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Methodology for preparing Multivariate Analysis of 2006 data

WESTERN GRAY WHALE MOVEMENT, BEHAVIOR, AND RELATIVE ABUNDANCE IN RELATION TO VESSEL AND PIPELINE CONSTRUCTION ACTIVITY IN 2006

The objective of this scope of work is to examine western gray whale (*Eschrichtius robustus*) movements, behaviors, and relative abundance as indicators of response to underwater industrial sound levels during pipeline construction activity as well as research vessels that occurred near the Piltun feeding area during the summer of 2006. The primary feeding grounds of this endangered population overlaps with existing and planned oil and gas development being conducted by Sakhalin Energy Investment Company (SEIC) and Exxon Neftegas Limited (ENL) and it is important to understand, minimize and/or mitigate potential anthropogenic activity that may disrupt western gray whales feeding in preferred habitats. Since 1997, SEIC and ENL have recognized these issues and sponsored several monitoring programs to understand both natural variation and potential sources of impacts that their activities may have on the health of the western gray whale population. These studies include acoustics, benthic, behavior, movement, abundance, distribution and population monitoring. This proposal intends on utilizing the information gathered from several of these studies to further understand the behavioral and spatial ecology of this population and investigate potential sources of disturbance.

One concern in the short- and long-terms is the amount and levels of noise in relation to vessel, construction, drilling, dredging, etc, produced during oil and gas project development and operation. The effects of marine noise on baleen whales have been documented for a number of species, such as bowhead whales (Ljungblad *et al.* 1988, Reeves *et al.* 1984, Richardson *et al.* 1999, Richardson *et al.* 1986), humpback whales (McCauley *et al.* 2000, McCauley *et al.* 1998), and gray whales (Malme and Miles 1985, Malme *et al.* 1986). For eastern gray whales, Malme *et al.* (1986) found that ~10% of the whales stopped feeding and moved away from an active seismic ship when received sound levels near the whales exceeded 163 dB re 1µPa (rms). For more continuous sounds, Malme *et al.* (1986) observed 10-50% of feeding eastern gray whales avoiding an area exposed to industrial noise levels of 120 dB. Western gray whales have also been documented to respond to sounds produced during seismic surveys (Gailey *et al.* in Press, Johnson *et al.* in Press, Würsig *et al.* 1999, Yazvenko *et al.* in Press). At higher received sound energy exposure levels, whales traveled faster, changed directions of movement less, were recorded further from shore, and stayed under water longer between respirations (Gailey *et al.* in Press). 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 summer of 2005, SEIC initiated construction of the Piltun Astokh-B (PA-B) platform with the placement of a Concrete Gravity Based Structure, or CGBS. The PA-B platform is located near-shore (~13 km from shore in 30 m water depth) and in close proximity to the Piltun gray whale feeding area. With the exception of distance from shore, both univariate and multivariate analyses found no significant effects in relation to gray whale movement and behavior for most of the subtle indicators of response. This could be a result of the noise mitigation strategy employed to minimize sound exposure levels above 120 dB within the Piltun feeding area during industrial/construction operations, and actively mitigating and monitoring sound levels in the field (SEIC 2005, Rutenko 2006). Distance from shore, however, was significantly associated with sound level, with gray whales predicted to be slightly further from shore as sound level increased. Sound levels in this study were confounded with nearshore research vessels and CGBS related activity and therefore we were unable to test the effects of one or the other sound source directly. Gray whales were observed to be particularly sensitive to nearshore research vessels approaching within 0.5 km of the whale, and this response could potentially have led to the offshore movement observed in relation to sound levels. Gailey *et al.* (2007b) argued that some of the highest sound levels were those due to nearshore research vessels as opposed to the construction activity.

In 2006, pipeline construction activity was initiated from Piltun Astokh-B (PA-B) and Molikpaq (PA-A) platforms. The route of the pipeline is illustrated in Figure 1, coming ashore south of the previously known (Piltun Area) nearshore feeding grounds of gray whales. We term this region as “Chaivo Area” for this report. The PA-A and PA-B platforms are located near-shore (~13-16 km from shore in 30 m water depth). Pipeline placement consisted of multiple phases and predictive acoustic models were conducted prior to construction and used as a mitigation measure to minimize sound levels within the known foraging habitat of western gray whales. Sound levels were monitored in the field in real-time to ensure that levels were below criteria levels (see Rutenko 2007). Prediction of sound levels generated by dredging, pipeline placement, and backfilling activities was part of a noise management strategy, initiated prior to the construction activity, and acoustic and behavior monitoring programs were employed during construction to monitor the potential impacts on western gray whales.

