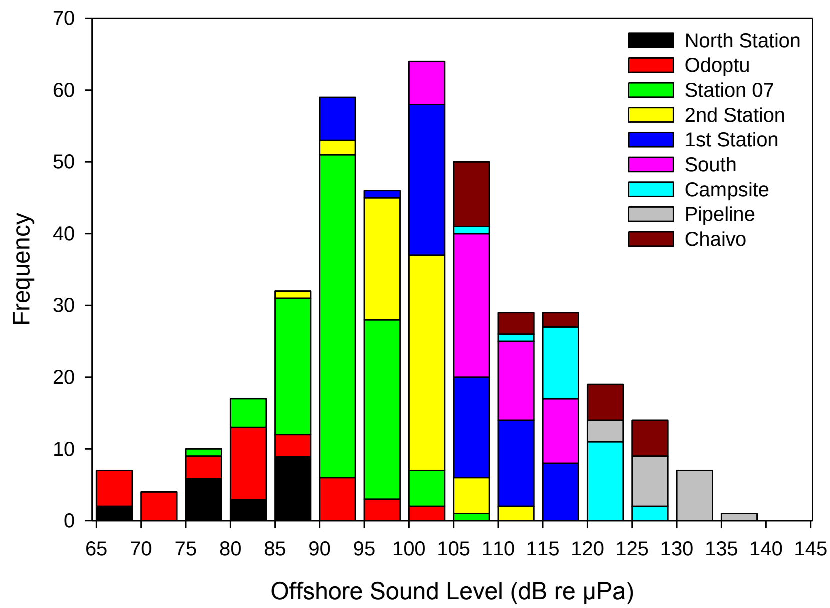


Figure B. 68. Frequency distribution of offshore underwater sound levels during focal follow observations.

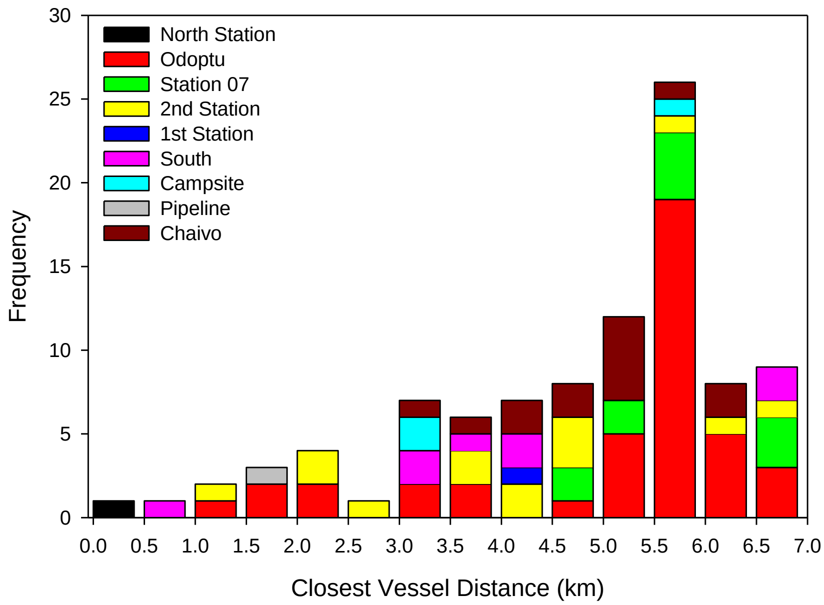


Figure B. 69. Frequency distribution of closest approach to a gray whale by any vessel theodolite tracking observations. Distances were measured to within 5 km of a whale. Positional information beyond 5 km was unavailable for each operational vessel; therefore, the closest vessel distance beyond 5 km is unknown.

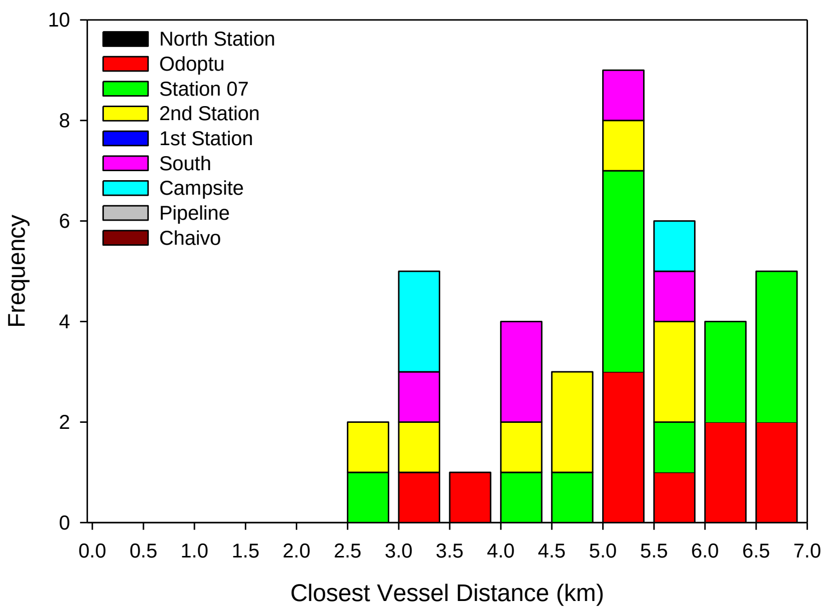


Figure B. 70. Frequency distribution of closest approach to a gray whale by any vessel during focal sessions. Distances were measured to within 5 km of a whale. Positional information beyond 5 km was unavailable for each operational vessel; therefore, the closest vessel distance beyond 5 km is unknown.

