STUDY TITLE: Support for JIP Controlled Exposure Experiments with Humpback Whales and Seismic Air Gun Arrays and Testing of Effectiveness of Ramp-Up

REPORT TITLE: Project BRAHSS: Behavioural Response of Australian Humpback Whales to Seismic Surveys Final Report

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BACKGROUND:
BRAHSS (Behavioural Response of Australian Humpback Whales to Seismic Surveys) aims to understand how humpback whales respond to seismic surveys and to provide the information that will allow these surveys to be conducted efficiently with minimal impact on whales. It also aims to determine how the whales react to ramp-up or soft start used at the start of surveys, and how effective this is as a mitigation measure. BRAHSS involved four major experiments in September and October of 2010, 2011, 2013 and 2014 (with additional work in 2015) during the southbound migration of humpback whales along the Australian coastlines. All experiments were conducted off Peregian Beach, north of Brisbane on the east coast, except for the experiment in 2013, which was off Dongara, north of Perth on the west coast.

OBJECTIVES:
(a) To determine the response of humpback whales to a typical commercial seismic survey in terms of the variables affecting the response, e.g., received sound level, distance between the source and the whales, behavioral state and social category of the whales, and environmental variables.

(b) To determine the response of humpback whales to soft start (ramp-up) and its components, and to assess the effectiveness of ramp-up as a mitigation measure in seismic surveys and the potential for improving its effectiveness.

(c) To relate these responses to the range of normal behavior.

DESCRIPTION:
The experimental design followed the "before, during and after" procedure, where whale groups were observed for at least 1 h before the treatment (the *before* phase), then for the 1 h of the treatment (the *during* phase), and then for 1h after the treatment had stopped (the *after* phase). Treatments were "active" with the air guns firing at 11 s intervals and towed at about 4 knots and "control" with the air guns towed but silent. Baseline studies of normal behavior were conducted with the vessel absent. Factors likely to affect behavior were measured and included in the analysis.

Experiment #1 (2010) exposed whales to a 20 cu in air gun towed both eastwards across the migration direction and parallel to the coast approximately northwards towards the approaching whales. Experiment #2 (2011) used a small array of six air guns as four stages of ramp-up (20 – 60 – 140 – 440 cu in) towed eastwards and as a constant source of 140 cu in. Experiment #4 (2014) used a commercial seismic array of 3,130 cu in, including ramp-up stages of 40 – 250 – 500 – 1,440 – 3,130 cu in, towed northwards parallel to the coast. These three experiments were off Peregian. Experiment #3 (2013) was a repeat of Experiment #2 off Dongara, with the array towed westwards across the migration.

Behavioral observations were made from two high points ashore (Peregian only) and from small boats (both sites). Observers were blind to whether a trial was *active* or *control* and also to the start time of the *during* phase. All data were fed into *VADAR* software, which was networked between all platforms and displayed all whale tracks from theodolite fixes ashore and boat observations together with behavioral data. Digital tags were also placed on some whales prior to the start of the *before* phase and recovered at the end of the *after* phase. Biopsies and blow samples were collected at the end of the trial. Calves were not tagged or biopsied. There was also an observation team on the source vessel for mitigation purposes and observations of whale behavior.

Recordings of the acoustic signals from the air guns were recorded on up to six moored autonomous systems ("loggers") at a number of positions, which were placed throughout each site and moved every few days. This allowed the development of empirical propagation loss models. It also allowed for the measurement of the horizontal directionality of the sound received from the air gun arrays (quite significant for the full array). Received sound levels at whales were determined using the logger recordings to provide the received level from the array as a function of distance from the array, applying the propagation loss models and then adjusting for the direction of the whale from the array. An array of five buoys with hydrophones were moored off Peregian and transmitted acoustic data to the base station ashore, allowing real time acoustic tracking of vocalizing whales, which were displayed on *VADAR*. *VADAR* also calculated the cumulative sound exposure level (SEL) at each group within 5 km of the source for mitigation.

The behavioral analysis aimed to determine the extent that changes in behavior resulted from exposure to the treatments rather than to the social, environmental or other variables that influence normal behavior. Most analysis was conducted by generating generalized linear mixed models (GLMMs). The first step was to generate a base model from the baseline data of normal. This base model was then extended by adding variables due to the treatments and the observation phases. If the predictions of the model significantly improved as a result of the addition of treatment variables, it suggested that these variables were significant predictors of the behavioral response.

SIGNIFICANT CONCLUSIONS:
The most consistent responses to exposure to the sounds of air guns were changes in movements of the whale groups in a way that resulted in a reduction in the rate at which they approached the source, either by increasing their distance from the source vessel (i.e., moving away) or keeping their distance from the vessel, relative to their predicted paths. The statistical modeling showed that the most likely deviation from the full array source was some hundreds of meters, but the confidence intervals were wide, showing

a large variation between groups. There were also responses to the controls, i.e., to the source vessel, but to a lesser extent and with much less deviation. Although there were changes in dive behavior and surface active behavior, these were very variable across whale group compositions.