Because gray whales are potentially impacted by several factors simultaneously -- such as natural and environmental parameters, various types and intensities of anthropogenic activities, and their own endogenous motivations potentially related to space, time, and/or season -- it is incumbent on us to conduct reasonable multivariate analyses to investigate potential impacts related to sound exposure and other potential impacts while attempting to account for natural variability. Multivariate analyses have been shown to be more useful analytical tools than univariate analyses in establishing statistical correlations between behavioral parameters and sound exposure (Gailey *et al.* in Press, 2007b). Furthermore, univariate analyses may not always provide adequate representation of potential impact given the above mentioned factors of potential influence. In 2001, we found non-significant results for our univariate approach relative to the transient sounds produced during a geophysical seismic survey, but after accounting for environmental and temporal factors in a multivariate analysis, several behavioral parameters were found to be statistically correlated with several sound variables that characterized sound exposure (Würsig *et al.* 2002, Gailey *et al.* in Press). In addition, multivariate techniques provide an advantage for greater statistical power due to the number of techniques available to account for autocorrelation between subsequent bins of the same track or focal-follow observation. These techniques increase the number of observations that can be included in the analyses, which increase the number of representatives. In contrast, in the univariate analyses, one representative bin was randomly selected from each focal or track session to avoid concerns about autocorrelation, which, consequently, reduced effective sample size and limited interpretation of the results.

Objectives

The primary objective of this proposal is to evaluate behavioral response indicators and their relationship to underwater industrial sound levels and vessel activity (number and distances) that occurred during the 2006 offshore pipeline construction season. Research vessel activity also occurred near and in the Piltun feeding area, and the effects of these vessels on whale movement, behavior, abundance, and distribution will be analyzed. We propose to accomplish these objectives by developing individual models that account for sources of natural variation prior to assessment of industrial or vessel effects. Multivariate regression techniques will be conducted to incorporate non-anthropogenic environmental, temporal, spatial, and behavioral variables. Sound levels and vessel distance variables will be added to the model one at a time to assess the potential impacts that industrial operations and other sources of anthropogenic activities may have had on western gray whales.

METHODS

Behavioral and Acoustic Monitoring

Both acoustics and behavioral monitoring occurred during dredging, pipeline placement, and backfilling activities. Behavioral monitoring was conducted on good weather days while acoustic monitoring occurred continuously throughout the gray whale foraging period. For behavioral observations, three methodological approaches were employed to monitor the relative abundance, behavior, and movement patterns of western gray whales from shore: 1) scan sampling, 2) focal animal follows, and 3) theodolite tracking. These techniques have been used since 2001 to understand and monitor natural as well as potential anthropogenic impacts on the behavior of western gray whales (Gailey *et al.* 2004, 2005, 2006, 2007a, 2007b, *in Press*, Würsig *et al.* 2002, Würsig *et al.* 2003). In conjunction with behavioral observations, the pipeline and construction activity was monitored acoustically with eight Autonomous Underwater Acoustic Recorders

(AUAR) (Rutenko 2007). Methodological details for acoustic and behavioral monitoring are described in Rutenko (2007) and Gailey *et al.* (2007a), respectively.

Effort

Behavioral research effort was conducted from 23 June to 26 September 2006 (see Gailey *et al.* 2007a, Appendix 1). Three behavioral teams were employed to monitor gray whale abundance, distribution, movement, and respiration patterns at nine geographic locations. Two observation teams conducted effort at the six most northern locations (North Station to South Station). These Piltun area platforms have been used since 2004. In 2006, a third behavior team monitored gray whales in the vicinity of the pipeline landfall location at three stations in the Chaivo area (Figure 1).