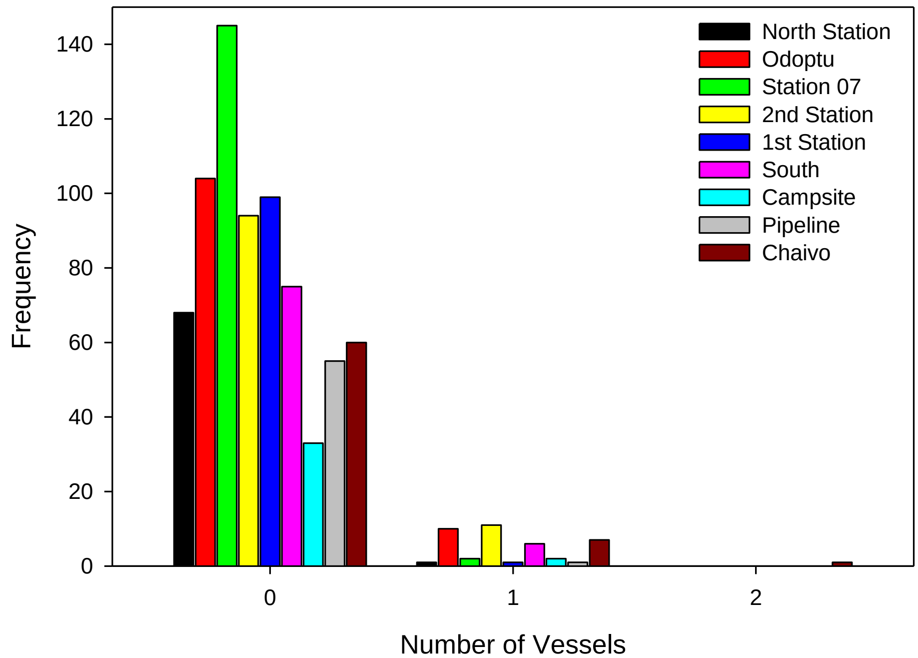


Figure B. 71. Frequency distribution of number of vessels within 5 km of gray whales during theodolite tracking observations.

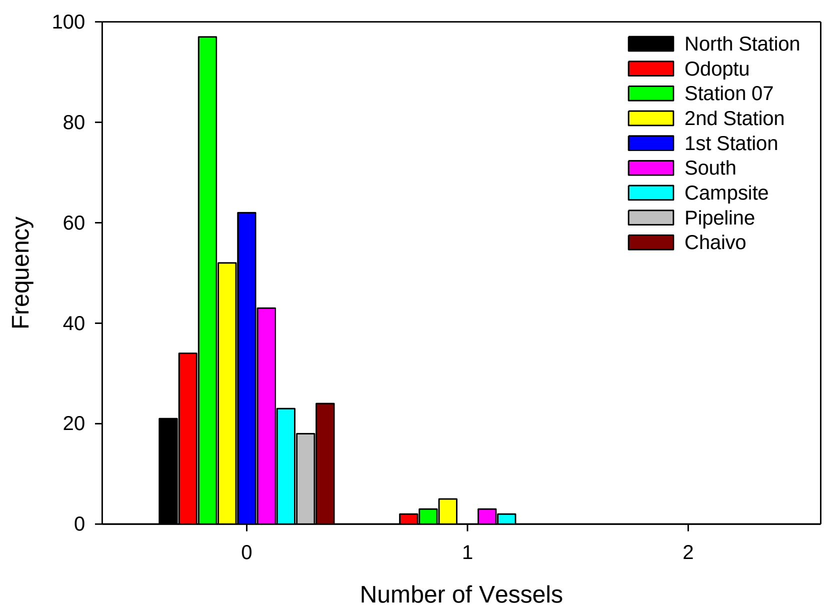


Figure B. 72. Frequency distribution of number of vessels within 5 km of gray whales during focal sessions.

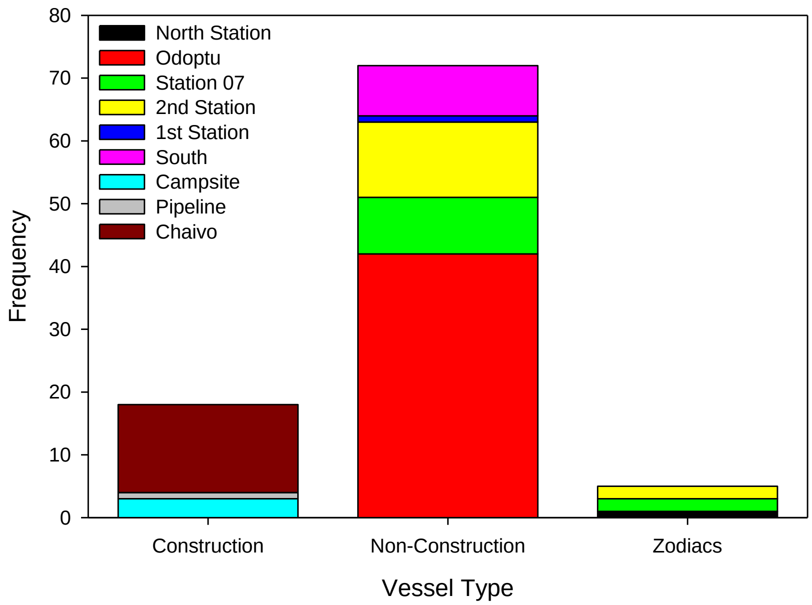


Figure B. 73. Frequency distribution of vessel types observed during theodolite tracking observations.

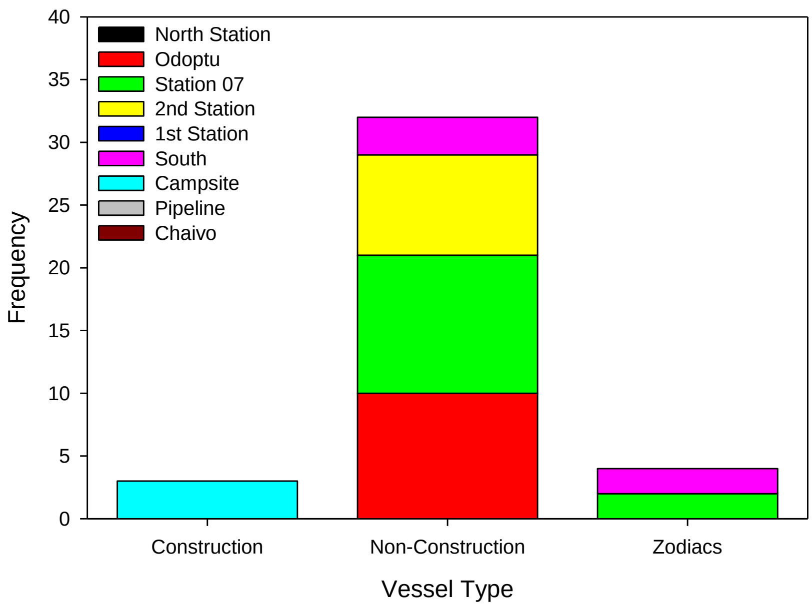


Figure B. 74. Frequency distribution of vessel types observed during focal observations.

