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FUTURE SEIC PLANS FOR WGW MONITORING AND RESEARCH

Elaboration of the concept of controlled exposure experiment(s)

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Elaboration of the concept of controlled exposure experiments

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There is general agreement that it is desirable to obtain additional data on the responses of gray whales to continuous and/or impulse noise. Field experiments to test responses to controlled stimuli offer a direct means to obtain such data. These experiments can take two primary forms. One option consists of direct observation during industrial activity such that the sources are known and the precise locations of the study subjects are known and thus the received doses can be measured, as can the subtle and overt responses of the subjects. The other option consists of controlled exposure experiments (CEEs), which are much like the first option except that the sources are under the direct control of the researchers. CEEs have a distinct advantage over observational experiments in that the dose and timing of an exposure can be controlled in each experiment, whereas in observational experiments the dose and timing are determined by the ongoing sound-generating activity. The timing of the exposure can be particularly important for testing responses in specific behavioral contexts, e.g., commencing an exposure as the experimental subject begins to feed. The dose is also important, as has been discussed frequently in the ISRP and WGWAP processes.

Observational experiments and CEEs are not mutually exclusive. Indeed, it is often advisable to combine the two approaches in order to fully exploit their respective strengths while minimizing the amount of nose to which individual animals are exposed. The ‘additional’ exposure caused by a CEE is one of the arguments frequently raised against this experimental paradigm, but in the case of exposure to industrial noise (continuous or impulsive) the added exposure of a CEE is usually negligible. Because the dose is carefully controlled, injury is virtually impossible. The combination of the two techniques can be quite powerful. For example, a CEE can document a specific response or suite of responses, and then those responses can be targets for measurement during the observational experiments. One of the primary benefits to be gained from combining the two approaches is the increase in sample sizes available for analysis.

In experiments measuring animal behavior, sample size is determined not by the number of times a particular response is measured, but by the number of individual animals being tested. This counting of response variables across individuals is one form of pseudoreplication. So, by identifying behavioral responses during CEEs and then using those results to guide sampling during observational studies, the combination of carefully designed observational experiments and CEEs can at once minimize exposure of the animals to noise and maximize the volume of data collected.

Designing these experiments can be challenging. The frequency range of best hearing is not known for gray whales, though it is often thought to coincide with that of the calls produced by the whales. Playback experiments with several baleen whale species have documented behavioral responses to conspecific calls (Clark and Clark 1980, Watkins

1981, Tyack 1983, Parks 2003). Playback experiments have also shown non-acoustic responses of gray whales to the calls of potential predators (i.e. killer whales) (Cummings and Thompson 1971). Additional studies of responses of baleen whales to anthropogenic noise indicated that they respond to sounds at higher frequencies, up to at least 15 kHz (Watkins 1986). Also, playback experiments have demonstrated directional hearing capabilities in mysticetes by showing precise orientation toward and localization of the sound source (Clark and Clark 1980, Tyack 1983, Parks 2003). Finally, playbacks have also demonstrated that right whales show no response to vessel noise while responding strongly to synthetic signals (Nowacek, *et al.* 2004). This latter study also demonstrated that the level of the signal is not the only factor that is important in eliciting a response. In fact, the right whales responded to the synthetic signal at relatively low received levels, ~ 140 dB re: 1 μPa, which indicates the importance of signal characteristics as well as signal:noise ratio (Nowacek *et al.* 2004).

Design of experimental stimuli in the current discussion of gray whales and noise is relatively straightforward, particularly in the case of seismic airgun impulses. The continuous noise from construction activities such as that carried out on the Sakhalin Shelf, however, can be a bit more variable, though many sources of industrial noise do have similar characteristics. The ability to reproduce a particular source signal in an exact and consistent manner is an important consideration when contemplating a CEE. Producing loud, low-frequency signals, for example, may require the use of a large sound source.

Another aspect requiring careful consideration is the nature and status of the experimental subjects. In the present case, there is a need to consider specifically whether CEEs should be conducted with eastern or western gray whales. Gray whales off the Pacific coast of Canada (i.e., eastern gray whales) form feeding aggregations (Moore et al. 2007) that can be found on the west coast of Vancouver Island in any month, but the largest numbers use that area (hereafter ‘the study area’) between mid-June and mid- August. Animals in the northward migration stream reach peak numbers between early March and mid-April. Southward migrants are encountered in nearshore waters of Vancouver Island only rarely and as scattered individuals and small groups in September, October and November. On the migration route, the whales cross heavily used shipping channels at the entrances of the Strait of Juan de Fuca to the south of Vancouver Island and Hecate Strait to the north. Commercial shipping and transport, several types of commercial fishing, sport fishing and commercial whale-watching occur all along the coasts of British Columbia. Seismic survey work is likely to occur in the near-term future.

As discussed above, one of the strengths of CEEs is that the timing, position and dose of the exposure is under the control of the researchers. To take full advantage of this ability, the behavior of the animal and the RL at its position must be measured. One tool for getting these measurements is the DTag (Johnson and Tyack 2003). DTag tagging and playback protocols have been implemented over the past 10 years on various species of marine mammals (Nowacek, *et al.* 2001, Johnson and Tyack 2003, Parks 2003, Nowacek, *et al.* 2004, Woodward & Winn 2006, Miller et al. 2004, Johnson et al. 2004, Friedlaender et al. in review, Hazen et al. in review, Stimpert et al. 2007). The DTag is a small, lightweight, pressure-tolerant and waterproof tag that is placed on a whale using a carbon-fiber pole and is attached via 4 silicon suction cups. The tag is equipped with a pressure sensor, a 3-axis magnetometer and accelerometers that measure depth, pitch, roll, and heading 5 times per second. It also records acoustic information through 2 embedded hydrophones. DTags can be programmed to collect data on flash memory for ~24 hours before releasing. The tag is also equipped with a VHF antenna and unique frequency which allows radio-tracking of animals when they are at the surface and either out of visual range or at night. Once tags have released from the whale they are retrieved and the stored data are downloaded through an infrared port directly to a personal computer for calibration and analysis.