A total of 64 (with both stations, 32 actual) days (413 hrs) of effort was spent at the six most northern-based shore stations in the Piltun region. A total of 33 days (203 hrs) of effort was spent at the three most southern-based shore stations in the Chaivo area. Unfortunately, weather conditions, primarily fog, continuously hampered behavioral observations at all stations for an extended period of time (21 days) from early to late August. Noise produced during anthropogenic activities was, however, monitored continuously throughout the gray whale feeding season by the acoustics monitoring team from the Pacific Oceanographic Institute, Vladivostok (Rutenko 2007).

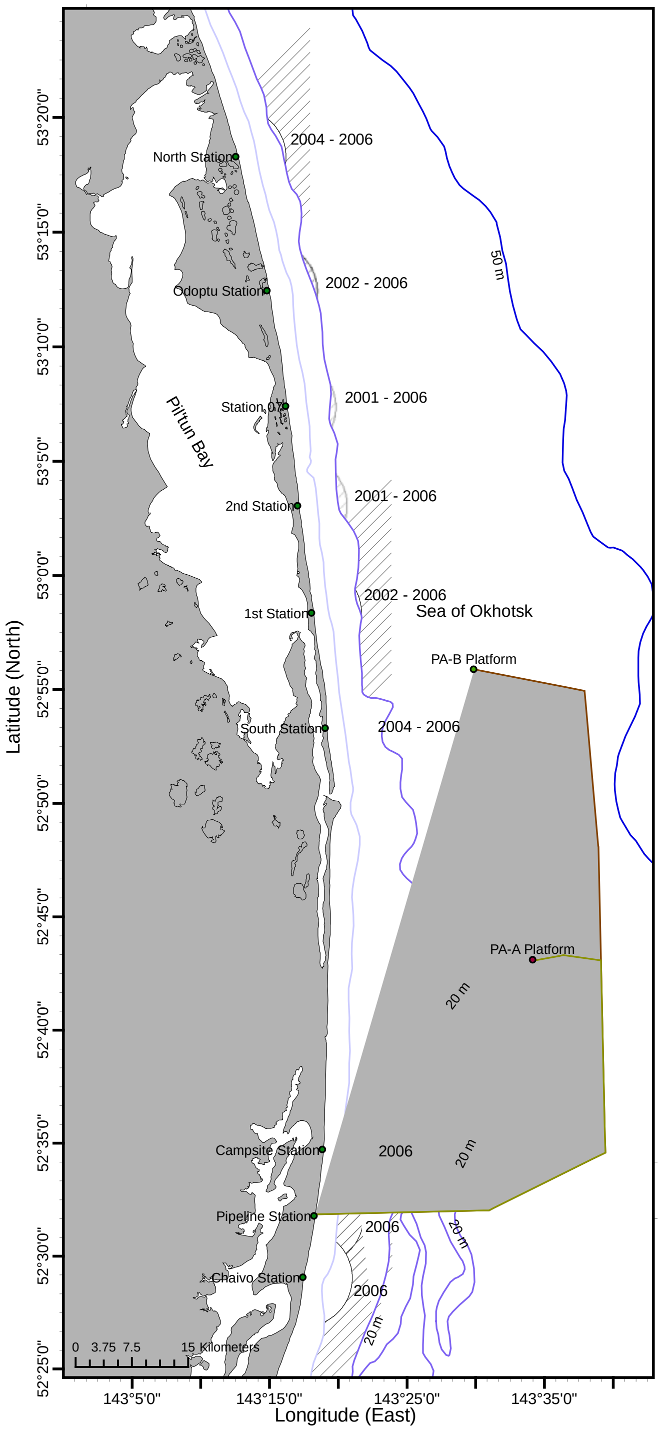

Figure 1. Geographic positions of nine shore-based stations in the northeastern coastal region of Sakhalin Island, Russia. Semi-circular grids illustrate approximate viewable range (4 km) from each shore-based station. Dates indicate years when data were collected at each station.