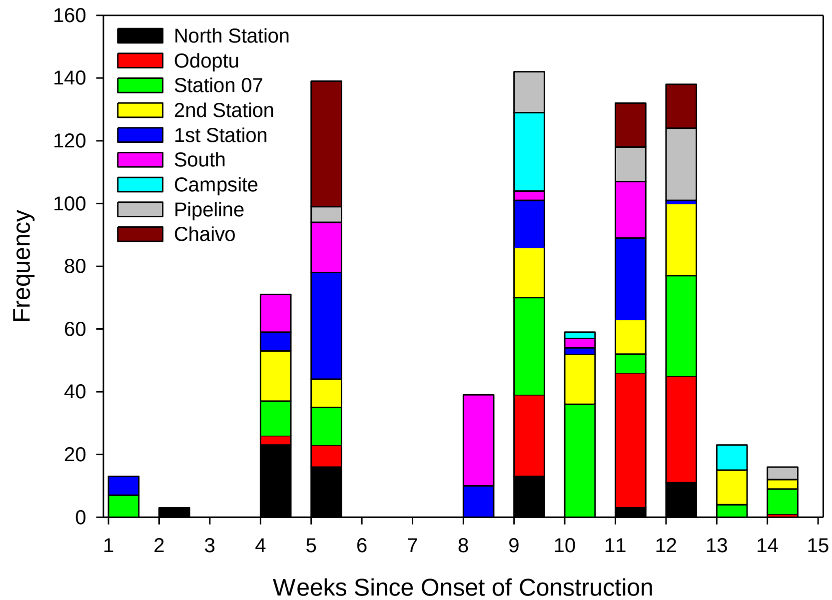


Figure B. 75. Frequency distribution of theodolite tracking observations from the onset of construction activity.

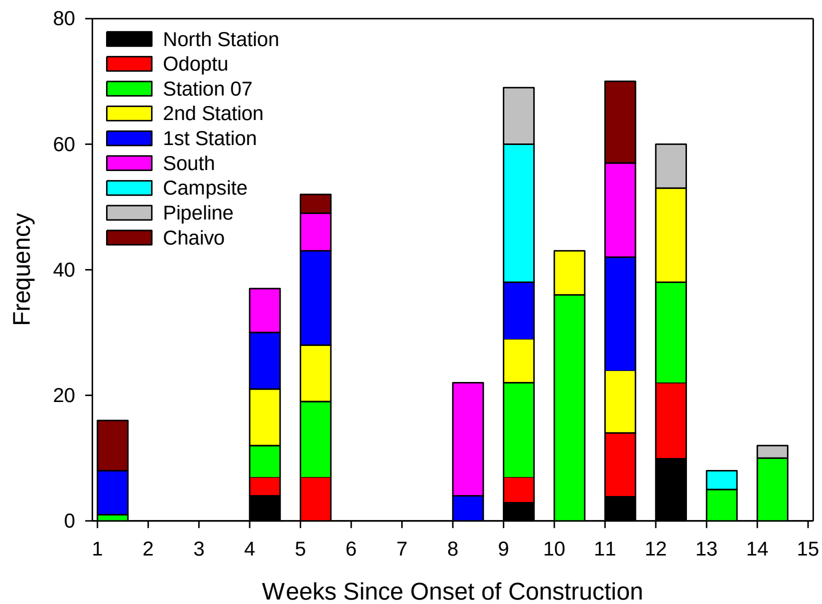


Figure B. 76. Frequency distribution of focal observations from the onset of construction activity.

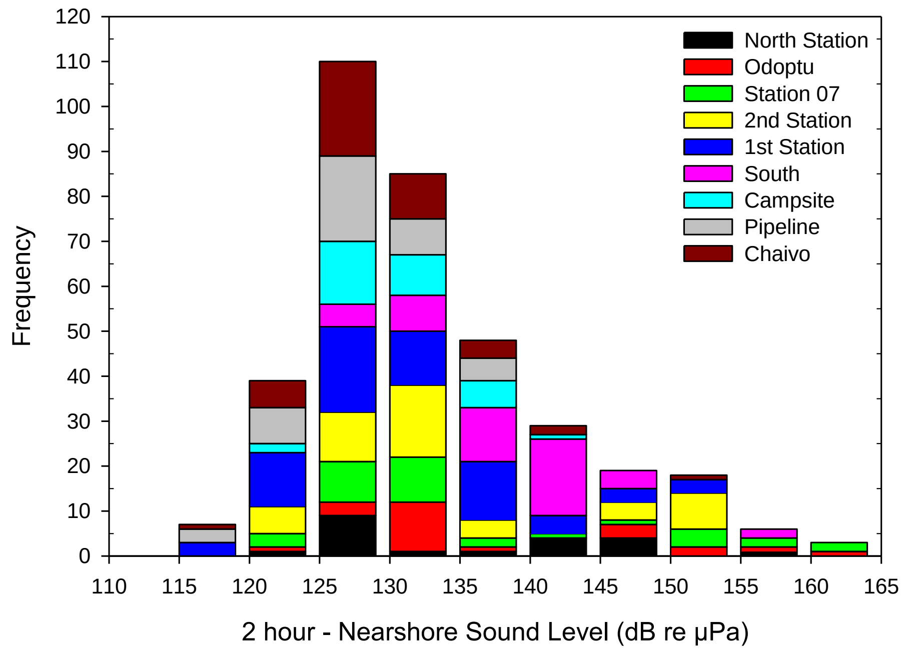


Figure B. 77. Frequency distribution of nearshore sound levels for the preceding 2 hours of a scan observation for the fine scale dataset.