The dose response for movement behavior showed that groups were most likely to respond to the sounds of air guns if they were within about 3 km of the source and the received SEL was greater than about 140 dB re 1 $\mu Pa^2 \cdot s$. These values do not indicate the thresholds of response, but that the whales were more likely to respond within these bounds than outside them. Some groups did not respond within these distances or at greater levels, and others responded at longer distances or lower levels.

There was no significant difference in movement responses to ramp-up compared to those for a constant 140 cu in source. This suggests that the design of ramp-up may not be important, and it may be no more effective than starting with a source at constant level. The value of starting at a low sound level is that it limits the exposure at those whales that are close enough to the source at the start (e.g., close to the limiting distance for mitigation) for the received levels to be of concern had the array started with a higher source level.

Propagation loss at the site was quite variable and could not have been adequately predicted using analytical models and the available knowledge of the sea bed acoustics at the start of the study.

STUDY RESULTS:

The experiments off Peregian Beach were very successful, achieving a significantly higher sample size than the target, for *active*, *control* and *baseline* data. The experiment off Dongara was less successful, due to bad weather and more difficult logistics, though we achieved the target sample size. During observations of focal whale groups, distances from the full array source (Peregian) varied from 1 to 10 km and the maximum received SELs from 115 to 165 dB re 1 $\mu Pa^2 \cdot s$.

Comparison of the effectiveness of land-based and boat-based observations showed that they gave similar results except that some blows were missed from land. Close approaches for tagging were found to cause short term disturbance to whales, but they returned to normal after about 20 min.

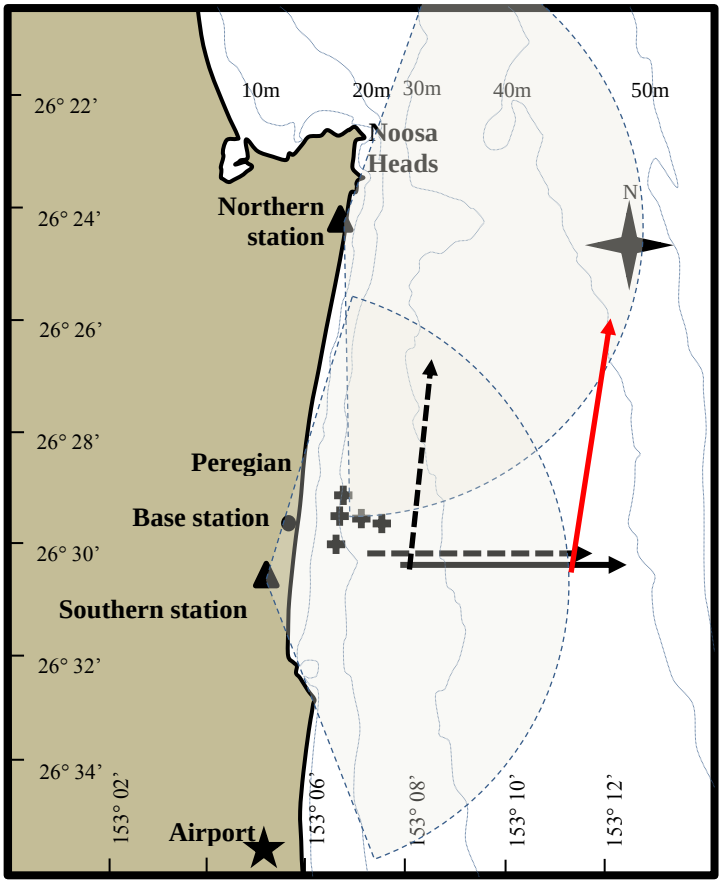
In addition to the movement responses described above, humpback whales showed changes in dive behavior and surface active behavior, but these were very variable across whale group compositions. Blow (respiration) rates in baseline data varied significantly with group composition and group behavior. Changes of blow rates in response to air guns were variable across different group compositions. These behavioral responses were generally within the range of normal behavior.

Tagging sample size was better than expected. Biopsies confirmed the original hypothesis about the social compositions of various groups, e.g., the escorts with female-calves were males.

STUDY PRODUCT(S):

Results to date have been published in nine journal papers, two book chapters and four conference proceedings. Two papers are in progress and two more are planned. Twenty papers have been presented at conferences, 12 internationally.

[*] P.I.'s affiliation may be different than that listed for Project Managers.



Experimental sites on map of Australia (top left).
Peregian Beach site (right) showing the land stations (triangles), the moored acoustic buoys (crosses). Dashed arrows are tow paths for the 20 cu in air gun and the ramp-up of the small array. Solid black arrow is the path of the 140 cu in air guns combination. The red arrow further out to sea is the path of the full seismic array.
Dongara site (below) with the circle showing the approximate bounds of the study area. Air guns were towed towards the west with the start positions varying depending on the positions of whale groups on the day.