Environment and the Response Variables

The proposed analyses will evaluate the relationship between behavioral and abundance estimates to sound levels and vessel activity. Three abundance and distribution variables, as well as seven movement and seven respiration parameters, are proposed to be analyzed as response indicators (Table 1). To standardize units for analyses, movement and focal animal response variables will be calculated for every 10.5 minute interval (hereafter referred to as a ‘bin’) of continuous observation. Because many response variables (such as linearity and reorientation rate) are not instantaneous measurements, some time is required to derive the response variables. We arbitrarily choose 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 responses. Similar length bins have been used in the past (Gailey *et al. in Press,* 2007b) and proved adequate for meaningful analyses. Prior to computing responses for each bin, all movement data will be resampled every 90 seconds to avoid under- or over-sampling issues and to standardize step lengths of movement (see Gailey *et al.* in Press, Turchin 1998). This resampling allows for standardized responses by connecting all observations of an individual through time, and then placing a point on this interpolated path every 90 seconds. A 90 second resampling interval is chosen based on an autocorrelation analysis of the movement data that indicated that correlation died out on average around 90 seconds (Würsig *et al.* 2002). For each of these bins, movement and focal response variables will be calculated (Table 1).

The relative number of whales and pods observed during scan sessions will be evaluated on a per-scan basis. Scan data will consist of several daily scans collected at the three observation stations by Gailey *et al.* (2007a), as well as broad scale single scan per location data collected at multiple stations by Vladimirov (2007). Distance from shore will be also be analyzed to evaluate potential distributional shifts in relation to environmental and anthropogenic related variables. Distance from shore has been used to explain a significant amount of variation in response variables relative to sound levels (Gailey *et al.* in Press, 2007b), and we intend on now evaluating this parameter for both track and scan based information.

Sound Level

Received sound levels for the analyses will be estimated at the mid-point location of a track or focal follow for each bin, rather than on a predetermined grid as was conducted in Gailey *et al.* (2007b). Sound level estimation will involve modeling propagating sound levels received at eight hydro-acoustic recording stations (AUARs) to the animal's mid-point location. The average sound level will then be calculated over each temporal bin. This methodology is similar to the procedures employed previously (Gailey *et al.* 2007b), consisting of the use of a numerical sound propagation model to estimate the received acoustic level both at the desired target location and at one or more sound monitoring stations closest to it, whereby the former can be adjusted based on the deviation of the latter from the measured values. The sound sources to be supplied to the model will include the principal construction vessels in the region positioned at tracked or estimated nominal locations at the relevant time, and all research vessels – operating in or near the feeding region – for which positional records are available. Unlike the approach taken in Gailey *et al.* (2007b) in which the total received sound level modeled from all sources was used as a single variable in the analysis, in this study the aggregate level from construction sources and that from research vessels will be estimated separately and included as two independent variables (Table 2).

In addition to the sound level estimation for movement and respiration bins, the total amount of sound energy will be estimated for abundance and distribution data derived from scan sampling techniques. Sound energy will be calculated at a location 2 km offshore of each observation station. These estimates will be calculated during 2-hour, 8-hour, 24-hour, and 72-hour period preceding each scan sampling session to evaluate gray whale response (i.e. increasing/decreasing in abundance) to increasing/decreasing sound exposure. Multiple temporal factors are considered for scan data to examine both short and long-term responses to noise activity.

Table 1. Response variables of scan, movement, and respiration parameters.

	Variable	Definition
Movement Parameters	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
	Distance-from-Shore	Distance of animal from the closest perindicular distance from the nearby coastline
	Ranging Index	measure the minimal diagonal area of the whale's track incorporating its course and track duration (Jahoda *et al.* 2003)
Respiration Parameters	Blow Interval	Times 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
	Percent Surface time	Pecent of time an individual remained at or near the surface per observation bin
	Number Blows/Surfacing	Total number of exhalations per surfacing
	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
Scan Parameters	Number of Whales	Number of whales observed during a scan session
	Number of Pods	Number of pods observed during a scan session
	Distance-from-Shore	Distance of an animal from the closest perindicular distance from the coastline.

Variation in response variables will be examined in relation to environmental, temporal, and industrial impact parameters (Table 2). Environmental and temporal parameters that were found to explain a significant amount of variation in movement and/or respiration variables in previous western gray whale noise-impact studies will also be considered. Environmental data will be provided by two sources: 1) the behavioral teams' environmental data, and 2) a near-by SEIC Oil Platform (Molikpaq).

Table 2. Environmental and impact variables.