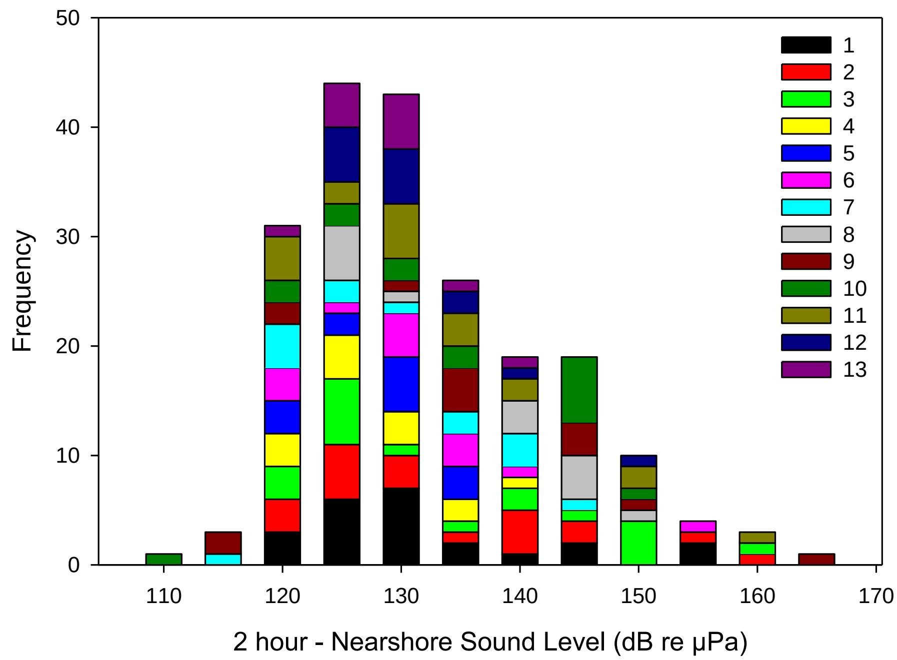


Figure B. 78. Frequency distribution of nearshore sound levels for the preceding 2 hours of a scan observation for the broad dataset.

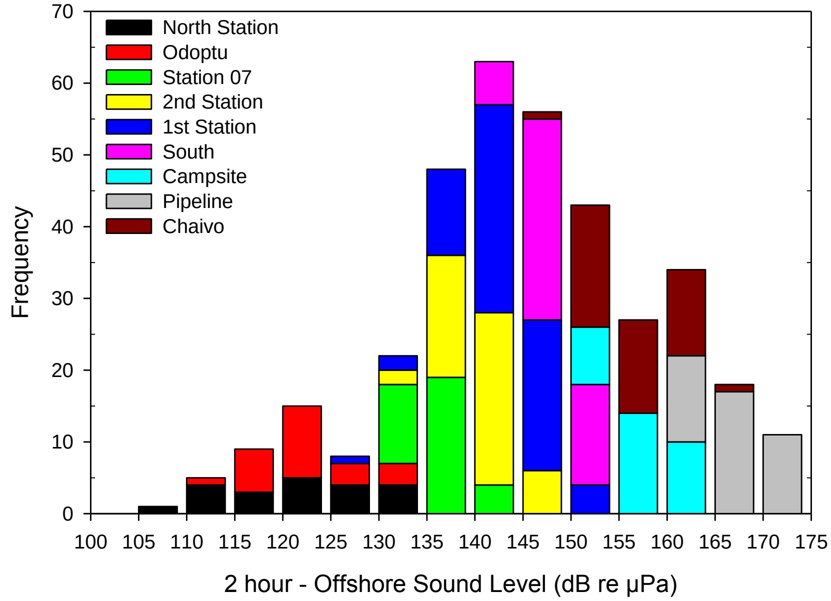


Figure B. 79. Frequency distribution of offshore sound levels for the preceding 2 hours of a scan observation for the fine scale dataset.

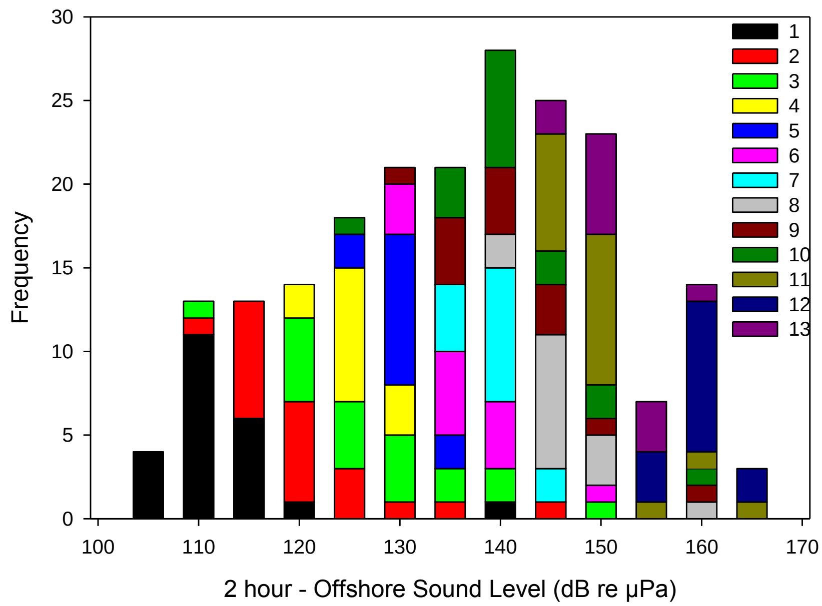


Figure B. 80. Frequency distribution of offshore sound levels for the preceding 2 hours of a scan observation for the broad scale dataset.

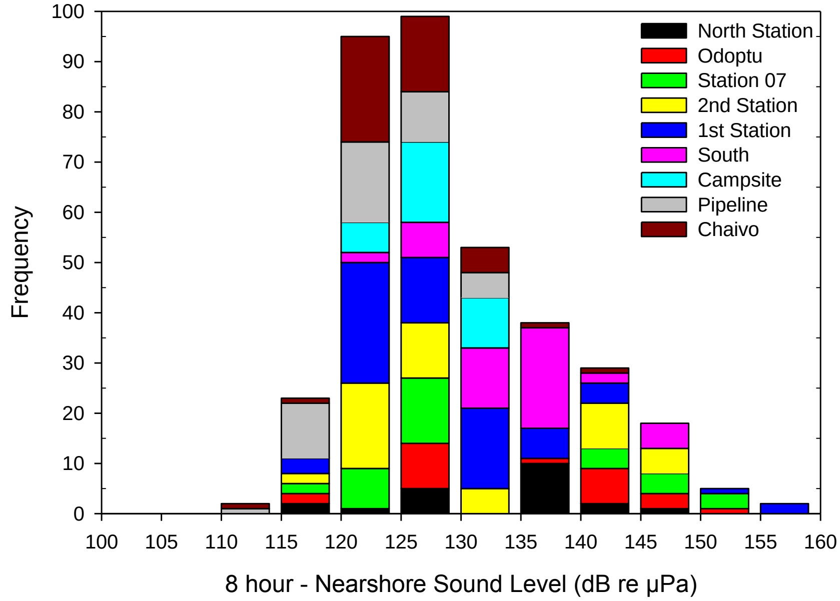


Figure B. 81. Frequency distribution of nearshore sound levels for the preceding 8 hours of a scan observation for the fine scale dataset.