Selection of methods to analyze the responses of animals is critical when contemplating or indeed planning the experiments. Behavior of the tagged animals can be assessed with DTag sensor data, and four primary quantities: i) changes in heading, ii) changes in diving behavior, iii) fluke stroke rate and iv) location relative to the source. The response of a given individual can exist on a continuum from subtle to overt, so it is essential to have the ability to detect changes in multiple parameters. Furthermore, even within a particular quantity, 'change' can take multiple forms. 'Changes' in heading as assessed through non-parametric circular statistics, for example, can take at least two forms, i.e. a difference in mean heading and/or a difference in variance, both relative to a control situation (Figure 1). Other straightforward measurements to compare between exposure and control situations include: respiration rate, group composition and/or cohesion, and behavioral state changes (e.g., foraging to resting or travelling). The response of an animal to a particular stimulus can be affected by many factors.

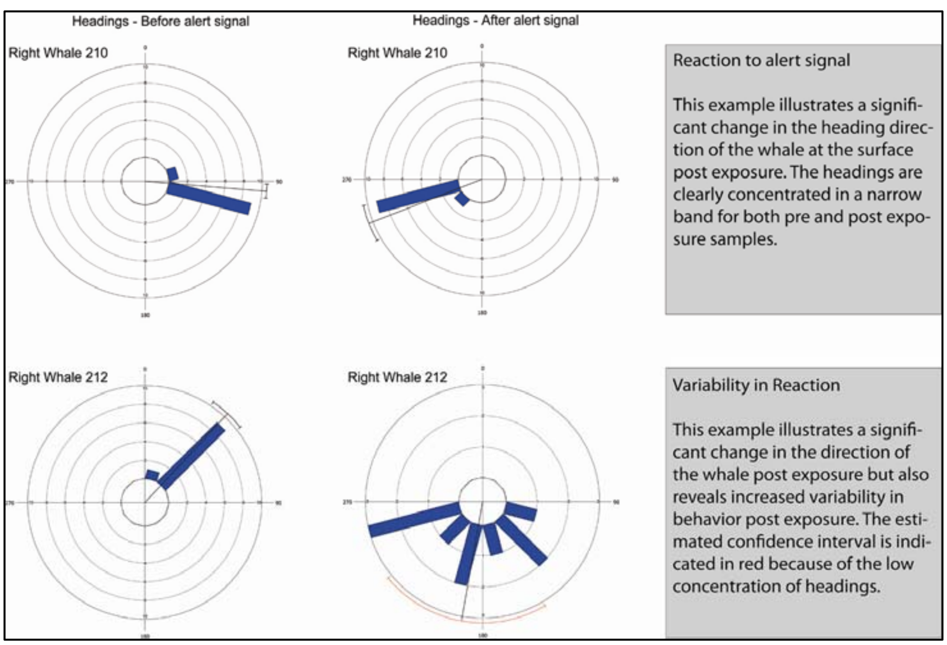

Figure 1. Headings of right whales exposed to alerting signal in 2005 assessed using circular statistics. The responses of these two whales were quite different, but in both cases the exposure data differed significantly from the control data. The variability displayed by whale 212 could be interpreted to be a response as strong as that shown by whale 210. Nowacek et al., unpublished data.

Most of the quantitative tag data can be divided into two categories for analysis: (1) point-process event rate data (e.g. fluke stroke rate, respiration rate, vocalization rate) and (2) nearly continuously sampled time-series of behavioural parameters or states (e.g. heading, location relative to sound source). The observed events in both categories are not likely to be statistically independent. They will likely exhibit significant autocorrelation, sequential dependence, and/or clumped distribution. For example, an animal's heading at one moment is likely to depend on its heading the moment before. Vocalizations, breaths and other events are not evenly spaced through time but instead often occur in bouts and animals often cycle through series of behavioural states in stereotyped patterns. Therefore, the current behavioural state often provides information about what the next behavioural state will be. Since the individual events in each data set are not independent, traditional parametric statistical analyses cannot be used to test for differences between exposure and control periods at the level of individual animals.

Since high power at small sample size will be critical to the interpretation of results from these experiments, one should consider alternate nonparametric statistical approaches that offer high power, account for the non-independence of the data points, and allow for the testing of changes in behavior at the level of individual animals or at the group level. To test for significant changes in event rates or correlation of behavioral parameters (e.g. heading or changes in heading) with source range or exposure level, a new statistical method, the rotation test, has been devised. It is a randomization method that takes into account sequential dependence of the data (DeRuiter and Solow *submitted*, Miller et al. 2004a, b). To detect changes in sequences of behavioural states, Markov chain or semi-Markov chain models can be used. These, like the rotation test, can be applied to describe behaviour patterns and test for experimental effects at either the individual or the group level (Haccou and Meelis 1992; Lusseau et al. 2003, 2004; Williams et al. 2006)

Finally, to conduct these experiments, it is important to assemble teams of scientists with expertise in, for example, source characteristics, cetacean bioacoustics and behavioral ecology.

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