	Variable	Definition
Envrionmental	Station	Name of observation station where effort was conducted
	Date	Day of the season
	Time of day	Time of the observation
	Behavior	Animal's behavioral state during observation bin (feeding, traveling, feeding/traveling, mixed)
	Subject	Individual composition of focal group (mom-calf, calf, yearling, unknown)
	Beaufort	Sea state measured on the Beaufort scale
	Visibility	Visibility conditions estimated at the time of observation.
	Distance-from-Station	Distance of whale from the observation platform
	Depth	Water depth during observation
	Tide Height	Tide level (m) during observation
	Wind Direction	Categorical wind direction (N, E, S, W)
	Wind Speed	Speed of the wind (m/s) during observation
	Swell Height	Swell height (m) in vicinity of station
Impact	Energy2h	Total amount of received sound energy 2 hours preceeding scan at a location 2 km from station
	Energy8h	Total amount of received sound energy 8 hours preceeding scan at a location 2 km from station
	Energy 1d	Total amount of received sound energy 24 hours (1 day) preceeding scan at a location 2 km from station
	Energy 3d	Total amount of received sound energy 72 hours (3 days) preceeding scan at a location 2 km from station
	Sound Level (nearshore vessels)	Predicted underwater sound level (db re 1μPa) from nearshore vessels at the mid-point location of the observation bin.
	Sound Level (construction)	Predicted underwater sound level (db re 1μPa) from construction vessels at the mid-point location of the observation bin.
	Number of Vessels	Total number of operational vessels within 5 km of the mid-point location of the observation bin.
	Closest Vessel	Distance of the closest approach vessel to the mid-point location of each observation bin.
	Vessel Type	Type of vessel closest (within 5 km) to the mid-point location of the observation bin

Relationships among Response and Explanatory Variables

The relationships among the proposed variables will be examined by univariate scatter plots, box plots, and correlation analyses, as well as by conducting a principal component analyses as suggested by the Western Gray Whale Advisory Panel (WGWAP 2006). These analyses will provide a better understanding of the degree of dependence among the responses, the degree of dependence among impact variables, and effects of this dependency on the tests. Such information can assist towards adjusting the experiment-wise significant levels, and thereby affect interpretation of the results.

Statistical Analysis

Univariate and multivariate analytical approaches will assess potential associations among the behavioral and abundance indicators to the pipeline construction sound variables and nearshore vessel activity. Univariate approaches will provide a broad overview and comparable results to previous whale noise impact studies, as well as existing data on western gray whales during relatively anthropogenic-free years (Würsig *et al.*, 2003; Gailey *et al.*, 2004; 2005; 2006; 2007a). Univariate analyses will consist mainly of ANOVA (or non-parametric equivalent) one-way or two-way statistical tests.

A multivariate analysis will be conducted to consider environmental, temporal and noise-impact effects in relation to the above mentioned response variables. Multivariate regression techniques will be used to investigate associations between behavioral response variables to both environmental and anthropogenic explanatory variables. The primary focus of these analyses will be with associations to sound levels from construction activity and nearshore research vessels operating in or close to the feeding area. The analytical approach proposed here to evaluate movement and respiration patterns builds on those developed from previous analyses (Gailey *et al.* 2007b). The approach taken differs from Gailey *et al.* (2007b) by 1) adding explanatory variables, such as subjects (mom-calf pairs, calves, yearlings, unknown), 2) separating sound levels for nearshore research vessels and construction related activity, 3) employing General Linear Model (GLM) procedures to avoid transformation of the response variables, 4) evaluating relationships among response variables (see above), 4) incorporating an additional respiration response variable (% time at the surface), and 5) providing analyses of abundance and distribution data.