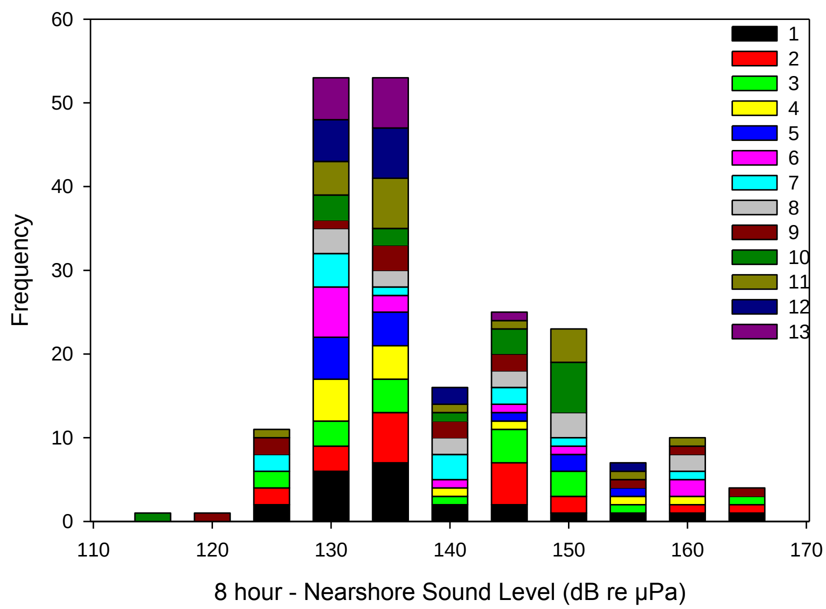


Figure B. 82. Frequency distribution of nearshore sound levels for the preceding 8 hours of a scan observation for the broad scale dataset.

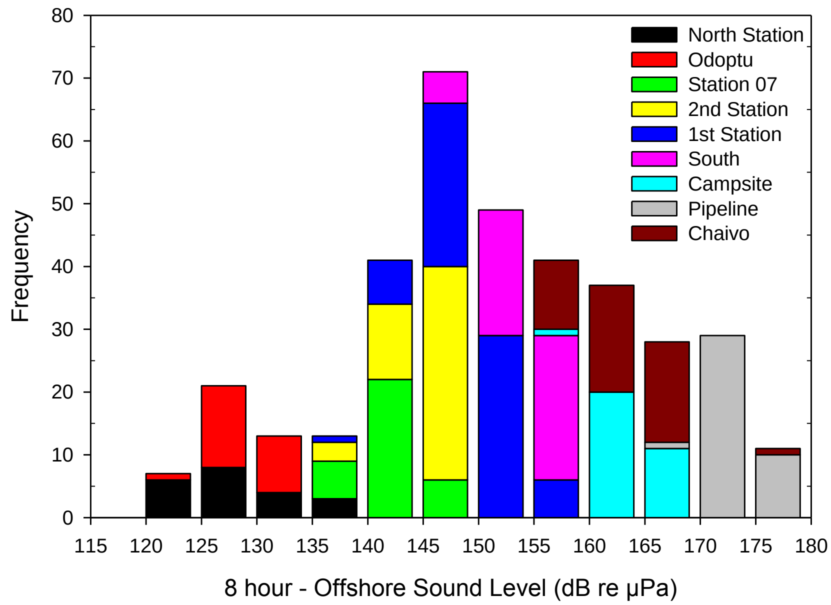


Figure B. 83. Frequency distribution of offshore sound levels for the preceding 8 hours of a scan observation for the fine scale dataset.

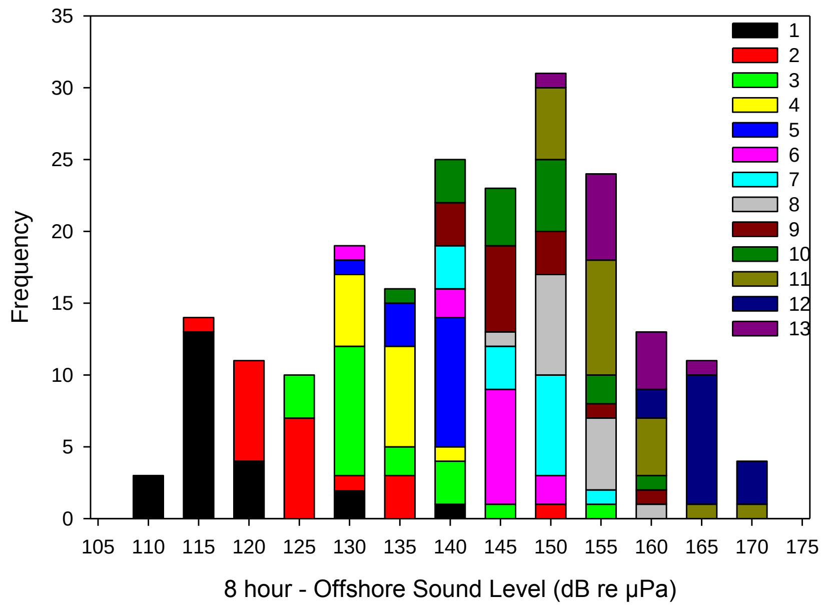


Figure B. 84. Frequency distribution of offshore sound levels for the preceding 8 hours of a scan observation for the broad scale dataset.