Movement and Respiration Analyses - Focal and track observation bins will consist of multiple bins per observation session which range in duration from 10 minutes to 7 hours. These data are consecutive in time (i.e. potentially autocorrelated) within one track/focal session and vary in number of bins among the different tracking/focal sessions. Standard multivariate regression methods, augmented with weighting and block permutation methods, are proposed here to investigate associations among the response variables to the explanatory variables while minimizing the effects of potential analytical issues. The weighting approach attempts to correct for unequal representation of whales displaying different behaviors, those at different offshore distances, and those observed during different environmental (Beaufort, visibility, swell, etc.) conditions. Each behavioral observation bin is weighted by the inverse of the total number of bins observed for that track or focal session. The use of weighting is 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. As a result, each animal in the analyses will have a total weight of 1.0. Weighting procedures are also likely to assist in minimizing pseudo-replication issues. For example, slower traveling individuals, such as mom-calf pairs, would likely have more representative bins than other individuals traveling through the region. Block permutation is used to adjust for temporal autocorrelation in responses (Lahiri 2003). This procedure constructs a distribution for the drop-in-sum-of-squares F statistic under the null hypothesis of no impact effect. This F distribution is constructed by computing residuals from the natural variable model (Phase I, see below), then assuming that individual whales are independent, randomly permuting blocks of the residuals, and repeating the analysis. In other words, all residuals associated with an individual whale are viewed as a block of data, these blocks are randomly shuffled, re-associated with un-permuted explanatory variables, and the model including impact variable(s) are refitted. An added benefit of block permutation is that the statistical significance levels produced by the analysis are nonparametric, and therefore the technique does not depend on distributional assumptions.

Model development will consist of two phases. In phase I, stepwise Bayesian Information Criteria (BIC) selection will be used to identify a reasonable model containing natural effects only. Stepwise selection of natural effects will consist of both forward and backward steps. Each forward step starts with the model resulting from the previous step, and adds natural variables not already in the model, one at a time. The BIC is then computed for each model, and the variable that reduced BIC the most will be added to the current model. If no variable reduces BIC, stepwise selection will be stopped and the model will be fixed as the final model. Following this forward step process, a backward step procedure will be conducted whereby all variables already in the current model are dropped one at a time and BIC is recomputed for each reduced model. If removal of at least one variable reduces BIC, the variable that reduces BIC most will be removed from the model. The initial model will contain an intercept only and estimation will be conducted by the method of least squares.

After the natural model has been developed from Phase I, the second phase will add impact variables one at a time to examine if these variables explain a significant amount of the remaining variation in the response variables. Significance of the F statistic will be computed by block permutation to mitigate the effects of autocorrelation and non-normality of responses.

Scan Analyses - The relative number of whales and pods will be evaluated on a per-scan basis. A quasi-likelihood regression model will be used to examine the relative number of whales and pods (response variables) in relation to potential influences of environmental and noise-impact factors (McCullagh and Nelder 1989). Quasi-likelihood approximate F tests (McCullagh and Nelder 1989, Venables and Ripley 1994, McDonald *et al.* 2000) will test for significant terms in the model. To construct a quasi-likelihood regression model that explains natural variation of whale and pod counts, stepwise variable selection will be used to include or exclude environmental variables. The significance of each environmental variable that accounts for variation in scan count data will be determined by (Type III) approximate F tests ($\alpha = 0.05$). Following analyses of environmental variables, sound and vessel variables will be introduced one-at-a-time (stepwise) to the model. The significance of each "impact" variable will be assessed using F tests. A Moran's I test (Moran 1950) will be conducted to further examine regression residuals to determine whether autocorrelation in whale counts adversely affected significance levels of terms in the final quasi-likelihood model. If temporal correlation is found in the residuals (Moran's $I > 0.5$), weighted least squares (with estimated covariance matrix) or generalized mixed linear models will be used to adjust for the correlation.

Acceptance of any of the noise-impact variables into any of the behavioral models will indicate that the variable explained a significant portion of the variation in the response variable that could not be explained by environmental and temporal considerations. As previously mentioned, the analytical approaches proposed here are similar to the previous studies of noise-impact conducted to evaluate western gray whale response to transient sounds from a seismic survey in 2001 (Gailey *et al.* in Press) as well as to more continuous sounds in relation to the installation of a Concrete Gravity Based Structure in 2005 (Gailey *et al.* 2007b). We believe that consistency in variable selection and analytical approach will provide results for appropriate comparisons and further insights of western gray whale behavior in relation to noise.

References

Gailey, G. and J. Ortega-Ortiz. 2002. A note on a computer-based system for theodolite tracking of cetaceans. J. Cetacean Res. Manage 4:213-218.

Gailey, G., O. Sychenko and B. Würsig. 2004. Western gray whale behavior and movement patterns: shore-based observations off Sakhalin Island, July-September 2003. Prepared for LGL ecological research associates Ltd, for Exxon-Neftegas Ltd.