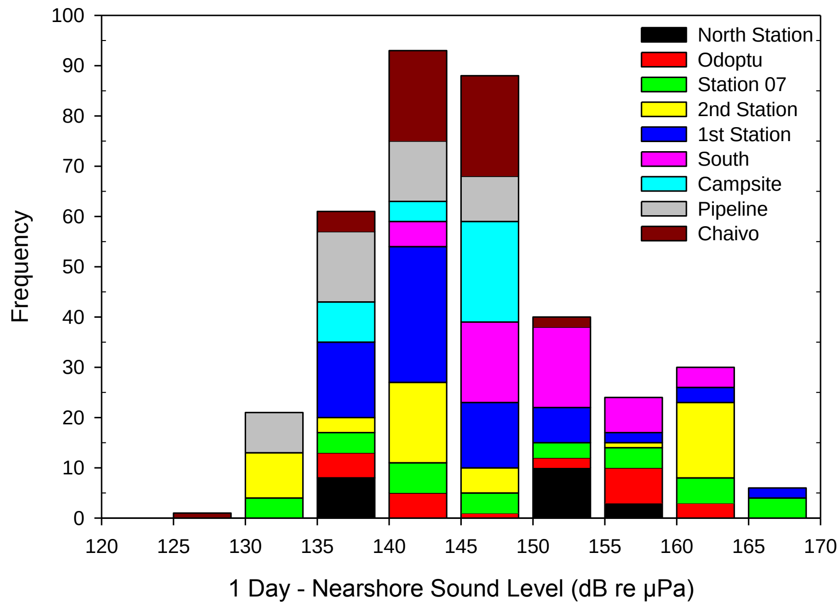


Figure B. 85. Frequency distribution of nearshore sound levels for the preceding 1 day of a scan observation for the fine scale dataset.

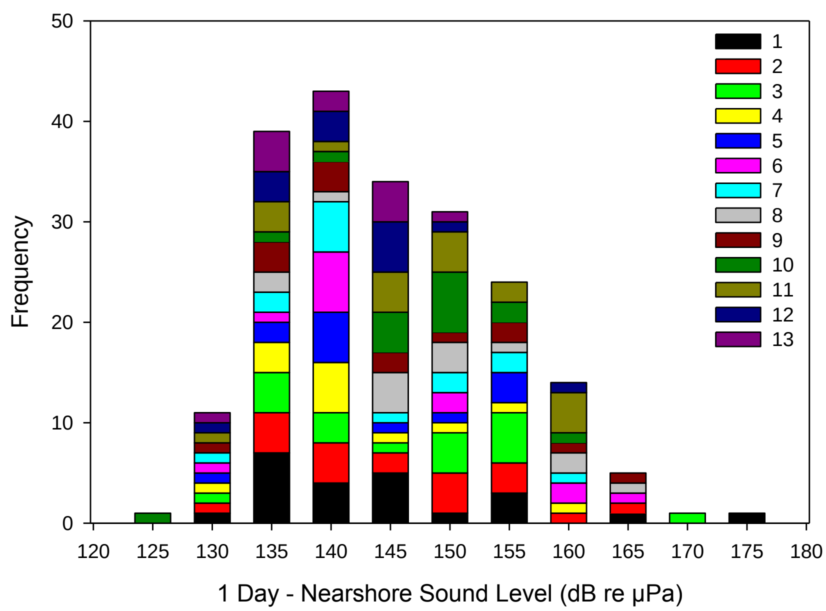


Figure B. 86. Frequency distribution of nearshore sound levels for the preceding 1 day of a scan observation for the broad scale dataset.

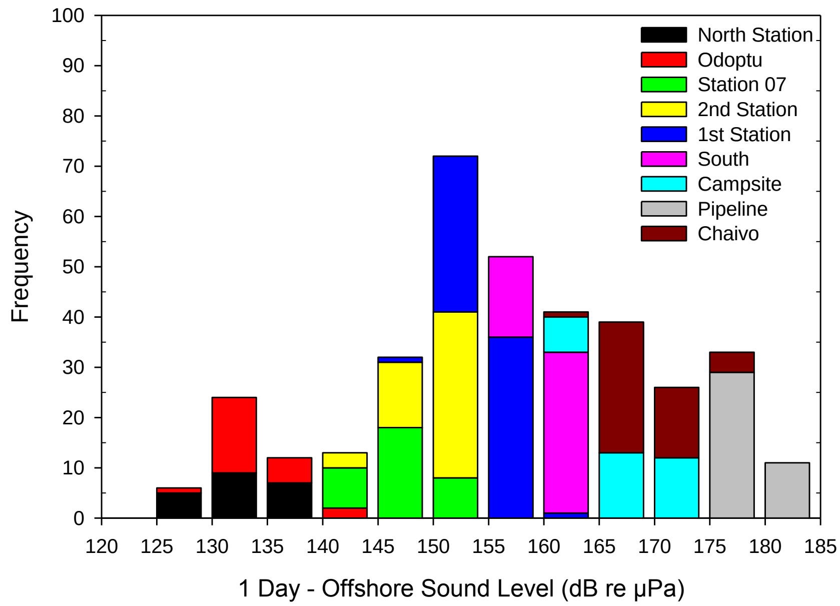


Figure B. 87. Frequency distribution of offshore sound levels for the preceding 1 day of a scan observation for the fine scale dataset.

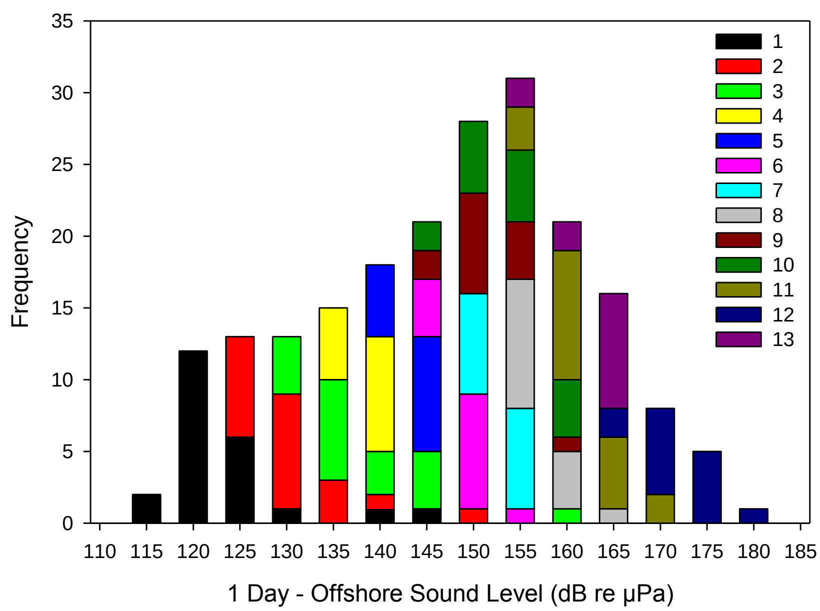


Figure B. 88. Frequency distribution of offshore sound levels for the preceding 1 day of a scan observation for the broad scale dataset.