Gailey, G., O. Sychenko and B. Würsig. 2005. Western gray whale behavior and movement patterns: shore-based observations off Sakhalin Island, July-September 2004. Prepared for LGL ecological research associates Ltd, for Exxon-Neftegas Ltd.

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. *In Press*. 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., O. Sychenko, and B. Würsig. 2007a. 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.

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.

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.

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. *in Press*. A western gray whale mitigation and monitoring program for a 3-D seismic survey, Sakhalin Island, Russia. Environmental Monitoring and Assessment.

Lahiri, S. N. 2003. Resampling methods for dependent data. Springer, New York.

Ljungblad, D.K., B. Würsig, S.L. Swartz and J.M. Keene. 1988. Observations on the behavioral responses of Bowhead Whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41:183-194.

Malme, C.I. and P.R. Miles. 1985. Behavioral responses of marine mammals (gray whales) to seismic discharge, Tech. Rep. 5. Can. Oil and Gas Lands Adm., Inviron. Prot. Br.

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.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch and K.A. McCabe. 2000. Marine seismic surveys – a study of environmental implications. APPEA Journal:692-708.

McCauley, R.D., M.N. Jenner, C. Jenner, K.A. McCabe and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: Preliminary results of observations about a working seismic vessel and experimental exposures. APPEA Journal 1998:692-707.

McCullagh, P. and J. Nelder. 1989. Generalized linear models (2nd ed.). Chapman and Hall, London.

McDonald, T. L., Erickson, W. P., and McDonald, L.L.: 2000, 'Analysis of count data from before-after control-impact studies', J. Agr. Biol. Envir. St., **3**, 262-279.

Moran, P.A.P. 1950. Notes on continuous stochastic phenomena. Biometrika 37:17-23.

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.

Reeves, R.R., D.K. Ljungblad and J.T. Clark. 1984. Bowhead whales and acoustic seismic surveys in the Beaufort Sea. Journal of Acoustic Society of America 62:271-280.

Richardson, W.J., G.W. Miller and C.R. Greene. 1999. Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. J. Acoust. Soc. Am. 106:2281.

Richardson, W.J., B. Würsig and C.R. Greene. 1986. Reactions of Bowhead whales, Balaena mysticetus, to seismic exploration in the Canadian Beaufort Sea J. Acoust. Soc. Am. 79:1117-1128.

Rutenko. 2006. Acoustic Studies on the North East Sakhalin Shelf. Final report to Exxon Neftegas and Sakhalin Energy Investment Company. Yuzhno-Sakhalinsk, Russia. 79pp.

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

SEIC. 2005. Acoustic Monitoring of PA-B CGBS installation. Page 28. Sakhalin Energy Investment Company.

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

Venables, W. N. and Ripley, B.D.: 1994, *Modern Applied Statistics in S-Plus,* Springer-Verlag, New York.

Vladimirov, V.A.,S.A. Blokhin, A.V. Vladimirov, V.L. Vladimirov, N.V. Doroshenko, and M.K. Maminov. 2007. Distribution and abundance of gray whales of the Okhotsk-Korean population in Northeastern Sakhalin waters in July-November 2004 (based on shore, aerial, and vessel-based surveys. Final report to Exxon Neftegas and Sakhalin Energy Investment Company. Yuzhno-Sakhalinsk, Russia.

WGWAP. 2006. Report of the western gray whale advisor panel at its first meeting. 9-11 November 2006, Pragins, Switzerland. IUCN (http://www.iucn.org/themes/marine/pdf/wgwap/WGWAP%201_3%2021%2011%2006.pdf). 42 pp.

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.

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

Würsig, B., G. Gailey, O. Sychenko and H. Peterson. 2003. Western gray whale occurrence patterns and behavior: shore-based observations off Sakhalin Island, August-September 2002. Prepared for LGL ecological research associates Ltd, for Exxon-Neftegas Ltd.

Würsig, B., D. Weller, A. Burdin, S. Blokhin, S. Reeve, A. Bradford and R.J. Brownell. 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.

Yazvenko, S.B., T. MacDonald, S.A. Blokhin, S.R. Johnson and V.L. Vladimirov. *in Press*. Distribution and abundance of western gray whales during a 3-D seismic survey, northeast Sakhalin Island, Russia: Multiple regression and BACA analyses. Environmental Monitoring and Assessment.