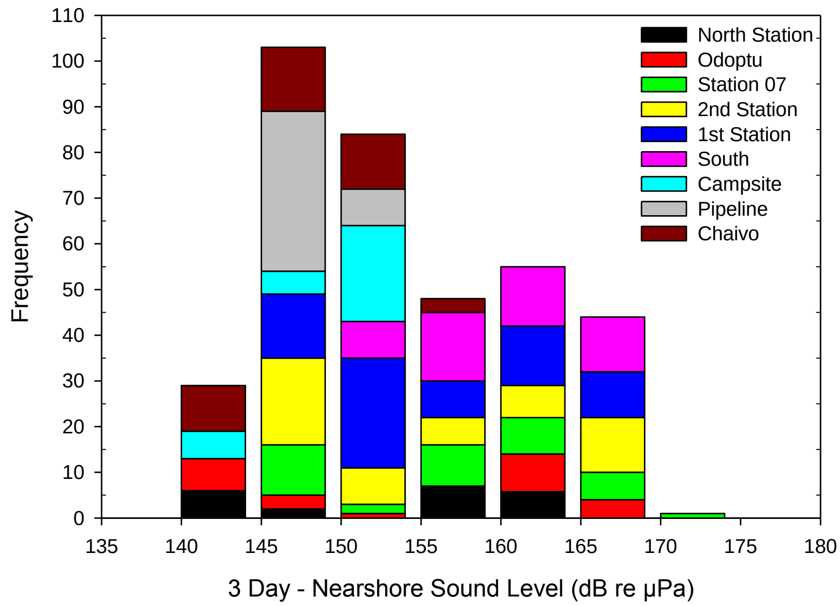


Figure B. 89. Frequency distribution of nearshore sound levels for the preceding 3 days of a scan observation for the fine scale dataset.

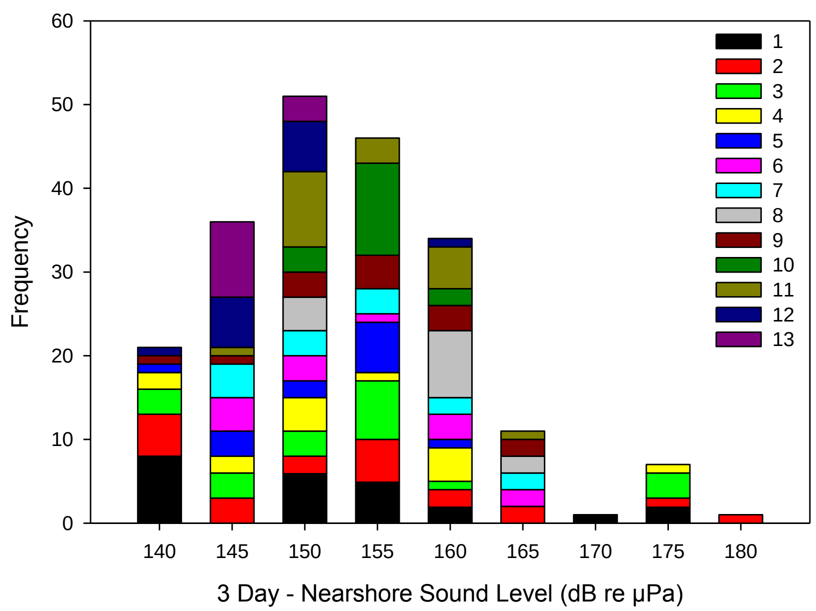


Figure B. 90. Frequency distribution of nearshore sound levels for the preceding 3 days of a scan observation for the broad scale dataset.

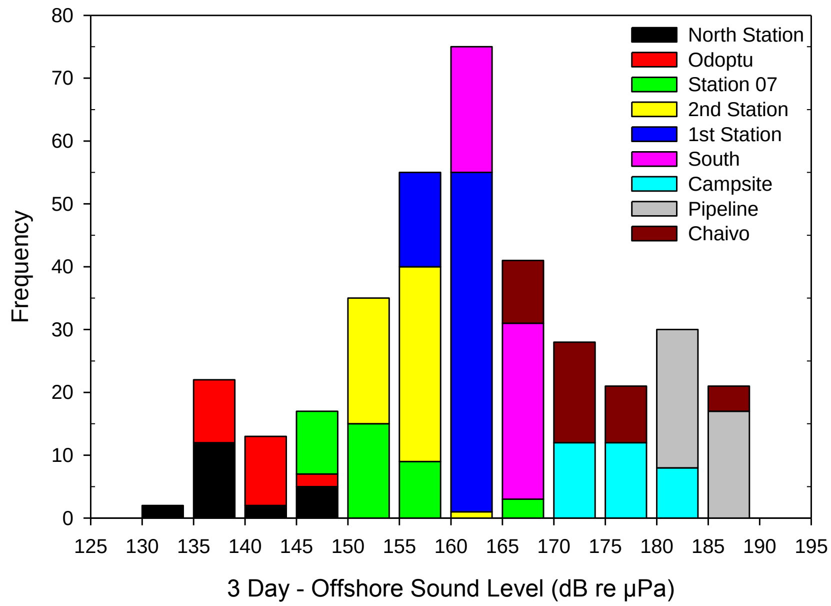


Figure B. 91. Frequency distribution of offshore sound levels for the preceding 3 days of a scan observation for the fine scale dataset.

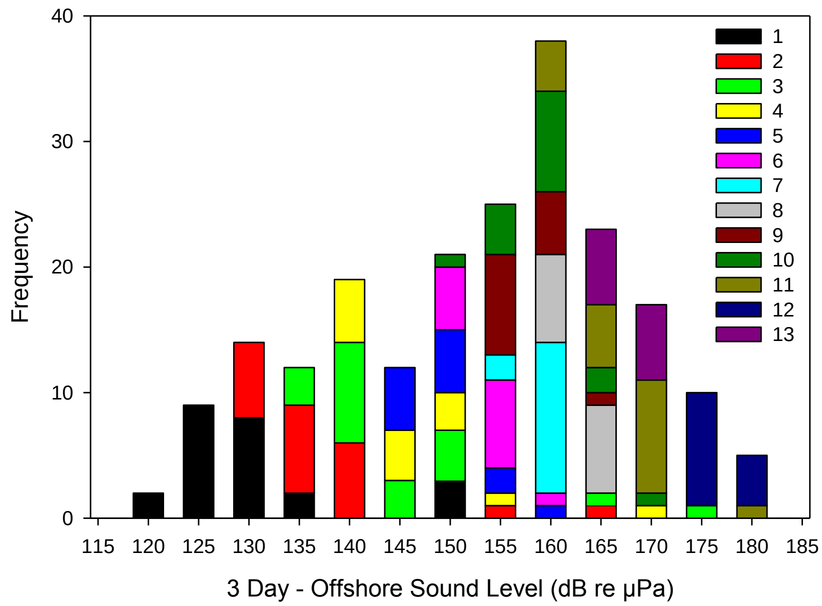


Figure B. 92. Frequency distribution of offshore sound levels for the preceding 3 days of a scan observation for the broad scale dataset.

Appendix C: Correlations

This appendix contains additional results and details concerning the correlations among the variables used in the movement, respiration, and abundance models.

Table C. 1. Pearson's correlation for explanatory variables used in the movement models.

Variables	Days	Time of Day	Distance From Station	Depth	Tide Height	Wind Speed	Swell Height	Number of Vessels	Sound Nearshore	Sound Offshore
Days	1.00	0.06	-0.32	-0.17	0.20	0.05	0.22	-0.07	0.29	-0.24
Time of Day	0.06	1.00	-0.14	-0.01	0.15	-0.08	0.09	0.04	0.01	0.04
Distance From Station	-0.32	-0.14	1.00	0.59	-0.17	0.02	-0.12	0.09	-0.29	0.35
Depth	-0.17	-0.01	0.59	1.00	-0.14	-0.03	-0.17	0.03	-0.14	0.06
Tide Height	0.20	0.15	-0.17	-0.14	1.00	0.06	-0.06	-0.08	0.02	-0.10
Wind Speed	0.05	-0.08	0.02	-0.03	0.06	1.00	0.26	0.03	0.07	-0.16
Swell Height	0.22	0.09	-0.12	-0.17	-0.06	0.26	1.00	0.10	0.29	-0.15
Number of Vessels	-0.07	0.04	0.09	0.03	-0.08	0.03	0.10	1.00	0.31	0.07
Sound Nearshore	0.29	0.01	-0.29	-0.14	0.02	0.07	0.29	0.31	1.00	-0.16
Sound Offshore	-0.24	0.04	0.35	0.06	-0.10	-0.16	-0.15	0.07	-0.16	1.00

Table C. 2. Pearson's correlation for explanatory variables used in the respiration models.

Variables	Days	Time of Day	Distance From Station	Depth	Tide Height	Wind Speed	Swell Height	Number of Vessels	Sound Nearshore	Sound Offshore
Days	1.00	0.02	-0.50	-0.30	0.24	0.34	0.22	0.05	0.27	-0.41
Time of Day	0.02	1.00	-0.06	-0.04	0.19	0.07	0.28	0.12	0.15	0.18
Distance From Station	-0.50	-0.06	1.00	0.63	-0.14	-0.30	-0.29	-0.06	-0.33	0.35
Depth	-0.30	-0.04	0.63	1.00	-0.21	-0.12	-0.32	-0.03	-0.19	0.18
Tide Height	0.24	0.19	-0.14	-0.21	1.00	0.12	0.04	0.07	0.08	-0.18
Wind Speed	0.34	0.07	-0.30	-0.12	0.12	1.00	0.30	0.00	0.13	-0.39
Swell Height	0.22	0.28	-0.29	-0.32	0.04	0.30	1.00	0.17	0.38	-0.16
Number of Vessels	0.05	0.12	-0.06	-0.03	0.07	0.00	0.17	1.00	0.42	0.05
Sound Nearshore	0.27	0.15	-0.33	-0.19	0.08	0.13	0.38	0.42	1.00	-0.20
Sound Offshore	-0.41	0.18	0.35	0.18	-0.18	-0.39	-0.16	0.05	-0.20	1.00

Table C. 3. Pearson's correlation for explanatory variables used in the abundance models.

Variables	Days	Time of Day	Tide Height	Wind Speed	Number of Vessels	Week Since	2H_OS	8H_OS	1D_OS	3D_OS	2H_NS	8H_NS	1D_NS	3D_NS
Days	1.00	-0.09	0.02	0.07	0.08	1.00	0.11	0.11	0.14	0.18	0.37	0.34	0.35	0.36
Time of Day	-0.09	1.00	-0.12	0.08	-0.01	-0.09	-0.05	-0.02	-0.06	-0.04	-0.05	0.06	0.00	0.03
Tide Height	0.02	-0.12	1.00	-0.05	0.03	0.02	0.00	-0.04	-0.06	-0.08	0.09	0.01	0.00	-0.06
Wind Speed	0.07	0.08	-0.05	1.00	-0.06	0.08	-0.02	-0.03	-0.03	-0.02	0.05	0.02	-0.04	0.00
# Vessels	0.08	-0.01	0.03	-0.06	1.00	0.08	-0.03	-0.03	-0.03	-0.03	0.29	0.28	0.25	0.20
Week Since	1.00	-0.09	0.02	0.08	0.08	1.00	0.11	0.11	0.13	0.18	0.35	0.32	0.35	0.36
2H_OS	0.11	-0.05	0.00	-0.02	-0.03	0.11	1.00	0.98	0.97	0.95	0.04	-0.05	-0.04	-0.06
8H_OS	0.11	-0.02	-0.04	-0.03	-0.03	0.11	0.98	1.00	0.99	0.97	-0.01	-0.06	-0.04	-0.04
1D_OS	0.14	-0.06	-0.06	-0.03	-0.03	0.13	0.97	0.99	1.00	0.98	-0.05	-0.09	-0.05	-0.05
3D_OS	0.18	-0.04	-0.08	-0.02	-0.03	0.18	0.95	0.97	0.98	1.00	-0.07	-0.10	-0.07	-0.04
2H_NS	0.37	-0.05	0.09	0.05	0.29	0.35	0.04	-0.01	-0.05	-0.07	1.00	0.90	0.78	0.56
8H_NS	0.34	0.06	0.01	0.02	0.28	0.32	-0.05	-0.06	-0.09	-0.10	0.90	1.00	0.89	0.65
1D_NS	0.35	0.00	0.00	-0.04	0.25	0.35	-0.04	-0.04	-0.05	-0.07	0.78	0.89	1.00	0.73

*Scan Vessels was excluded from the list of possible covariates for models when both datasets were included.